Electrostatic spraying is a method of atomizing a fluid using a high voltage as an atomization auxiliary device, and various spraying modes exist according to experimental parameters and viscosity. A maximum of 11 spray modes were identified according to the changes in the applied voltage and flow rate. To produce fine droplets and a uniform size, which are the advantages of electrostatic spraying, in this experiment, the Sauter mean diameter (SMD) and SMD distribution were evaluated in each spray mode of electrostatic spraying. By comparing the other spray modes with the cone jet mode, it was confirmed that the maximum difference of the SMD was less than 1.5 times and the standard deviation of the rotated and pulsed jets was 2.5 times or more. In the cone shape range, the SMD and SMD distribution according to the applied voltage confirmed that the droplet size was the smallest in the middle of the cone jet mode, and the droplet distribution was also narrow. In the cone jet mode, the droplet size increased linearly with the viscosity and flow rate. In addition, the droplet distribution range was distinctive depending on the type of fluid. In the case of the relationship between the droplet size and current, it was proven that the higher the viscosity, the higher the current value for the same SMD; furthermore, the difference in the current–SMD increase rate was insignificant. Through experiments, this work presents experimental data of SMD, SMD distribution, and current–SMD in electrostatic spray experiments under various conditions.

1. INTRODUCTION
Electrostatic spraying is a method of atomizing a liquid by using the change in the liquid surface caused by a strong electric field applied to a liquid flowing through a micro-tubule. As a result of the repulsive force of an electric charge on the droplet surface, there is no polymerization or complexation between droplets, which is a major advantage of using electrospaying. Compared to other spraying methods, such as pressure atomization and twin-fluid atomization, it is possible to produce relatively uniform and continuous droplets. Moreover, a negatively charged nozzle and positively charged substrate minimize the droplet scattering range. In particular, electrospaying is an efficient and economic method because it makes use of a small amount of material to develop droplets. The electrostatic spraying system has the additional advantage of being able to control the size and movement of droplets easily by changing the spray conditions and having a fast response to its electrical parameters.

The patterns of electrostatic spraying are largely divided into dripping, cone jet, and multijet depending on the change in the applied voltage. When variables such as fluid properties and flow rate are added along with the applied voltage, up to 11 modes are observed: microdripping, spindle, long cone jet, pulsed jet, ramified jet, tilted jet, and unstable. In the cone jet mode, when the voltage acting on the fluid in the normal direction and the fluid surface tension reach equilibrium, the droplets have isocharge distribution. After a certain level of relaxation time, the nozzle makes a theoretical pyramid shape with a half-angle of 49.3°. On the surface of the cone, the repulsive force of ions acts in the fluid tangential direction, and the atomization is accelerated to the bottom of the atomization. Gravity acts in the direction of the bottom of the spray, but the viscosity acts in the opposite direction of gravity.

The cone jet mode can generate droplets with a scale that is up to tens to hundreds of times smaller than the nozzle diameter. In particular, the spray stability is excellent and has advantages such as a high water concentration, uniform particle generation characteristics, and fast system response compared with other electrostatic spraying modes. These superior attributes have led researchers to study the cone jet mode more than other spray modes. Research products of the cone

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jet mode include the fabrication of structures that are composed of fine particles, thin-film fabrication, biomedical engineering materials, food packaging, etc., and are used in various industrial fields.\textsuperscript{17–19}

In particular, as environmental concerns grow recently, the air purification technology using the principle\textsuperscript{20} of destroying and inactivating the cell walls of microorganisms using the characteristics of active oxygen generated by ionizing water during electrostatic spraying has been commercialized. An environmentally friendly technology to simultaneously reduce fine dust, NO\textsubscript{x}, and SO\textsubscript{2} by using an electrostatic spray scrubber which uses electrostatic properties is being studied.\textsuperscript{21} Therefore, it is necessary to study the optimization of spray pattern characteristics and spray patterns.

Variables affecting the electrostatic spraying mode can be largely categorized into fluid properties and experimental conditions. Fluid properties can be subdivided into surface tension, viscosity, and electrical conductivity. Experimental conditions include variables such as nozzle-to-substrate (NTS) distance and nozzle diameter.\textsuperscript{4,14,22,23}

Unlike other spray systems, the electrostatic spray system develops into various spray patterns according to these two sets of variables, fluid properties, and experimental conditions. These have been worked on by many researchers under various variable conditions.\textsuperscript{22,23}

As a study on the viscosity of the working fluid of electrostatic spraying, Rosell-Llompart and de la Mora\textsuperscript{24} have confirmed that the larger the working fluid viscosity, the wider the cone thickness and the longer the duration of the jet. Therefore, the droplet size was relatively large. Ku and Kim\textsuperscript{25} also studied spray properties in the cone jet mode according to the viscosity and observed similar results to those of Rosell-Llompart and de la Mora.\textsuperscript{24} Most of the studies on the electrostatic spray pattern and droplet size were concentrated only in the cone jet mode, and few studies were conducted in other spray modes.

With respect to the droplet distribution of electrostatic spray, according to studies by Saville\textsuperscript{26} and Mestel,\textsuperscript{27} the droplet distribution of a high-viscosity-charged solution was the narrowest in a specific flow range. However, for this result, Saville\textsuperscript{26} and Mestel\textsuperscript{27} did not specify the experimental conditions under various fluid conditions. Accordingly, the correlation between high viscosity and droplet distribution and its significance in research are unclear. Therefore, it is necessary for researchers to verify the effect of the fluid viscosity on the droplet distribution.

According to a study on droplet size by Suhendi et al.,\textsuperscript{28} increasing the current under the same conditions resulted in a thinner cone and smaller droplet sizes. A study by Gañán-Calvo et al.\textsuperscript{29} has substantiated that the size of the droplet in the cone jet mode is proportional to the 1/2 power of the actual measured current.

Most of the preceding studies on electrostatic spraying were mainly conducted in the cone jet mode that continuously generates uniform droplets.\textsuperscript{1} There are two methods of checking the cone jet mode. The first one is a qualitative method, which is a flow visualization method that confirms the clear shape of the cone. The other is a quantitative method that confirms the cone mode by quantifying the current data according to the overvoltage and applied voltage.\textsuperscript{20} In previous studies, each researcher derived and expressed a theoretical equation for the applied voltage for the cone shape based on experimentally acquired data.\textsuperscript{25}

However, a standard for the cone jet mode has not been clearly determined according to fluid properties and spray conditions, and most are set as the cone jet mode based on the shape of the cone. Because the cone jet appears as a range within a specific experimental condition, it can be subdivided from the range where the cone mode starts to the range where the mode ends.\textsuperscript{31} Therefore, even the same cone jet can be classified as different phases. For instance, there is a difference in the responsiveness of the spray pattern determined by the development phase. For these reasons, even when researchers conduct the same experiment, errors in the experimental results inevitably occur.

Conversely, when a current is applied to the working fluid, a strong electric field is formed when the current value is increased to a threshold value or more, eventually resulting in corona discharge. When corona discharge appears, the spray pattern becomes unstable.\textsuperscript{1} The unstable pattern does not form uniform and continuous droplets, entailing blue sparks and hissing around the nozzle. Accordingly, it is expected that the effect of the current on the droplets as well as the aforementioned experimental variables will be tremendous.\textsuperscript{30}

In conclusion, this work documents the construction of a laboratory-scale electrostatic spray system to conduct exper-
imemental research on the viscosity of the working fluid, the spray pattern according to the experimental conditions, the amount of applied current, droplet size, and distribution. Furthermore, unlike previous studies that checked the spray mode only by visualization, in this work, the current of the cone jet mode was checked using an ammeter with visualization. Through these experiments, it was observed that the current was kept constant over time and the applied voltage within the cone jet mode increased. In particular, while previous research focused only on the cone jet mode, this work provides a reference point for experimental research on electrostatic spraying by presenting the characteristics of various electrostatic spraying modes.

2. RESULTS AND DISCUSSION

2.1. Electrospray Images. Figure 1 shows spray images according to the increase of voltage applied to the nozzle under the same electrostatic spray test conditions. It was confirmed that dripping, microdripping, spindle, long cone jet, cone jet, tilted jet, multijet, pulsed jet, rotated jet, ramified jet, and unstable modes were generated as the applied voltage increased.11−13 Dripping to cone jet modes was formed under all flow conditions. Electric field had little dominance during dripping, which is quite contrast with the effect of gravity. During dripping, droplets larger than the inner diameter of the nozzle are sprayed at a constant frequency. In the case of microdripping, droplets with a diameter smaller than the nozzle were formed. As the applied voltage to the nozzle increases, the droplets are projected at a faster rate than in the dripping mode. In the case of the long cone jet, the cone shape was stably formed and the axial length of the cone was longer than the inner diameter of the nozzle. Eventually, it was transformed into a jet at the bottom of the cone and split into droplets. The cone jet mode shows a spray pattern similar to that of a long cone jet, but the axial length of the cone is shorter than the nozzle diameter as the applied voltage increases, and the thickness of the jet was also thinner than that of the long cone jet. The cone jet’s cone has a theoretical half-angle of 49.3°, as claimed by Taylor,7 which was verified through visualization.

In particular, even if the voltage applied to the nozzle is the same, spray patterns can be split into various phases according to the flow rate. Under low-flow conditions (0.3−0.6 mL/h), in the case of the tilted jet, cones and jets are formed. However, when they are split from the jet, they are split into droplets not only at the end of the jet but also at the side of the jet, forming a relatively unstable pattern compared to the cone jet. When the applied voltage increased, the thickness of the cone became smaller, which in turn made a multijet that sprayed the fluid in several branches at the same time. In the case of medium-flow conditions (0.9−2.1 mL/h), a pulsed jet shape with pulsation was observed after the cone jet mode. A rotated jet with a cone moving counter clockwise when the applied voltage was increased was also observed. In the case of high-flow conditions (2.1−6 mL/h), it was possible to check the shape of the ramified jet that is torn into multiple branches when transforming from a cone to a jet or torn into multiple branches from a jet, and the cone is maintained when the applied voltage is increased. It was observed that the jet and cone are sprayed without forming a uniform spray pattern.

2.2. Spray Patterns according to Experimental Conditions and Viscosity. Figure 2 shows the spray pattern area. In the case of modes, the name of each spraying mode was defined. In the case of patterns, the range of each area according to the spray mode was hatched and expressed, and in the case of the image, each spray mode is represented.

Figures 3 and 4 show a graph showing the relationship between the flow rate and voltage according to the working fluid, NTS distance, nozzle diameter, etc. Figure 3 uses working fluid S (ethanol 72 wt %, glycerol 18 wt %, citric acid 10 wt %) and has the conditions of NTS of 30 mm with a nozzle diameter of 0.5 mm. As the applied voltage increases, dripping, microdripping, spindle, long cone jet, and cone jet modes were observed under all flow conditions. At relatively low flow rates (0.3−1.2 mL/h) of the experimental conditions, the tilted jet and multijet modes were formed. In addition, it was confirmed that the pulsed and rotated jets appeared as the applied voltage increased to a relatively medium flow rate (1.5−3 mL/h). In the case of relatively high-flow conditions (3−6 mL/h), the ramified and rotated jets were made as the applied voltage increased. The applied voltage slightly
increased as the flow rate increased. Figure 4 differs from Figure 3 only in fluid viscosity; all other experimental conditions are the same. Compared with Figure 3, it turned out that working fluid V (ethanol 55.3 wt %, glycerol 27.7 wt %, citric acid 17 wt %) with high viscosity had a wide cone formation range and a high applied voltage. In addition, the range of the tilted, pulsed, and ramified jets was widened, and the applied voltage of each spraying mode was delayed as the flow rate increased for working fluid S.

2.3. Current Value Data. Figures 5–8 display the amount of change in the flow rate, NTS, nozzle diameter, and current as the voltage increases. Figure 5 shows the cone-shape range conforming to working fluid S or V and the current in consonance with the increase of applied voltage. Experimental conditions are a flow rate of 3.0 mL/h at NTS of 30 mm with a nozzle diameter of 0.5 mm. The current value could be obtained from the value exceeding the threshold of the ammeter. Before the cone shape was formed, the current value increased as the applied voltage increased. The current data of the long cone and cone jets, where the cone shape is generated, showed a constant current value even when the applied voltage was increased. This current tendency appeared to be similar to the visualization data. Similar to the results of a previous study by Gan et al., it can be stated that the current value remained constant even when the applied voltage increased during the cone-shape range. By comparing working fluids S and V, it was discovered that the current value was the highest at V. In addition, working fluid V with a long-lasting cone formation had a wide area in which the current value was kept constant. Figure 6 shows the current values in working fluids S and V versus the flow rate in the cone jet mode. Experimental conditions are NTS of 30 mm and a nozzle diameter of 0.5 mm. The box area shown in the graph shows the experimental conditions of Figure 5. In the case of working fluids S and V, it was noted that they increased linearly as the flow rate increased.
increased. In addition, as for the overall current value, the working fluid S average is approximately 72% of the working fluid V average. Figure 7 shows the current according to the nozzle diameter in the cone jet mode. Experimental conditions were fixed at a flow rate of 3.0 mL/h and NTS of 30 mm, and the experiment was conducted while increasing the nozzle diameter. The box area shown in the graph shows the experimental conditions of Figure 5. As the nozzle diameter increases, the current value increases similar to the flow rate, and the current value of working fluid V differs by up to 20% depending on the nozzle diameter. Conversely, in the case of S, a difference of up to 17% was marked. As shown in Figure 8, the nozzle diameter of 0.5 mm and a flow rate of 3.0 mL/h were fixed and NTS was increased in increments of 10 mm to proceed with the experiment. The box area shown in the graph shows the experimental conditions of Figure 5. With the current data of working fluids S or V according to NTS in the cone jet mode, it was found that the current decreases linearly as NTS increases. It is determined that this is because as the distance between the nozzle and substrate increases, the strength of the electric field decreases and the current value decreases accordingly. Working fluid S decreased by up to 46% with increasing NTS, and working fluid V decreased by up to 22% with increasing NTS.

2.4. Sauter Mean Diameter and Standard Deviation According to the Spray Mode. Figures 9 and 10 describe the relationship between the droplet size and distribution according to the spray mode. Figures 9 and 10 show the Sauter mean diameter (SMD) and standard deviation of the denominator according to working fluid S or V. Experimental conditions were NTS of 30 mm; a nozzle diameter of 1.0 mm; and a flow rate of 0.3, 2.1, or 6 mL/h. According to the flow conditions in Figures 3 and 4 above, the spray mode is formed differently when the applied voltage is increased, so the flow conditions are set differently. SMD and standard deviation were checked for each spray mode by setting the cone jet mode's middle phase, created under all flow conditions, as 1 to present an accurate standard for each spray mode. As a result, in the case of SMD, both working fluids S and V were 1.5 times smaller than the cone jet mode middle phase compared to other modes. In the case of standard deviation, the standard deviations of both working fluids S and V in the pulsed jet and the rotated jet were 2−2.5 times greater than that of the cone jet mode. In the pulsed jet, the cone is not maintained due to pulsation, so the mode entails large droplet distribution. In the rotated jet, it is presumed that the cone constantly rotates counterclockwise so that the cone and jet cannot be kept constant.

In the case of the pulsed jet, the cone jet is formed. In addition, pulsation is generated periodically under the influence of flow rate and voltage, and it was confirmed that the SMD standard deviation is large.

2.5. Comparison of SMD and SMD Standard Deviation in the Cone Jet Mode. Figures 11−13 display the connection between droplet size and droplet distribution in the cone-shape range. Figure 11 presents SMD in the long cone jet and cone jet modes. Experimental conditions were NTS of 30 mm, a nozzle diameter of 1.0 mm, and a flow rate of 3.0 mL/h. The classification divided the range from the long cone jet to the cone jet into five points according to the increased voltage at the same flow rate.

For both working fluids S and V, it was found that the droplet size decreased toward the cone jet middle phase. Figure 12 shows the spray pattern of Figure 11 as an image. In the image, when the applied voltage was increased, the cone became thinner and the length was shortened. In the cone jet finish phase, a cone shape is generated. However, the voltage in the fluid is strongly applied to the normal direction, and it was perceived that the cone moves and the droplet size increases minutely. Figure 13 is a graph arranging the droplet distribution under the same experimental conditions as in Figure 11 (nozzle diameter 1.0 mm, NTS 30 mm, flow rate 3.0 mL/h).

Figure 10. SMD and standard deviation according to the mode of working fluid V (nozzle diameter, 1.0 mm; nozzle to substrate, 30 mm; flow rate, 3.0 mL/h).
With respect to droplet standard deviation, both working fluids have the smallest values in the cone jet middle phase. However, the standard deviation of working fluid V was relatively higher than that of working fluid S. In the case of working fluid S, the standard deviation decreased toward the cone jet middle phase, whereas the difference was insignificant in the case of working fluid V.

2.6. SMD and Standard Deviation in the Cone Jet. Figures 14–16 show the relationship between droplet size and distribution according to the working fluid and flow variables. Figure 14 displays the SMD according to the flow rate of the S or V working fluid in the cone jet mode. The experiment was conducted at NTS of 30 mm and a nozzle diameter of 1.0 mm.
In addition, the following theoretical droplet-size formula was used to compare with the present experiment. The detailed formula is as follows.

De la Mora and Loscertales’ theoretical formula of droplet size is

\[ d = G(e) r^* \]  

(1)

\[ r^* = (e \varepsilon_0 Q / K)^{1/3} \]  

(2)

\[ G(e) = -10.9 e^{-6} + 4.08 e^{-1/3} \]  

(3)

\[ G(e) = 1.66 e^{-1/6} \]  

(4)

Gañán-Calvo’s theoretical formula of droplet size is

\[ d = 2 \times 1.89 R_{dfb} = 3.78 \times 0.6 \pi^{-2/3} Q^{1/2} \left( \frac{\rho e_0}{\gamma K} \right)^{1/6} \]  

(5)

Hartman’s theoretical formula of droplet size is

\[ d \sim \left( \frac{\rho e_0 Q^3}{\gamma K} \right)^{1/6} \]  

(6)

According to De la Mora and Loscertales, eq 1 is applicable to liquids with a high conductivity of 0.1 \( \mu \)S/cm. In eq 1, \( d \) is the theoretical droplet-size formula, and \( r^* \) is the electrical characteristic length. Equation 3 or 4 is used as a function of \( e \) as the \( G(e) \) proportional constant. Gañán-Calvo presented eq 5, where \( R_0 \) = nondimensional flow rate \( 1/2 \), and \( d_0 = (\pi^{-2/3} e_0^2 \rho^{-1} K^{-2})^{1/3} \). Hartman et al. presented a dominant droplet-size equation for the flow rate, as shown in eq 6. It was found that the theoretical equations presented by them are most dominantly affected by flow rate conditions and are additionally affected by fluid conductivity and density.

By applying the above theoretical formulas, the difference between this experimental value and SMD was at least 1.5 times and at most 6.5 times. This is because the experimental conditions for deriving the theoretical droplet size are different from the experimental conditions used in this work. Also, it is assumed that there is a difference depending on the experimental measurement method. In addition, it is judged to be an error of theoretical value caused by the fact that the variables proposed in the theoretical equation are not realistically reflected in the actual experiment. Moreover, there may be an effect caused by the splitting of the liquid jet as a result of the difference in viscosity. In the case of the theoretical droplet size proposed by Hartman, there is a difference between working fluids S and V is insignificant because viscosity is excluded from the theoretical droplet-size formula. However, in this experiment, working fluid V, which has a higher viscosity than working fluid S, recorded an average 8% higher SMD result. From Figure 14, it can be seen that SMD increases with the increase in the flow rate for all data. In the image in Figure 15, when the flow rate increases in the cone jet mode, the length and thickness of the cone widen, and it can be seen that the length and thickness of the jet also increase.

In the case of working fluid V with high viscosity, it was observed that the length of the cone became longer and the length of splitting of the jet increased through the comparison of S and V of the working fluids. It can be assumed that the split length was increased due to the surface shear stress acting on the tip of the cone, and it was confirmed that the droplets were formed relatively larger than working fluid S.

Figure 16 is a graph confirming the standard deviation of the droplet size using the SMD result of Figure 14. Uniform droplet formation is one of the characteristics of electrostatic spraying. In the study of Ku and Kim, it was claimed that the degree of dispersion was excellent. However, in this study, the standard deviation was as small as 6 or less at 0.3 and 3.0 mL/h for working fluid S, not just at one specific set of flow conditions. In addition, in the case of working fluid V, the standard deviation was as small as 6 or less at 0.6, 1.2, 1.5, and 3.0 mL/h. This indicates that the standard deviation of SMD is small under various flow conditions, unlike the result of Ku’s previous study that found that droplet distribution was the best at a specific flow rate. In addition, when comparing the droplet distribution to fluid properties, it turned out that the standard deviation of working fluid V was smaller than that of working fluid S at 0.6–2.1 mL/h under the experimental conditions.

2.7. Current–SMD Graph. Figure 17 describes the current value according to the increase in SMD. The experiment was conducted at NTS of 30 mm and a nozzle diameter of 1.0 mm. The current of both working fluids S and V increased linearly with the increase of SMD. Working fluid V has a relatively high viscosity compared to working fluid S, so the current value at the same SMD is higher. To linearize the current according to SMD, it is expressed as the SMD—current increase rate

\[ Y = AX + B \]  

(7)

In eq 7, A is the SMD—current increase rate and B is the current value according to the fluid properties.

A in Figure 17 is the SMD—current increase rate, and the difference between working fluids S and V is 0.5793 and 0.5531, which is insignificant. Through the above experiment, various sizes of SMDs can be derived according to the amount of charge.

3. CONCLUSIONS

This experiment investigated factors affecting the spray pattern as they related to the spray characteristics and droplets of electrostatic spraying and clarified the droplet size, distribution, and current value of each spray mode. Through these processes, this work presents a reference point for experimental research on electrostatic spraying.
1. spray modes were recognized according to the applied voltage versus flow rate, and it was found that the cone jet mode was delayed by differences in viscosity.

2. In the case of the cone jet mode, the cone-shaped spray mode is determined by checking the value at which the current becomes constant in the cone jet mode as well as by visualization. The larger the viscosity, flow rate, and nozzle diameter, the larger the current; the smaller the NTS value, the smaller the current.

3. By relatively comparing SMD and SMD standard deviation of other spray modes with the cone jet mode shown through experiments in working fluids S and V, it was observed that SMD differed by up to 1.5 times. Besides, the SMD standard deviations found in pulsed and rotated jet modes are more than 2.5 times larger than those in the cone jet mode.

4. The smallest SMD and standard deviation were recorded for both working fluids S and V in the cone jet middle phase, and the standard deviation difference was insignificant for working fluid V with high viscosity.

5. The theoretical droplet-size formula and experimental droplet size differ by a maximum of 6.5 times, and it was confirmed that SMD was approximately 8% larger as the viscosity increased under the same experimental conditions. The theoretical equations should be additionally derived under various conditions in line with experimental conditions and fluid properties. In the case of droplet distribution, it was noted that the standard deviation was small under the flow conditions of 0.6–2.1 mL/h in working fluid V with high viscosity.

6. The current increases linearly according to SMD for working fluids S and V. Working fluid V with high viscosity has a high current, but the difference in the increase rate is minute. Through the correlation of SMD–current, a wider range of droplet size and current values can be extracted.

4. METHODS
4.1. Material. In this experiment, glycerol, ethanol, and citric acid were used to adjust wt % to fix other physical properties except for viscosity as much as possible. To verify the characteristics of differences due to viscosity among fluid properties, only glycerol, ethanol, and citric acid were used to stir the two working fluids.

To make the mixed working fluids (glycerin, ethyl alcohol, and citric acid) in this experiment, glycerin (99%, Ducksan), ethyl alcohol (94%, Duksan), and citric acid monohydrate (99.5%, Puriss, meets analytical specification of Ph. Eur., BP, USP, E330 Sigma-Aldrich) were used. The mixed solution was prepared using a multiheating magnetic stirrer (S07-72-050, Mi-Sung). In the process of
using the multheating magnetic stirrer, the ambient temperature was fixed at 25 °C. The solution was stirred for approximately 12 h at 40 rpm. In the case of glycerol and citric acid, the compound was stirred using the property of dissolving well with distilled water because of the hydrophilic nature of OH−. 35

4.2. Fluid Property Measurements. The following instruments were used to measure the variable fluid property conditions in this experiment. Electrical conductivity was measured using a CON 150, and the standard solution was corrected using 111.8 mS/cm. Viscosity was metered using an SV-10 kinematic viscometer, and surface tension was measured using a DCA-200. The dielectric constant was measured using a liquid dielectric constant meter 871.

In quantifying the fluid properties, other fluid properties were fixed and fluids that only had a difference in viscosity were fabricated. The specifics of the working fluids are shown in Table 1.

4.3. Experimental Setup. Figure 18 is a diagram of the laboratory-scale experimental setup. It records the spray shape and properties of the electrostatic spray. The center of the figure consists of a nozzle, substrate, cover, and fluid supply part. The left side of the figure is the voltage supply part, and the right part of the figure consists of the measuring part. The syringe pump used was an NE-1000 model, the syringe capacity was 1 cm³ (HSW Norm-Ject), and the nozzle used was a radial nozzle (single plastic nozzle, NNC-PN 21-34GA). The substrate was made of aluminum (D: 70, H: 10 mm) with a flat surface. The cover was made of acrylic to prevent changes in the physical properties of the fluid during the experiment. The relative humidity that can affect the electrostatic spray pattern was reduced as much as possible.

The atmospheric temperature was fixed at 25 °C, and atmospheric pressure was used to minimize changes in the physical properties of the fluid during the experiment. The relative humidity that can affect the electrostatic spray pattern was reduced as much as possible through the cover, and the experiment was carried out by fixing the relative humidity to 40 ± 10% as much as possible.

4.4. Experimental Conditions. Table 2 describes the experimental conditions. All experiments were performed 30 times per experimental condition, and then, the data test averaged more than 30 times. The nozzle diameters were 0.2, 0.4, 0.5, 0.7, and 1.0 mm (nozzle gauges: 17, 19, 21, 22, and 27), and NTS was increased by 10 mm increments from 10 to 50 mm as the experiment was conducted. The voltage was increased in intensity from 0 to a maximum of 20 kV to minimize hysteresis. The flow rate was increased in increments of 0.3 mL/h from 0.3 to 6.0 mL/h, and the experiment was performed according to the flow-rate change. The atmospheric temperature was fixed at 25 °C, and atmospheric pressure was used to minimize changes in the physical properties of the fluid during the experiment. The relative humidity that can affect the electrostatic spray pattern was reduced as much as possible through the cover, and the experiment was carried out by fixing the relative humidity to 40 ± 10% as much as possible.

| Table 2. Experimental Conditions |
|----------------------------------|
| condition                     | value |
| nozzle diameter (mm)           | 0.2, 0.4, 0.5, 0.7, 1.0 |
| nozzle to substrate (NTS, mm)  | 10, 20, 30, 40, 50 |
| flow rate (mL/h)               | 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 3.0, 6.0 |
| ambient temperature (°C)       | 25 |
| relative humidity (%)          | 40 ± 10 |

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Notes
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