EFFECTS OF WALL GEOMETRY ON ATOMIZATION CHARACTERISTICS OF A WALL-IMPINGEMENT TYPE JET ENGINE ATOMIZER

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ABSTRACT

This paper presents effect of wall geometry in a wall-impingement type jet engine atomizer. The effects of pressure atomization with the wall impingement on the atomization characteristics have been examined in a real scale jet engine atomizer. The air velocity was varied from 41 to 92 m/s and the liquid injection pressure was from 0.5 MPa to 7.5 MPa. The atomization characteristics were evaluated by the droplet size (S.M.D.) by using a light scattering sizing (LDSA). Combining the pressure atomization with the air-blasting gives remarkable improvement of the atomization, which comes from the contribution of droplets produced by the pressure atomization mode. However, at the same time, liquid cluster was observed, which dropped from the atomizer. The liquid cluster is considered to have bad effects on combustion for jet engines. As a result, it is shown that the wall geometry have remarkable effects on the liquid atomization and on the prevention of the liquid cluster.

1. INTRODUCTION

NOx in the stratosphere is considered to cause serious damage to the ozone layer, and 60 % of NOx emission in the stratosphere comes from an airplane. Therefore, the need of NOx reduction from airplane engines is increasing. A common way of the NOx reduction in jet engines is the pre-vaporized and pre-mixed combustion at a fuel-lean condition. In order to achieve such the lean pre-vaporized pre-mixed (LPP) combustion, the improvement of atomization characteristics of the atomizer is necessary. In current jet engines, so-called air-blast atomizer is widely used due to its highly homogeneous fuel distribution leading to little soot emission even at a high load. However, it has a problem of poor atomization at a low load, since the atomization is determined by the relative velocity between an air stream and a liquid film. Furthermore, the S.M.D. (Sauter Mean Diameter) range of such an air-blast atomizer is from 50 to 300 μm which is not sufficient for realizing LPP combustion.

In this study, effects of a pressure atomization with wall impingement on the atomization characteristics were investigated, experimentally. As a result, the combination of the pressure atomization and the air-blast atomization gives remarkable improvement of the atomization, due to the contribution of the pressure atomization mode. However, at the same time, a liquid cluster was observed, which dropped from the atomizer. The liquid cluster is considered to have bad effects on combustion for jet engines. Therefore, the wall geometry of the atomizer was varied to solve this problem.

2. EXPERIMENTAL SETUP

A schematic of the experimental setup is shown in Fig. 1. A real size atomizer was installed at the exit of a capacity chamber through which air was supplied from a blower. The stagnation pressure inside the capacity chamber was measured with a manometer, and the air velocity inside the atomizer was estimated. The air velocity was controlled by a by-pass valve installed just upstream of the chamber.

Pure water was used as a test liquid. The water in a pressure vessel was pressurized with an N_2 gas bottle, being supplied to the atomizer. The atomization characteristics were evaluated on the basis of the droplet size, designated an LDSA (narrow-angle forward-scattering principle, Toh-nichi Computer Applications Co., LDSA-1300A).

Cross-sectional views of the real scale atomizer are shown in Fig. 2. Three kinds of wall geometries were used. The atomizer has coaxial air channels, both of which have swirlers (the same direction and the same swirl ratio). The liquid was injected from 0.2 mm-dia hole-type nozzles in the central part of the atomizer (named “spindle”). The hole was made with a spacing of 20 deg. The liquid jet impinges onto the inner surface of the intermediate ring, forming a liquid film. For all the wall geometry conditions, the intermediate ring position was set, so that the impingement point would be 2.5 mm upstream from the wall-end. The effects of the impingement point were investigated in a previous study [1]. According to the preliminary experiment, the average discharge coefficient of these holes was about 0.7. This value is close to that of the straight-type nozzle in a previous study [2].

It is considered that the impingement wall geometry has remarkable effects on the atomization characteristics. The

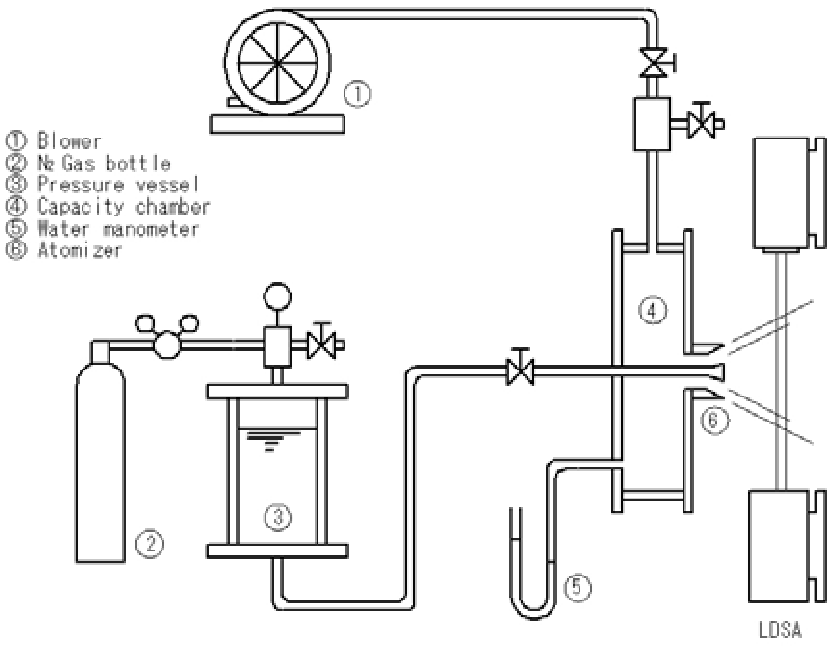

Fig. 1 Schematic of experimental setup.

angle (slope) of the wall dominates the discharge direction of the liquid film formation. The size (area) of the wall dominates the liquid film velocity. It is shown that the liquid film velocity decreases with the increase in the impingement wall size [3]. In the present study, effects of the slope and area of the impingement wall was investigated.

Figure 2 (a) shows a schematic of the conventional model (Slope Type)[1]. In this type, the liquid jet impinges onto the slope wall, forming a liquid film. Fig. 2 (b) shows a trial model (Hollow Type). In this type, the liquid jet impinges onto the parallel wall. The hollow was made to prevent the liquid film flowing upstream of the atomizer. The depth of the hollow is 1 mm while the length of the hollow, X, was varied from 2 to 6 mm. Fig. 2 (c) shows a trial model (Cylinder Type). In this type, the liquid jet impinges onto the end of a cylinder bar. The cylinder was used to separate the liquid film from the wall quickly. The diameter, d, was varied from 2 to 4 mm and height, h, was from 2 to 4 mm.

3. RESULTS AND DISCUSSIONS

3.1 Conventional Model (Slope Type)

In Fig. 3, the S.M.D. obtained by the LDSA is shown against the air velocity together with the effect of the liquid injection pressure. In case of the Slope Type, at a lower liquid injection pressure, 0.5 MPa, the S.M.D. decreases with the increase in the air velocity (Air-Blast Atomization Mode). It is considered that, for such a lower liquid injection pressure, the liquid film velocity on the impingement wall is decreased because of the viscous friction, and that the atomization process becomes similar to an air-blast atomizer. On the other hand, at a higher liquid injection pressure, over 2.5 MPa, the S.M.D. varies little with the air velocity (Pressure Atomization Mode).It is considered that the air velocity is no more effective factor at a higher liquid injection pressure. It is shown that there are two typical behaviors of the S.M.D. Then, the liquid injection pressure of 1.0 MPa is considered to be the transitional area. As for the effect of the liquid injection pressure, it gives remarkable improvement of the atomization, especially at a lower air velocity. By increasing the liquid injection pressure from 0.5 to 7.5 MPa (15 times), the S.M.D. can be decreased from about 300 μm to 20 μm (1/15 times) at the air velocity of 41 m/s.

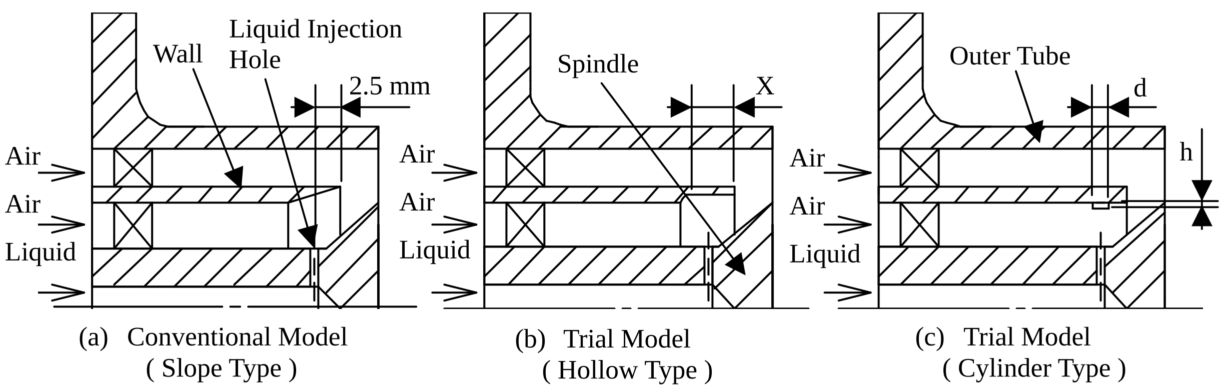

Fig. 2 Cross-sectional views of atomizer.

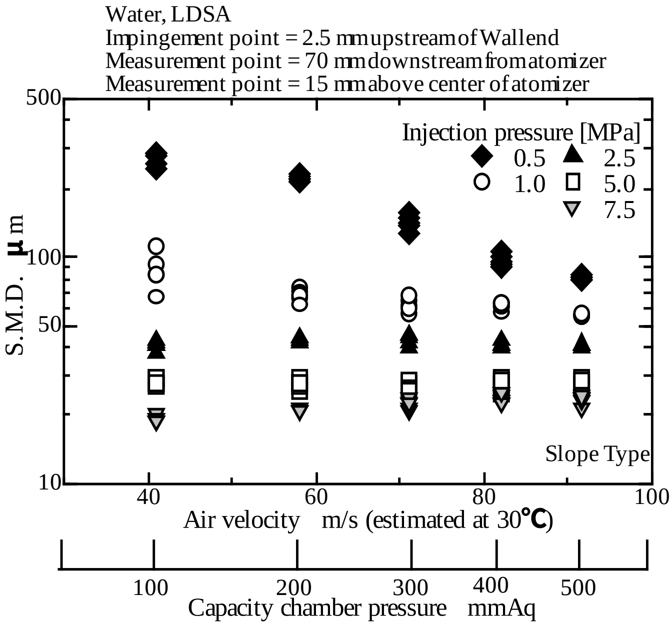

Fig. 3 S.M.D. variation with air velocity and liquid injection pressure, for Slope Type.

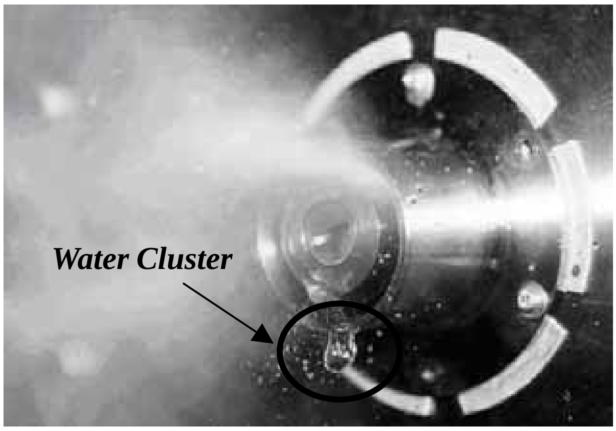

Fig. 4 Direct photograph of atomization, for Slope Type, liquid injection pressure = 7.5 MPa, air velocity = 41 m/s.

In Fig. 4, a direct photograph taken with a strobo-light for the highest liquid injection pressure of 7.5 MPa is shown. In this condition, regardless of the air velocity, fine droplets are observed. However, especially for a lower air velocity, water cluster is formed. It is observed that some of the droplets produced from the liquid film impinge onto the outer tube of the atomizer. It is considered that this re-impingement cause the water cluster.

3.2 Trial Model (Hollow Type)

In Fig. 5, the S.M.D. obtained by the LDSA is shown against the air velocity together with the effect of the liquid injection pressure. In case of the Hollow Type, the results for the length of the hollow is 2 mm are shown in Fig. 5 (a), and the results for the length of the hollow is 6 mm in Fig. 5 (b). First, in this type, the water cluster was not observed. Therefore, this wall geometry, especially the angle of the wall, is effective to prevent the water cluster. Next, in this type, two typical behaviors of the S.M.D. were observed, that are the same as the Slope Type. However, with the decrease in the length of the hollow, the atomization mode tends to shift from the air-blast to the pressure atomization mode, especially at a lower injection pressure region. This mode shift is considered to be important, since it leads to improvement of the atomization characteristics at a lower air velocity condition.

However, in this type, the S.M.D. was larger, at a higher liquid injection pressure condition compared with the Slope Type. It is observed that, after the impingement onto the Hollow wall, the liquid impinges again onto the end of the spindle and that the atomization becomes poor.

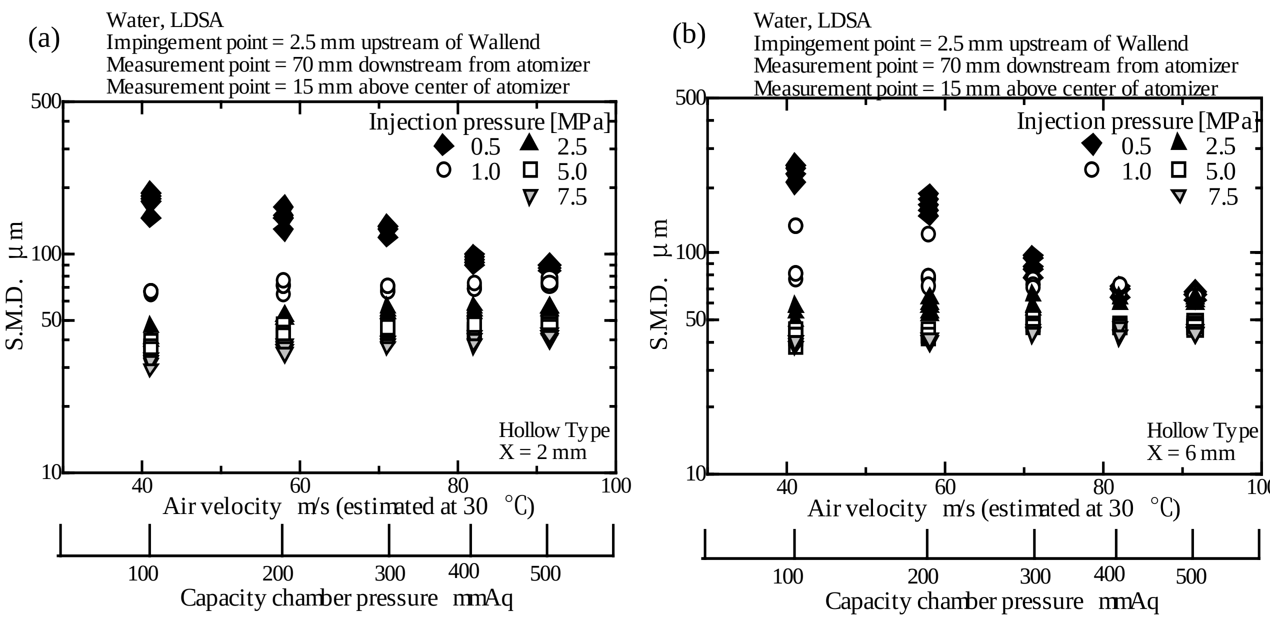

Fig. 5 S.M.D. variation with air velocity and liquid injection pressure, for Hollow Type, (a) X = 2 mm, (b) X = 6 mm.

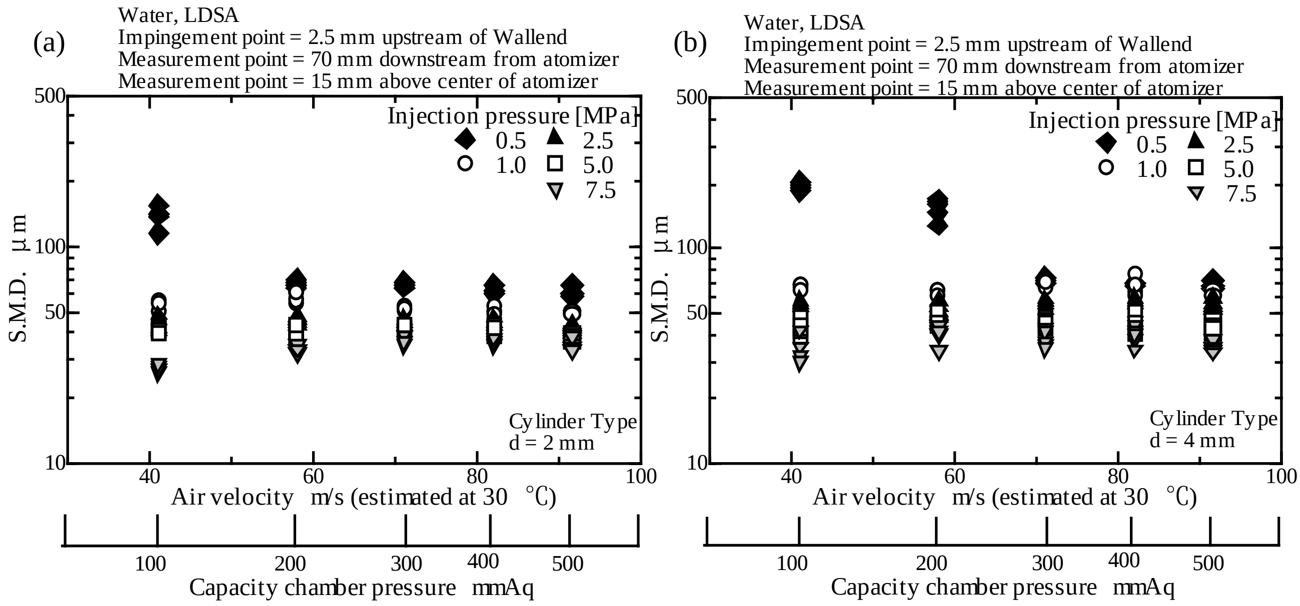

Fig. 6 S.M.D. variation with air velocity and liquid injection pressure, for Cylinder Type (Variation of Cylinder diameter), (a) d = 2 mm, (b) d = 4 mm.

3.3 Trial Model (Cylinder Type (Variation of Cylinder diameter))

In Fig. 6, the S.M.D. obtained by the LDSA is shown against the air velocity together with the effect of the liquid injection pressure. In case of the Cylinder Type, the results for 2 mm of the cylinder diameter and 2 mm of the cylinder height are shown in Fig. 6 (a). The results for 4 mm of the cylinder diameter and 2 mm of the cylinder height are shown in Fig. 6 (b). First, in this type, the water cluster was not observed. Therefore, this wall geometry, especially the angle of the wall, is effective to prevent the water cluster. Next, in this type, two characteristic behaviors of the S.M.D. were observed, that are the same as the Slope Type. With the decrease in the cylinder diameter, the atomization mode tends to shift from the air-blast to the pressure atomization mode, especially at a lower injection pressure region. In this condition, the mode shift trend is much stronger than that for the Hollow Type. It is considered that, for such a cylinder wall, the liquid film easily separates from the wall surface and that the velocity drop due to viscous friction is small.

However, in condition of a liquid injection pressure of 7.5 MPa, the S.M.D. was larger compared with the Slop Type, like the Hollow Type. It is observed that, after the impingement onto the Cylinder wall, the liquid impinges again onto the end of the spindle and that the atomization becomes poor. It is considered that the clearance between the cylinder wall and the spindle is not enough.

3.4 Trial Model (Cylinder Type (Variation of Cylinder height))

In Fig. 7, the S.M.D. obtained by the LDSA is shown against the air velocity together with the effect of the liquid

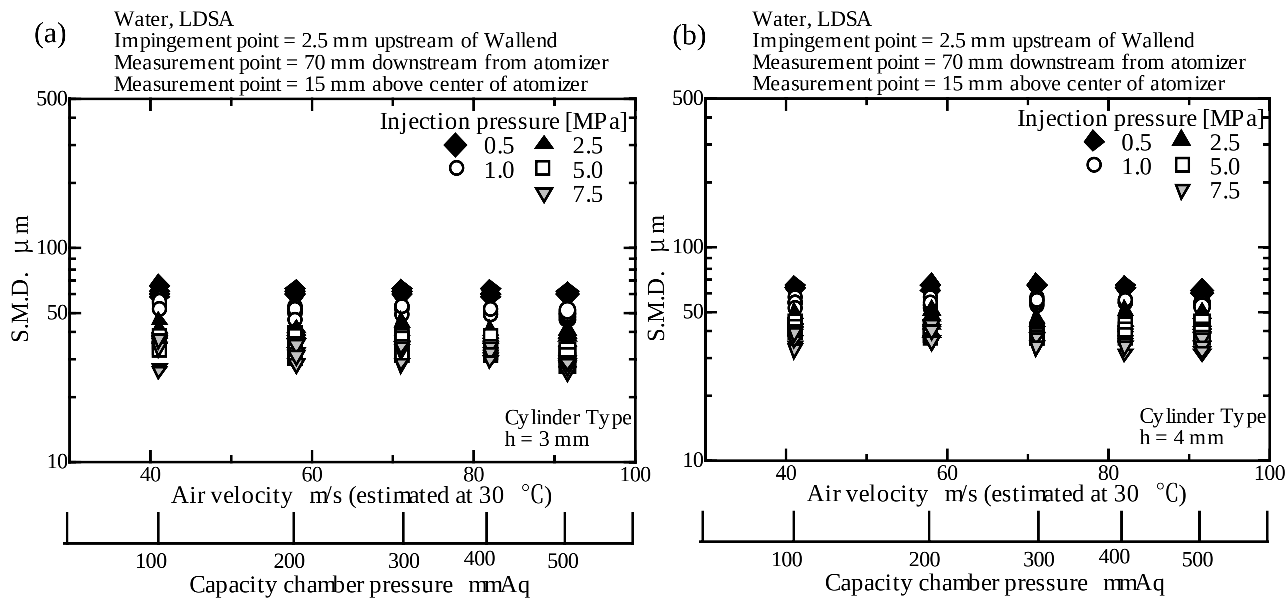

Fig. 7 S.M.D. variation with air velocity and liquid injection pressure, for Cylinder Type (Variation of Cylinder height), (a) h = 3 mm, (b) h = 4 mm.

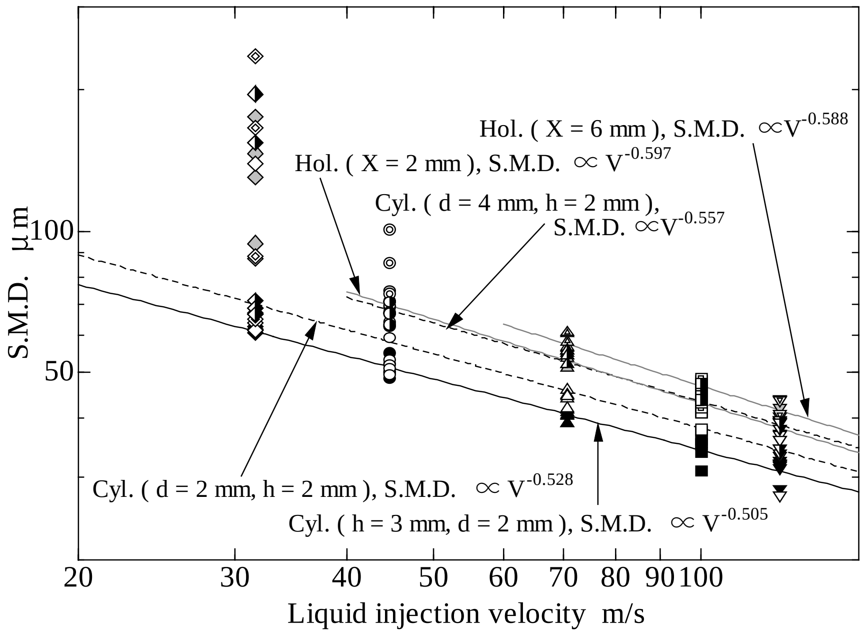

Fig. 8 S.M.D. variation with liquid injection velocity.

injection pressure. In case of the Cylinder Type, the results for 3 mm of the cylinder height and 2 mm of the cylinder diameter are shown in Fig. 7 (a). The results for 4 mm of the cylinder height and 2 mm of the cylinder diameter are shown in Fig. 7 (b). First, in this type, the water cluster was not observed. Therefore, this wall geometry, especially the angle of the wall, is effective to prevent the water cluster. Next, in this type, the air-blast atomization mode completely disappears and, for all the conditions, the atomization mode shifts to the pressure atomization mode. However, in the condition of the liquid injection pressure of 7.5 MPa the S.M.D. was poor compared with the Slop Type. However, a problem is remained that the clearance between the Cylinder wall and the spindle is small.

3.5 The optimum wall geometry

From the discussions above, it is shown that the water cluster can be avoided by changing the slope of the impingement wall. It is shown that the atomization mode shifts from the air-blast to the pressure atomization mode with the decrease in the wall size. And it is shown that the pressure atomization mode is desirable, since, in this mode, rather fine droplets can be obtained regardless of the air flow velocity. Here, the atomization characteristics in the pressure atomization mode are investigated.

In Fig. 8, the S.M.D. obtained by the LDSA is shown against the liquid injection velocity. The liquid injection velocity here is the potential velocity which is estimated from the liquid injection pressure. In Fig. 8, the S.M.D. decreases linearly with the increase in the liquid injection velocity. An index, namely, a gradient is almost the same for all the wall geometry conditions. In a fundamental study of a wall impingement jet [3], it is shown that the S.M.D. decreases with the increase in the liquid injection velocity, and that the gradient is about -0.5. It is shown, from Fig. 8, that quite similar results are obtained. However, the absolute value of the S.M.D. varies with the change in the different wall conditions. It is shown that the absolute value of the S.M.D. decreases with the decrease in the wall size. Therefore, from Fig. 8, the optimum wall geometry was the Cylinder Type at h = 3 mm at which the S.M.D. was minimum.

4. CONCLUSIONS

(1) By changing the slope of the impingement wall, the water cluster can be avoid.
(2) By decreasing the wall size, the atomization mode shifts to the pressure atomization mode.
(3) It is shown that the Cylinder Type (h = 3 mm) was the optimum wall geometry in terms of the water cluster prevention and the atomization mode.

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