# Formation and Modeling of Droplet Ejection for Electrohydrodynamic Inkjet Printing

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## ABSTRACT

EHD inkjet printing which based on EHD spray phenomenon and theory is attracting attention as one of the ink-jet printing technologies capable of sub-micron patterning. Among the ejection modes of EHD spray, the micro-dripping mode is suitable for EHD inkjet printing because it can form one micro droplet. Therefore, the modeling is necessary to understand the principle of ejection of micro-dripping mode which is not established in previous studies. In order to investigate micro-dripping mode, the meniscus was divided into layers, and the electric force, pressure and surface tension acting on each layer were obtained by image processing and curve fitting method. Using this value, the equilibrium state of the surface tension and the sum of the electric force and the pressure of the divided layers according to each meniscus appearance are compared. The meniscus change was predicted and a model for stable ejection was established as a result.

***Keywords***: EHD(Electrohydrodynamic), inkjet, printing, droplet, ejection, micro-dripping mode

## 1 INTRODUCTION

Since the advent of Mechanical Electro Micro Systems (MEMS) technology, MEMS inkjet printing (the same as MEMS inkjet print) among the many microfluidic devices for controlling fluid in the micro area has been the most successful commercialized product. In particular, MEMS inkjet printing has been used in office area for printing paper, but it has recently become an alternative to traditional process methods due to its ability to make devices and products at a lower cost than semiconductor fabrication process[1-2].

Therefore, MEMS inkjet printing has received much attention in the industry fabrication area. A lot of money and manpower are invested in the research of industrial printing applied to industrial process of MEMS inkjet printing, and it is aimed to achieve the development and commercialization of printed electronics [3-4].

In response to this trend, the development of MEMS inkjet printing for industrial and process has been widely studied in industrial printing application of thermal bubble and piezoelectric inkjet printing, which is commercialized as office equipment and succeeded as a product. As a result, many research teams have published results of pattern formation and device development using thermal bubble and piezoelectric inkjet, and several companies have introduced their own inkjet printing equipment on the market[5].

EHD(Electro-Hydrodynamic) inkjet printing technology is attracting attention recently as the necessity of forming sub-micron patterns with inkjet printing technology is emerging in industrial process along with that[6]. EHD inkjet printing based on electrospray and EHD discharging for tiny droplet/jet is known to be able to generate higher resolution and higher aspect ratio of patterns than the conventional inkjet printing[7].

EHD inkjet printing is a suitable ejection mode for industrial inkjet printing technology in micro-dripping mode, pulsed cone jet mode and continuous cone jet mode among ejection modes at the classification of electrospray phenomenon. The meniscus shape of continuous cone jet mode and pulsed cone jet mode are most similar to the conical Taylor cone[8]. The analysis of meniscus of conical shape(Taylor cone) which are pulsed cone jet mode and continuous cone jet mode has been conducted long time study on the principle of the meniscus in electric field[9-10]. However, the study on micro-dripping mode, which meniscus appearance is similar to the hemisphere or elliptical shape and discharges one droplet, has not been well established.

## 2 MICRO-DRIPPING MODE

One of the most suitable ejection modes for EHD inkjet printing is the micro dripping mode, in which the meniscus is hemispherical or elliptical due to the electric field applied to the meniscus as shown in blue box of Figure 1. The micro dripping mode differs from the dripping mode in that the meniscus does not shrink after the droplet is separated and droplets are formed much smaller than the nozzle diameter only at the end of the meniscus where the electric field is concentrated. The droplets separated from the meniscus are no longer fragmented and form one droplet(see Figure 1). The diameter of the formed droplet is from several micrometers to several hundred micrometers depending on the nozzle diameter and electric field strength, and the droplet size distribution is mainly the same size. The ejection frequency of the droplet is several tens to several thousand Hz per second, and the amount of charge in the droplet is about half of the Rayleigh limit[11].

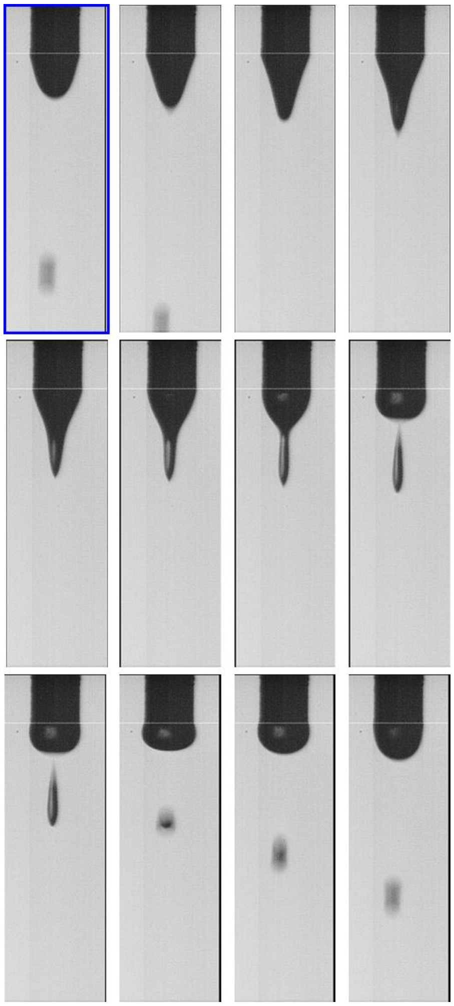

Figure 1: The ejection images of micro-dripping mode.

## 3 RESULT AND DISCUSSTION

For the modeling of ejection at micro-dripping mode, the meniscus is divided into layers (see Figure 2), and use the method of calculating the force (surface tension(Fst), pressure(Fp) and electric force(Fe)) acting on each layer based on the coordinates on the nozzle and analyzed how each force generates and changes at the boundary of meniscus.

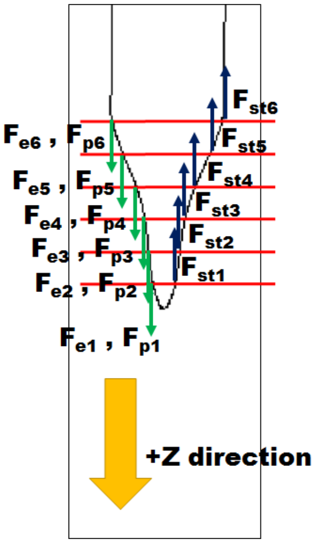

Figure 2: Method of ejection modeling for micro-dripping mode.

To obtain the exact electric field intensity and surface tension acting on the meniscus in micro-dripping mode, the coordinate values of the meniscus were obtained through image processing, and the radius of curvature of each layer was obtained by the curve fitting (see Figure 3 and 4). The sum of electric force and pressure of the divided layers according to the respective meniscus shape during ejection at micro-dripping mode and the surface tension were compared by using the obtained values.

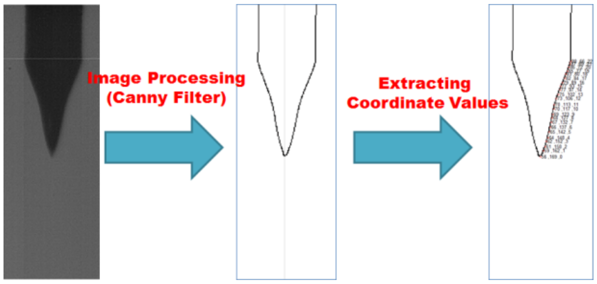

Figure 3: Image processing and extracting coordinate values.

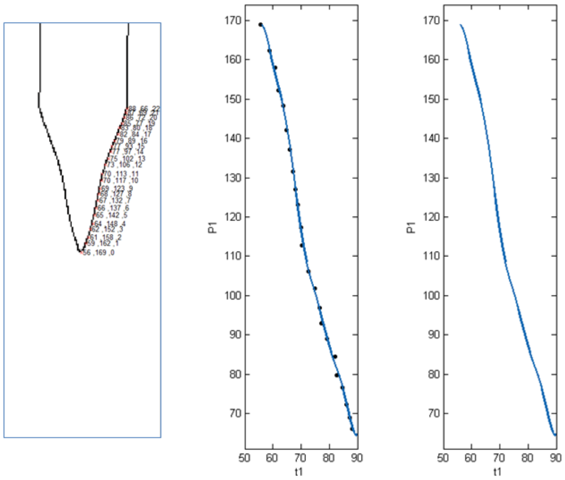

Figure 4: Method of curve fitting.

Figure 5 is a graph comparing the sum of electric force and pressure of the divided layers and the surface tension at the meniscus shape with the nozzle radius being x axis when ejection at micro-dripping mode. As the meniscus gets closer to the ejection, the equilibrium point (color circle of each graph) gradually goes to the center of the nozzle. This is because the meniscus interface at the center of the nozzle is initially hemispherical or elliptical shape, so that the distance from the substrate is the closest, the electric force is pulled in the +z direction by the electric force. Since the surface tension is larger in right part of the equilibrium point, the meniscus is pulled in the -z direction. For this reason, the shape of the meniscus gradually changes, so that the size of the portion to be torn off (red circle on image) is gradually reduced, which is a condition for forming droplet.

In the final stage of ejection (ocher graph), left part of the equilibrium point is formed as droplet because the electric force is much larger than the surface tension, and the right part of the equilibrium point is the stable part of the equilibrium state for preparing next ejection.

## 4 CONCLUSION

The electric force, the pressure and the surface tension acting on each divided layer of meniscus is compared and analyzed, and the interaction is analyzed to establish the micro-dripping mode ejection model.

In order to obtain the exact surface tension and electric force acting on the meniscus during ejection, the coordinate values and radius of curvature according to each meniscus shape were obtained through image processing and curve fitting method. The calculated radius of curvature was added to the developed equation, and the sum of the electric force(Fe) and the pressure(Fp) of the divided layers and the surface tension(Fst) according to each meniscus shape were compared.

As the meniscus gets closer to the ejection, the left part of the equilibrium point(the meniscus interface at the center of the nozzle) is pulled in the +z direction by the electric force, so that the sum of the electric force and the pressure is much larger than the surface tension. Since the surface tension on the right side of the equilibrium point is larger than the sum of the electric force and the pressure, the shape of the meniscus is changed at the -z direction.

The left part of the equilibrium point, which has a larger sum of the electric force and the pressure than the surface tension, is formed as the droplet, and the right part of the equilibrium point is returned to the stable meniscus of the complete equilibrium state to prepare for the next ejection in the shape of meniscus just before the droplet ejection

Therefore, the principle of droplet ejection in micro-dripping mode and the stability of meniscus after droplet ejection are analyzed, and it is expected to predict the droplet size and condition of ejection droplet in this study.

## 5 ACKNOWLEDGEMENT

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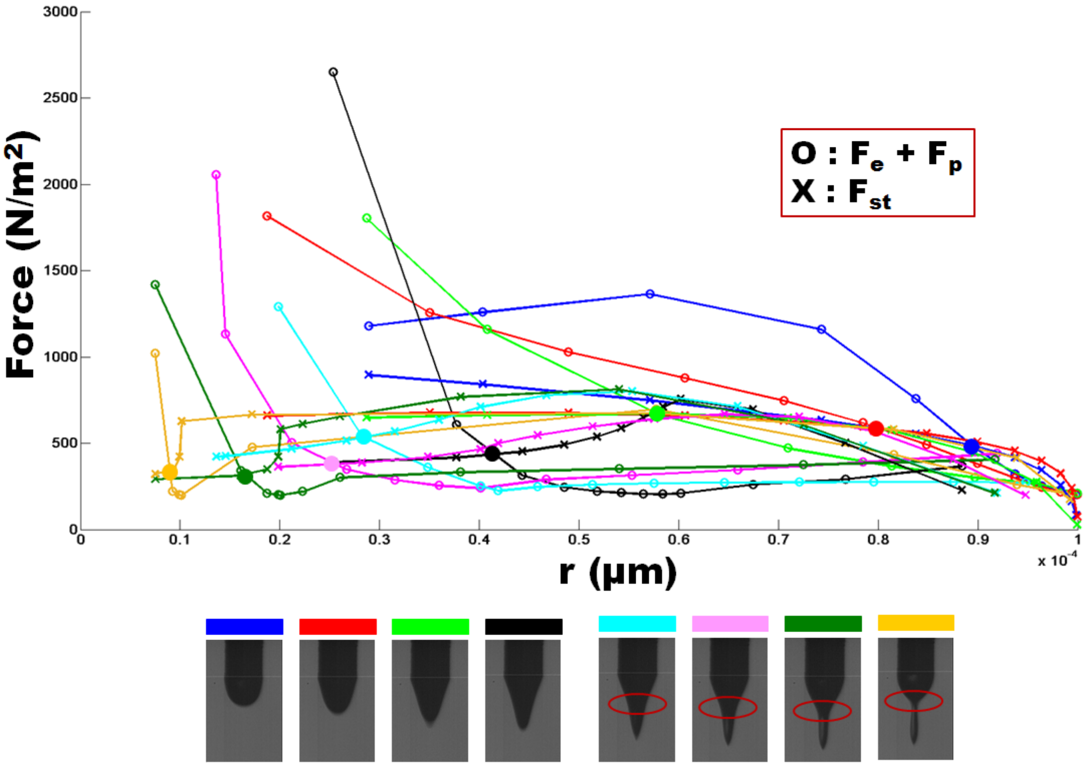

Figure 5: The modeling of force balance for micro-dripping mode.

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