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Effect of Voltage on Morphology and Diameter of Electrospun Nanofibers

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Abstract: *Effect of voltage on morphology and diameter of electrospun nanofibers is studied theoretically, a scaling relation between voltage and the average diameter of the electrospun nanofibers is obtained. Experiment verification is made by nonwoven biodegradable nanofibers which are formed from electrospinning Poly(butylene succinate) solutions in chloroform in a single processing step.*

Keywords: *electrospinning, biodegradable polymer, nanofiber*

I. INTRODUCTION

Electrospinning [1-9] is the cheapest, most straightforward way to produce nanofibers, and it has attracted more and more interest because of its easy maneuverability and numerous unique properties including an enormous surface area per unit volume and its enormous potential in creating novel materials that have advanced applications [10-12].

Applications of electrospun nanofibers cover in various fields including photonics, sensorics, medicine, pharmacy, wound dressing, filtration, tissue engineering, drug delivery, catalyst supports, fiber mats serving as reinforcing component in composite systems, fiber templates for the preparation of functional nanotubes, just say few. China has an excellent nanotechnology textile industry already.

In this paper we will study the effect of voltage on morphology and diameter of electrospun nanofibers.

II. THEORETICAL ANALYSIS

In this paper, we consider a steady state flow of an infinite viscous jet pulled from a capillary orifice and accelerated by a constant external electric field.

Conservation of mass gives

$$\pi r^2 u = Q, \tag{1}$$

where Q is the volume flow rate, r is radius of the jet, u is the velocity.

Letting the surface charge be σ, conservation of charges gives

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$$2\pi ru\sigma + k\pi r^2 E = I \qquad (2)$$

where k is the dimensionless conductivity of the fluid, E applied electric field, and I is the current passing through the jet.

In case electrical force is zero or weakly, a pendant droplet of the polymer solution at the capillary tip is deformed into a conical shape, where the surface tension is dominant. If the voltage surpasses a threshold value, electrostatic force overcomes the surface tension, and a fine charged jet is ejected. In the initial case, we assume that the acceleration of the charged jet is constant, when we have

$$u = u_0 + at \qquad (3)$$

where u_0 is initial velocity, a is the acceleration. In the initial stage, the viscous force is ignored, thus the acceleration depends upon the electrostatic force:

$$a \propto 2\pi r\sigma E \qquad (4)$$

From Eq.(2), we have

$$2\pi ru\sigma \propto I \qquad (5)$$

We, therefore, obtain

$$a \propto \frac{EI}{u}. \qquad (6)$$

We assume that the acceleration in the initial stage is a constant, thus we obtain

$$u \propto EI \cdot \qquad (7)$$

Assume allometric scaling relationship between current and voltage has the form

$$I \propto E^b \qquad (8)$$

where b is a scaling exponent, which differs among different polymer solutions. In view of (7) we have

$$u \propto E^{1+b} \qquad (9)$$

Considering that the volume flow rate is constant during electrospinning, from Eq.(1), we have

$$r \propto E^{-(1+b)/2} \qquad (10)$$

In the next section, we will verify the scaling relation (10) experimentally via Biodegradable poly(butylene succinate) (PBS).

III. ELECTROSPUN BIODEGRADABLE POLY(BUTYLENE SUCCINATE) (PBS) FIBERS

Biodegradable polymers are designed to degrade upon disposal by the action of living organisms. Extraordinary progress has been made in the development of practical processes and productsfrom polymers such as starch, cellulose, and lactic acid [13-15]. Recently fabrication of biodegradable ultrafine fibers by electrospinning has been caught much attention[16-21] due to their small diameter, low density, high specific surface and excellent surface properties.

The utilization of biodegradable polymers has been expected to decrease the ecological pollution problems all over the world due to waste plastics, particularly those for outdoor purpose. The most important family of the biodegradable polymers currently developed consists of aliphatic polyesters such as poly (e-caprolactone) (PCL), poly(L-lactic acid) (PLLA), poly (3-hydroxybutyrate) (PHB), and poly(butylene succinate) (PBS). Among these aliphatic polyesters, PBS is a typical two-component aliphatic polyester that is considered to be one of the most accessible biodegradable polymers in terms of synthetic easiness[17,22]. Combination of electrospinning process and excellent biodegradability of PBS in a natural environment, their enhanced properties are required for application in various fields, such as catalysis, filtration, NEMS, medical implants, cell supports, nanocomposites, nanofibrous structures, tissue scaffolds, drug delivery systems, protective textiles, storage cells for hydrogen fuel cells[23].

IV. EXPERIMENTAL

Materials. To prepare electrospinning fibers of PBS, a molecular weight of 200,000-300,000g/mol (provided by Shanghai Institute of Organic Chemistry, Chinese Academy of Science) was used. Other solvent system studied was chloroform ($CHCL_3$) (supplied by Shanghai Chemical Reagent Co., Ltd) with a molecular weight of 119.38g/mol and density of 1.471-1.484g/cm3. The polymer, PBS, was dissolved in $CHCL_3$ solvent at

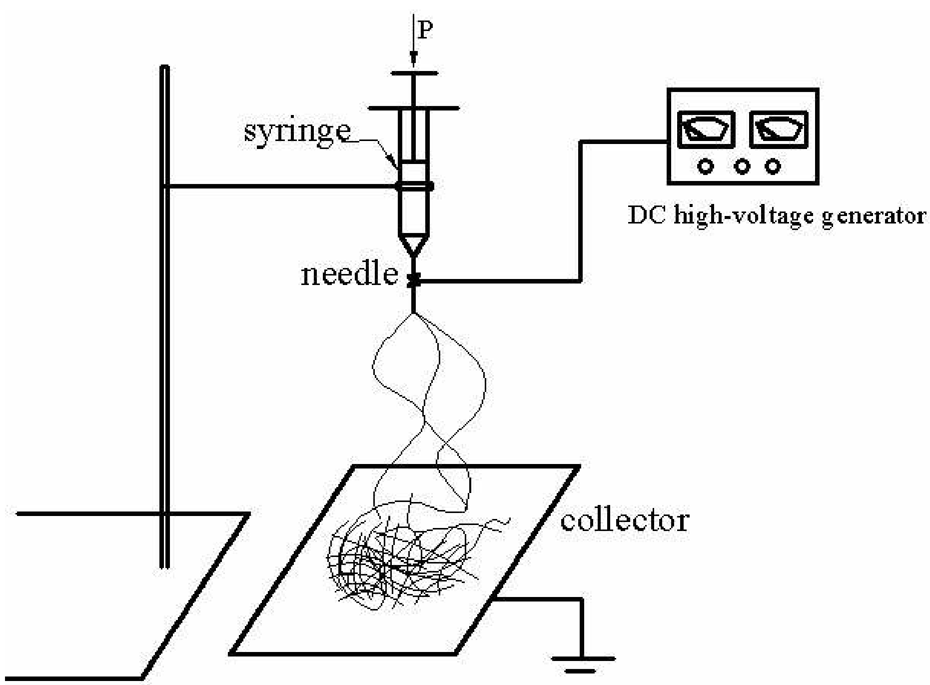

Fig. 1: Electrospinning set-up

room temperature with 2 hours of stirring in an electromagnetism stirrer (Angel Electronic Equipment(Shanghai)Co., Ltd) to prepare a polymer solution with a concentration of 14 wt%.

Electrospinning Experiment. A schematic of the electrospinning apparatus is illustrated in Figure 1. The polymer solution was placed into a 20mL syringe attached to a syringe pump. Electrospinning was carried out under room temperature in a vertical spinning configuration using a 0.5mm inner diameter needle with spinning distance of 5 ~ 10cm. The applied voltages were in the range 25-50kV connected to the needle by a DC high-voltage power supply (F180-L, Shanghai Fudan high school) via an alligator clip.

V. RESULTS AND DISCUSSION

For the investigation of the morphology and diameter of the electrospinning nanofibers, PBS nanofiber films were determined by a scanning electron microscope (SEM, JSM-5610). To obtain SEM images the fibers were collected on a SEM disk and coated with gold. SEM micrographs are illustrated in Figs. 2-5. The average diameter varies from 700nm to 1200 nm, and can be adjusted by the applied voltage.

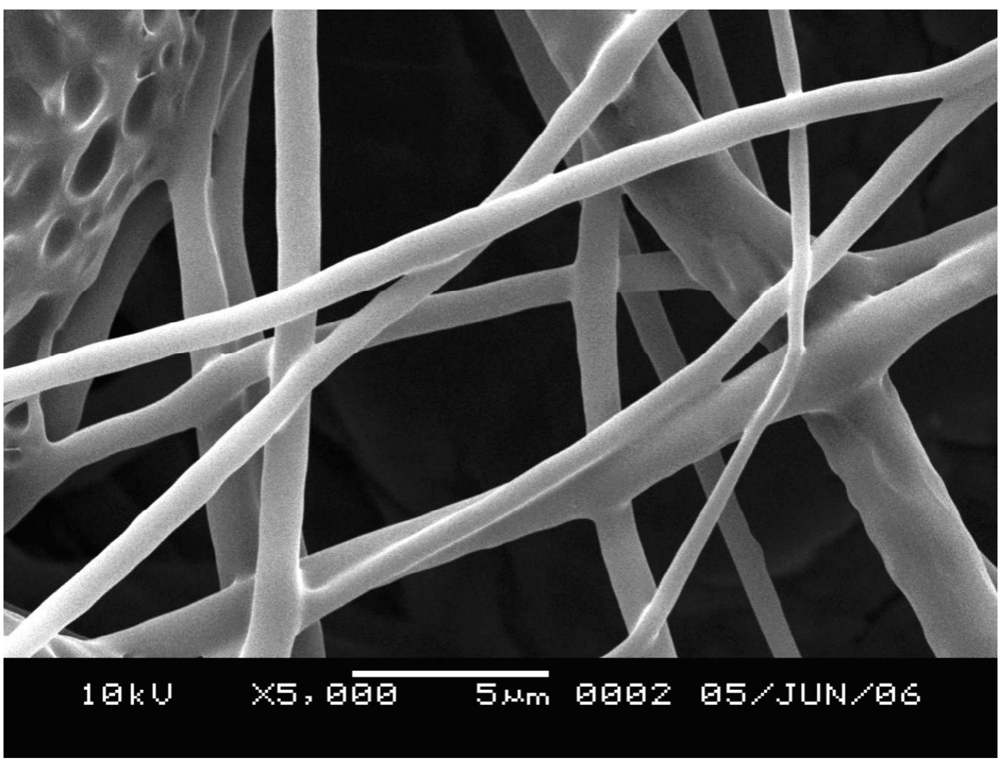

Fig. 2: SEM photograph of PBS/CF electrospun fibers. The concentration and voltage are 14wt% and 30kV. The average fiber diameter is about 1087nm.

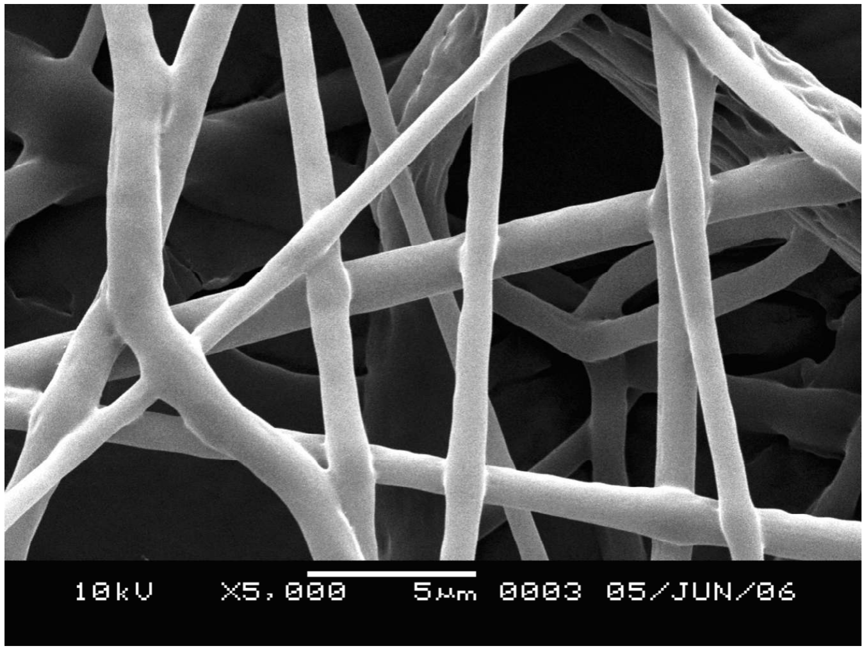

Fig. 3: SEM photograph of PBS/CF electrospun fibers. The concentration and voltage are 14wt% and 35kV. The average fiber diameter is about 994 nm.

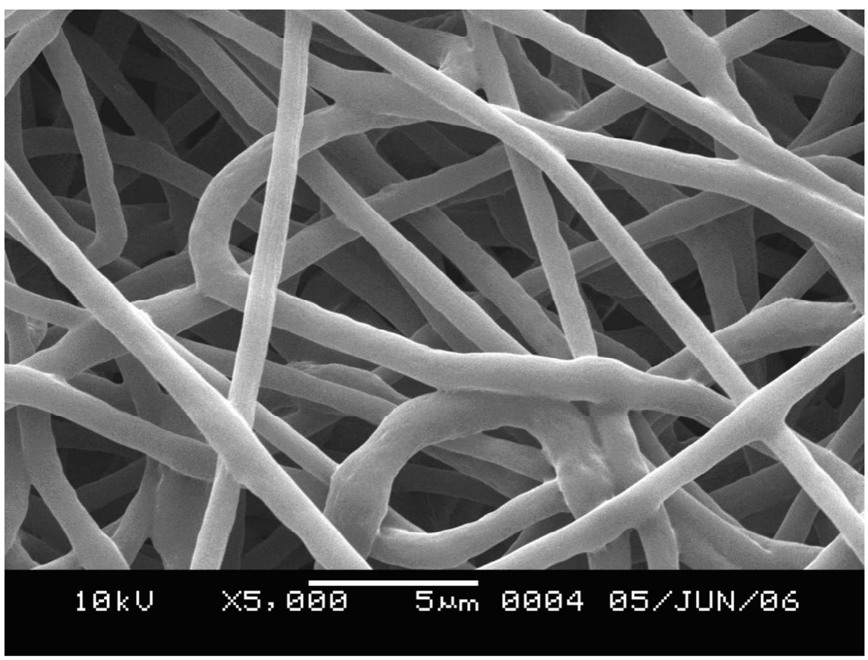

Fig. 4: SEM photograph of PBS/CF electrospun fibers. The concentration and voltage are 14wt% and 40kV. The average fiber diameter is about 856nm.

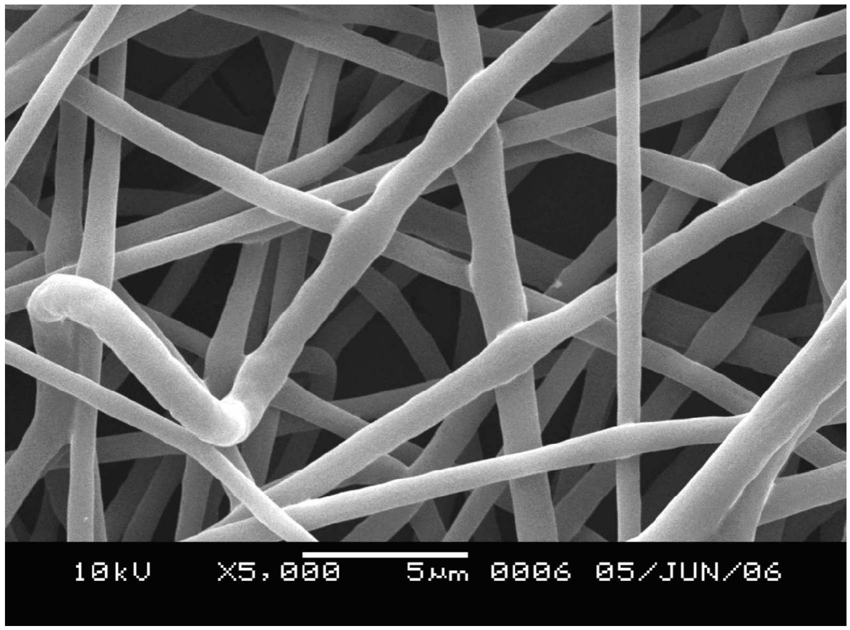

Fig. 5: SEM photograph of PBS/CF electrospun fibers. The concentration and voltage are 14wt% and 50kV. The average fiber diameter is about 760nm.

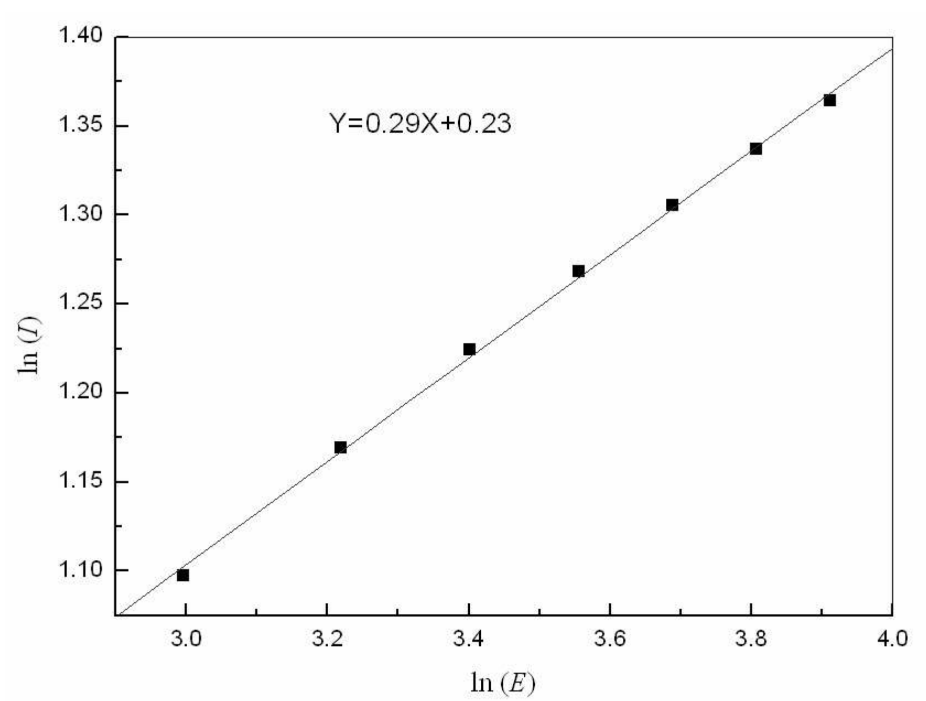

Fig. 6: The relationship between applied voltage and current. dot: experiment data, continued line: I $\propto$ $E^{0.29}$.

The relationship between current and applied voltage is illustrated in Fig. 6, which from we known that

$$I \propto E^{0.29} \tag{11}$$

According to (10) we have

$$r \propto E^{-0.645} \tag{12}$$

The prediction (12) agrees very well with the experiment data as illustrated in Fig.7.

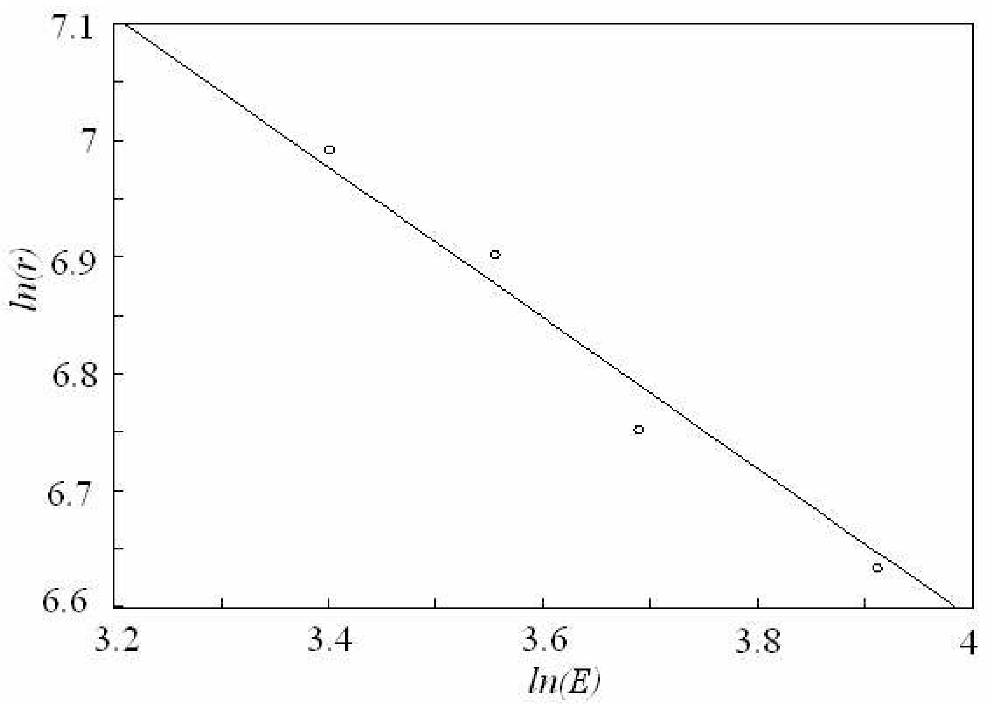

Fig. 7: Average diameter vs. applied voltage. Dot: experiment data, continued line.

IV. CONCLUSIONS

The theoretical analysis is of deceptively simplicity without loss of accuracy and the insightful scaling relation is very useful. Electrospinning is a promising approach to fabrication of biodegradable nanofibers with 700-1200nm diameters. The electrospinning technique described in this article could be extended as a versatile route to prepare nanofibers of other biodegradable polymer.

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