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Investigations on ElectroHydroDynamical Drop-On-Demand Inkjet Printing

Yinhong Dai, Donghang Chen, Lingyun Wang, Daoheng Sun *

Dept. of Mechanical and Electrical Engineering, Xiamen University, Xiamen, China, 361005

Abstract — **The effects of electrohydrodynamical(EHD) drop-on-demand inkjet variables on the droplet diameter are presented in this paper. The EHD printer uses a high pulsed voltage to generate strong electric field in the vicinity of the apex of the dome-shaped liquid meniscus and thus micro-jetting ejection of droplet comes forth. And the liquid shaping processes are revealed through CCD. The droplets with 50μm diameter were formed on the silicon collector. We have evaluated systematically the effects of EHD inkjet printing design variables such as the voltage, the frequency, the solution concentration, the voltage duty cycle and the contact angle on the droplet diameters. The experiment results show the droplet diameters get larger with the voltage, the solution concentration and the voltage duty cycle increasing respectively. And when the frequency, the contact angle increases respectively, the droplet diameters get smaller.**

Keywords —design variables, electrostatic inkjet printing, droplets size

I. INTRODUCTION

With the quick development of drop-on-demand (DOD) inkjet printing technique, it plays an important role not only in the office printing applications, but also in the front edge technology such as liquid crystal display (LCD)[1], lithography direct writing [2], drug distributor [3], micro jet propulsion [4] because of its characteristics of non-contact deposition, non-mode processing and subminiature manufacture etc.

From 1976, the inkjet printers have brought out surprises and conveniences and developed into many different kinds. The main mechanisms of ejecting ink droplets are categorized in two groups: one is the thermal type and the other is piezoelectric. But both categories have their own head drawbacks to meet the requirement for future generation of jetting devices. Generally speaking, the former consumes too much power and the thermal actuator resistance has limited life by cavitation damage. And in the latter, it is difficult to fabricate and hard to reduce head size [5].

Here, we report one kind of low-cost and simple inkjet printing technique, where the droplet is actuated by strong electrostatic force. This kind of direct liquid-electric field interacting jetting owns the advantages of (1) rapid and smart control by changing electric field; (2) easy control of droplet size, nozzle array, and ejection frequency; (3) applicability to single- and multi-phase liquids, and (4) non-mechanical driving in design [6]. But so far, there are few reports about the effects of printing variables on the droplet diameter, Akira Sou analyzed the voltage condition of 2D (two-dimensional) EHD ink jetting mode by numerical calculation and have provided valuable information [7].

In this work, we have evaluated the effects of EHD inkjet printing variables on the droplet diameter. Figure 1 shows a schematic diagram of the direct liquid-electric field interacting jetting. The design variables of the droplet generator, such as the voltage, the frequency, the solution concentration, the voltage duty cycle and the contact angle on the droplet diameter were all considered in the mode. The printing mechanism is based on the EHD theory. When voltage is applied between the needle and the grounded metal plate, EHD phenomena appears that the fluid inks come out of the needle and travel onto the collector. The silicon collector is glued up to the grounded metal plate and transmitted in horizontal by a transport. The high pulsed voltage brings out an electric field that causes solution free charges in the ink to accumulate near the surface of the pendent meniscus at outlet of the spinneret. The mutual coulombic repulsion between these charges induces a tangential stress on the liquid surface, thereby deforming the meniscus into a cone [8]. Under enough high electric field, this electrostatic stress overcomes the surface tension at the apex of the liquid cone and as illustrated in Fig. 2, one jet ejects from the apex of the cone to form one droplet on the collector in the jetting mode, which is different from the dripping mode [9].

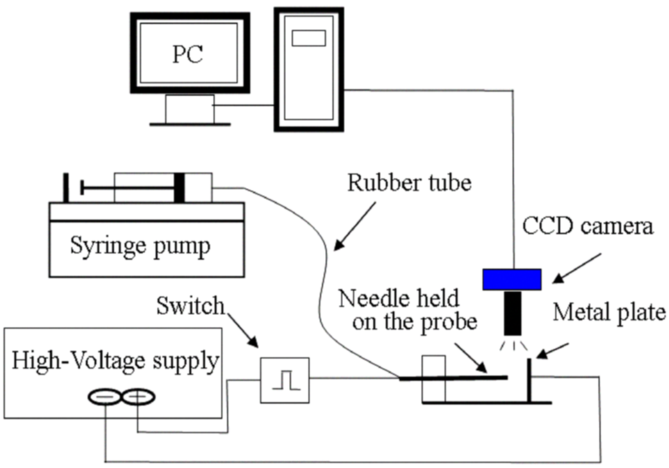

Fig.1. The schematic diagram of experiment apparatus. A wax-coated nozzle (internal diameter: 60μm) was located beside the ground metal plate with 450μm electrode distance. A pulse power is connected to the needle.

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All authors are with the Department of Mechanical & Electrical Engineering, Xiamen University, Xiamen, China

*Contacting Author: Daoheng Sun (phone: 086-0592-2185927; email: sundh@xmu.edu.cn).

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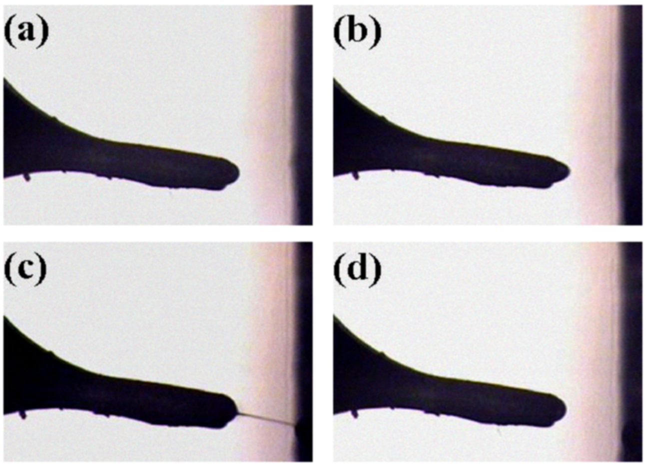

Fig.2. Time-lapse images of the pulsating liquid in one cycle (a) before the pulse potential, the droplet formed at the tip needle treated with wax on the surface, (b) a high pulse voltage applied brought out an electric field that caused solution free ions in the ink to accumulate near the surface of the pendent meniscus at the needle thereby the meniscus deforming, (c) later, this electrostatic stress overcame the surface tension at the apex of the liquid cone, jets from the apex to expel some portion of the surface charge, (d) as the voltage stopped the jet brake off, one droplet was collected on the substrate.

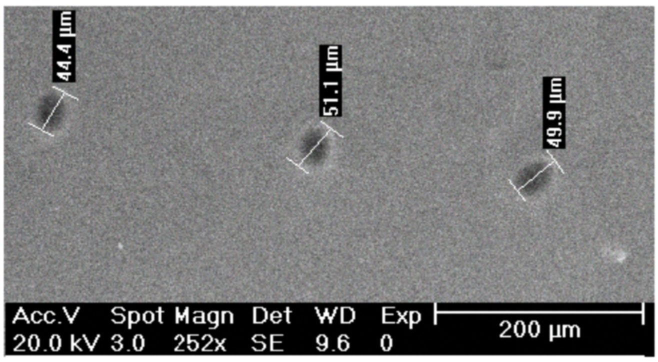

Fig.3. SEM of the droplets. The voltage, duty cycle, frequency and solution concentration is 1.55kV, 3:7, 50Hz and 4% respectively.

II. EXPERIMENT

The experimental setup used in this work is shown in Fig. 1. The stainless steel needle, which has a circular cross-section with the inner diameter and outside diameter of 60 and 190µm respectively, is connected to the positive terminal of the high voltage supply (Tianjin Dongwen High Voltage Supply Plant) connected to the pulsed voltage switch which input is connected to high voltage supply. The needle surface coated wax is held on the probe. The probe can feed to coordinate the gap between the tip of needle and the contrary collective substrate. The inks is Poly (ethylene oxide) (PEO, Tianjin Longjiang Fine Chemicals Co.,Ltd.) with concentration of 2%, 4%, 6% and 8%wt in DI water. The inks are delivered to the needle through a rubber tube by a syringe pump (HARVARD 11 PLUS, U.S.A.). A CCD is used to study the behavior of ink deforming and calculate the gap between the needle and grounded metal, which is kept 0.45mm. Experiments are carried out at low flow rates and the applied pulse voltage amplitude is varied up 1.5kV and a silicon collector kept on the metal plate is used to collect the droplet samples. Droplets on silicon substrate are characterized by XL30 scanned electron microscope (SEM) as shown in Fig.3.

III. RESULTS AND DISCUSSIONS

A. droplet diameter vs. voltage

As been said in the introduction, the ink jet is pulled out from the deforming cone by the electrostatic force, but the amplitude of pulse voltage only keeps in an extent that the jetting can happens. As other variables are fixed, such as 450µm gap, 2% concentration, 25Hz frequency and 3:7 voltage duty cycle, it is found that as the pulse voltage is lower than 1.5kV or larger than 1.85kV, there is no ink jet except that there exists sparkle in 1.85kV. And the pulse voltage being between 1.55kV and 1.75kV, it is easy to achieve an ink jet. Five voltages (1.55, 1.60, 1.65, 1.70, 1.75kV) are tested. As shown in Fig. 4, the droplet diameters increase from about 45µm to 95µm as the voltages increase from 1.55kV to 1.75kV. As we know, the magnitude of electrostatic force is rested on the magnitude of electric field. In our experiments, as the voltage amplitude is lower than 1.5kV, the electrostatic force can not overcome the solution surface tension that there is no jet. But as the voltage amplitude is larger than 1.85kV, the electric field is so strong that the air breakdown happened. And the voltage amplitude between 1.55kV and 1.75kV are suitable to form the jet. As the larger voltage amplitude, bringing out the stronger electric field, the electrostatic force become greater that act on the deforming cone to make the jet velocity faster comparison to the lower amplitude. That means there are more inks on the collector.

B. droplet diameter vs. concentration

Concentration is changed (2%, 4%, 6% and 8%wt) to study the effect of the solution concentration on droplet diameter. These solution viscosities vary in the range of 0.5–8 poise and surface tensions are in the range of 60–40 dynes/cm [10]. When the solution concentrations increase, the viscosities increase and the surface tension force decreases. The results show that the solution surface tension and viscosity play

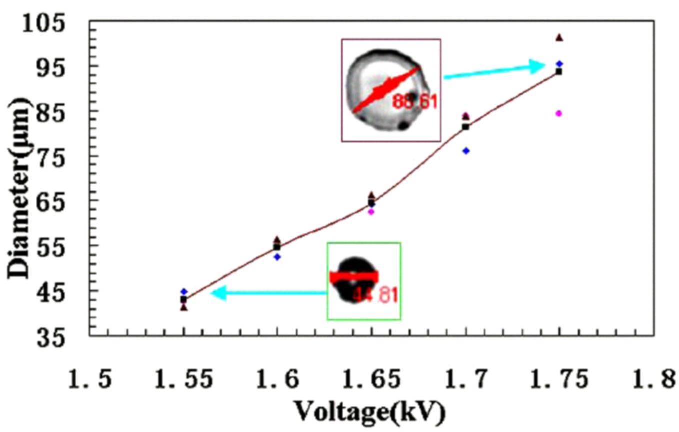

Fig.4. The droplet diameter vs. applied voltage. The duty cycle, frequency, and solution concentration is 3:7, 25Hz and 2% respectively.

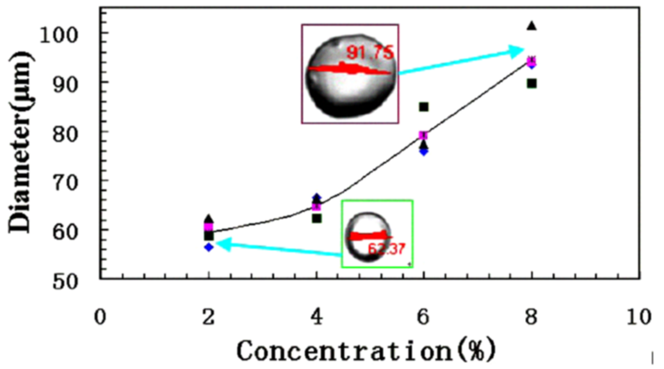

Fig.5. The droplet diameter vs. PEO concentration. The duty cycle, frequency and voltage is 3:7, 25Hz and 1.65kV respectively.

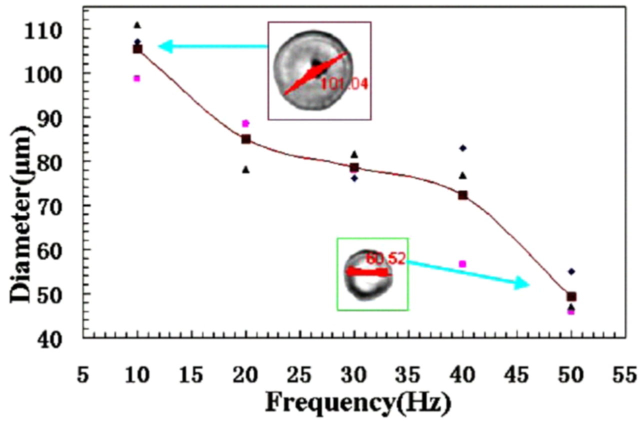

Fig.6. The droplet diameter vs. frequency. The duty cycle, voltage and concentration is 3:7, 1.65kV and 2% respectively.

important roles in determining the droplet diameters. As shown in Fig. 5, the droplet diameters increase from about 55μm to 95μm as the solution concentration increasing from 2% to 8%. And it is found that the higher viscosity solutions are extremely difficult to be used with the 60μm needle in these experiments, because of making hard and unstable to control the solution flow to the needle tip. From Fig.5, there is an apparent change in the droplet diameters dependence on the solution concentration that may be reflective that it is probable to change the solution concentration for coordinating the droplet diameters. As been discussed above, the surface tensions of PEO solution become smaller as the solution concentration getting higher. So for the higher concentration solution, it needs smaller voltage amplitude to overcome the surface tensions comparison to the low concentration solution. It is happened that at the same pulse voltage amplitude the jet velocity pulled out from the higher concentration solution is faster than the jet velocity pulled out from the lower concentration solution. From the result, it can be concluded that the droplet diameter increases as the solution concentration increases (2% to 8%). This may be helpful and practical for the EHD printer to improve the operating voltage.

C. droplet diameter vs. frequency

All of the Drop-on-demand inkjet printers are functioning by the periodic activations to realize the drop-on-demand. The high voltage is changed to the high pulsed voltage by a switch. From the procession of the deforming cone, discussed above, we know that it needs one charging phase for the charges of the ink accumulating to the surface of the pendent, less than 1ms [11]. And then there will be one jet pulled out by the electrostatic force. But the charging phase time is changing with the altering of variables, likes the solution, the amplitude of voltage. In order to form the jet at the pendent, the time of the high voltage must sustain longer than the charging phase. The experiment results of the dependence between the droplet diameter and the frequency is shown in the Fig.6. The droplet diameters become smaller from about 105μm to 50μm as the frequency increases from 10Hz to 50Hz. And we can induce that because of the higher frequency, the shorter cycle time, the jetting time is shorter for forming smaller droplets comparison to the lower frequency.

Also, the different duty cycle has different output time. It means we change the property of voltage duty cycle to alter the jetting time to form the different diameter droplets. A series of the voltage duty cycle of 3:7, 1:1 and 7:4 have been tested to study the effects of the duty cycle on the droplet diameter. The Fig.7 shows the experiment results of the dependence between the droplet diameter and the voltage duty cycle. The droplet diameters increase from about 65μm to 95μm as duty cycle increases from 3:7 to 7:4. As the larger voltage duty cycle has a longer voltage output time, the droplet is larger. So the voltage duty cycle is another way to influence the diameter of droplet.

D. droplet diameter vs. contact angle

The different collectors have different surface wettability, hydrophilic or hydrophobic. The collector surface wettability plays an important role on the morphology of the droplet on the substrate. We use the CFD software to simulate the droplet deformation and contact area between the droplet and the substrate surface. The simulation procession is from the droplet with the speed of 1.5m/s colliding the substrate to the steady one on the substrate. And then we study the deforming behavior and calculate the contact areas of the droplet on the

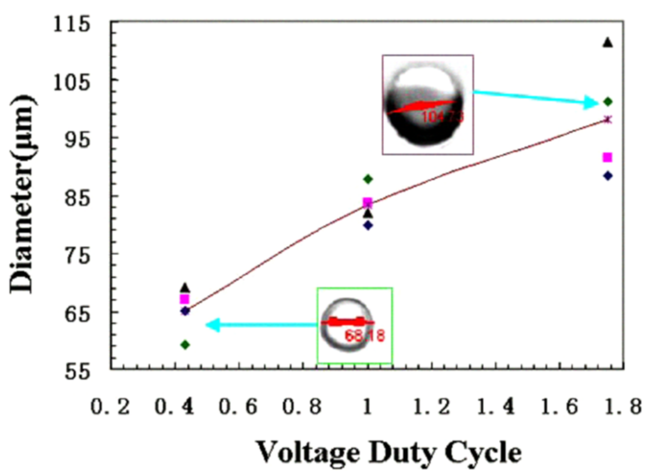

Fig.7. The droplet diameter vs. the voltage duty cycle. The frequency, voltage and PEO solution concentration is 25Hz, 1.65kV and 2% respectively.

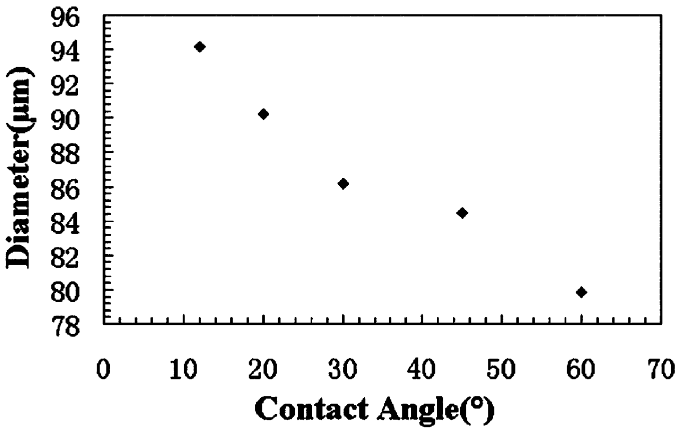

Fig.8. The droplet diameter vs. contact angle.

substrate with the contact angles of 10, 20, 30, 45 and 60 degree respectively. The simulation result of the dependence between the droplet diameter and the contact angle is shown in the Fig.8. The droplet diameters decrease from about 95μm to 78μm as the contact angles increase from 10 to 60 degree.

IV. CONCLUSIONS

This paper presents the effect of electrohydrodynamical drop-on-demand inkjet printing variables on the droplet, which can generate micro-liquid droplets in the jetting mode. The experiment results show that the droplet diameter gets smaller from about 95μm to 45μm with the voltage decreasing from 1.75kV to 1.55kV. That is because the electrostatic force decreases that the velocity of the jet turns down. Also the droplet diameter reduces from about 95μm to 55μm as the solution concentration decreased from 8% to 2%. And the frequency, the voltage duty cycle and the contact angle also would affect the droplet diameter. From the results, the droplet diameter becomes smaller from about 105μm to 50μm as the frequency increases from 10Hz to 50Hz. The droplet diameter decreases from about 95μm to 65μm as duty cycle decreases from 7:4 to 3:7. The droplet diameter decreases from about 95μm to 78μm as the contact angles increase from 10 to 60 degree.

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