A Scaling Model for Predicting the Gas-Channel Formation Period in Crater-Like Electrospinning of Nanofibers

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Abstract: Crater-like electrospinning is a novel and cost-effective method for the mass scale production of nanofibers. The gas channel in the polymer solution plays a key role to produce a bubble Taylor cone or a crater-like Taylor cone, which is the key to eject the thin fluid jets (finally solidified into nanofibers) in electrospinning process. However, the formation mechanism of gas channel of crater-like Taylor cone is still unclear, which hinders further development of this process. In this work, a simple and effective scaling model was firstly established to predict the period of the gas-channel formation in the polymer solution during electrospinning process. Our theoretical analysis showed that the gas-channel formation period was mainly determined by the input air pressure during the process. The relationship between the formation period and the input air pressure followed a scaling law. In order to verify the model, crater-like electrospinning process was carried out and a high-speed digital camera was employed to observe the gas channel. The experimental results agree well with the scaling model, which indicates that the proposed system is feasible. The scaling model could be useful in helping us to understand the process.

Keywords: Electrospinning, mathematics analysis, nanofibers, polymer, scaling model.

1. INTRODUCTION

In the 1930s electrospinning was developed as one of the important methods for fiber fabrication, and has produced various polymer nanofibers with the diameter range from several nanometers to several micrometers [1-3]. The nanofibrous materials obtained by electrospinning has nonwoven structure with unique features, including interconnected pores and a very large surface to volume ratio, which enable such nanofiber materials to have many applications such as filters, energy storage, environment engineering, protective clothing and tissue engineering [4, 5]. With the rapid increase in application of nanofibers in more and more industry areas, electrospinning has been one of the most important and basic techniques in the fabrication of nanofibers since the early 2000s.

These applications require large number of electrospun fibers, however, the major challenges encountered in the electrospinning process are poor efficiency and low output, about 0.01-0.3g/h [6], which has been the technological bottleneck for the industry. Many researchers has proved that the number of fluid jets (finally turned into nanofibers) was the key to improving the yield of nanofibers. In order to address the low number of jets, some novel electrospinning processes have been invented to produce simultaneously multiple fluid jets and fabricate a high yield of nanofibers recently [7].

Bubble electrospinning and crater-like electrospinning are both new electrospinning techniques having the potential to fabricate nanofibers with a high output, which designed by our group [8-10]. It is well known that the Taylor cone plays a key role in the production of nanofibers in electrospinning process, bubble electrospinning and crater-like electrospinning are no exceptions. In these two processes, Taylor cone, a bubble or a crater-like solution ridge, has significant influence on producing multiple jets continuously. However, bubble electrospinning process is discontinuous due to the repeat of burst and reformation of fluid bubble, according to our previous study [11].

Recently, many researchers have studied bubble electrospinning process and wondered about how to improve the properties and the yield of nanofibers. In order to improve the discontinuity of bubble electrospinning process, the time of gas channel formation should be decreased. Obviously, if a bubble is changed into a crater-like solution ridge, the gas-channel formation period could be shorter, the number of fluid jets could be greater and the yield of nanofibers be higher. This is why a crater-like electrospinning process was developed in our group.

Most previous studies have given the readers basic knowledge for understanding the process [12-14]. Unfortunately, almost all the previous literatures paid their attention on the fabrication of nanofibers. The reason of the

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(*a*)

30*Pm*

Fig. (3). (**a**) SEM photo of nanofibers obtained in crater-like electrospinning, (**b**, **c**) High-speed photographs of gas channel at different air pressure in crater-like electrospinning process(**b**- Air pressure P=10kPa, period T=66.7ms ; **c**- Air pressure P=25kPa, period T=50ms).

Table 1. The air pressure and its formation period in experiments.

Air Pressure (kPa)	Period (ms)
4	225
10	66.7
16	58.3
25	50.0
35	41.7
50	33.3

Fig. (4). Theoretical and experimental results of relationship between the air pressure and the period of gas-channel formation.

CONCLUSION

In this presentation, PVP was used to study the effect of air pressure on gas-channel formation period in crater-like electrospinning process. The theoretical analysis showed that the gas-channel formation period was greatly influenced by air pressure, and the period had an allometric relationship with air pressure. The experimental results verified the above theoretical prediction well. The relationship between the period and the air pressure is in the form, $T \propto P^{-3/2}$, in crater-like electrospinning. The scale model might be used to understand the new electrospinning process of nanofibers with great yield.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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