

Effect of Concentration on Electrospun Polyacrylonitrile (PAN) Nanofibers

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Abstract: An allometrical scaling relationship between the diameter of electrospun nanofiber and solution concentration is established, the scaling exponent differs greatly between different polymers and the same polymer with different molecules or the same molecules with different properties. The diameter of electrospun polyacrylonitrile (PAN) nanofibers increases approximately linearly with solution concentration.

Keywords: Nanofiber, Electrospinning, Concentration, Mathematical model, Allometrical scaling

Introduction

Electrospinning is a process which can produce superfine fibers ranging from several micrometers to several hundred nanometers. The process is much simpler and lower cost than any other processes that can produce nano-scale fibers. It involves applying very high voltage to a capillary jointed on a bump, while bumping solution through the capillary. The high voltage will induce electric charge to the solution and once electric force overcomes the solution surface tension, superfine fibers are produced. Electrospinning process can be affected by many factors, including solution characteristics, process conditions, etc. During the last 10 years extensive research has been conducted on various aspects of electrospinning [1-15].

Polyacrylonitrile (PAN) [7,16] is the most extensively used in electrospinning because of its excellent properties. Along with the emergence of Carbon Nanotube (CNT), PAN becomes the basic material of continuous CNT. So PAN is used here to study effect of solution concentration on electrospun nanofibers.

Theoretical Analysis

Experimental data [9] and theoretical analysis [3,4] show that viscosity affects much on the diameter of electrospun fibers. Baumgarten [9] pointed out that as viscosity increased, the spinning drop changed from approximately hemispherical to conical, the length of the jet increased as well. Fiber diameter also increased with solution viscosity and was approximately proportional to jet length. The jet length was measured from the tip of the spinning drop to the onset of waves in the fiber. Those phenomena have recently been subjected to theoretical treatment [1-8] and it was shown that the fiber diameter depends allometrically on solution viscosity in the form:

$$d \propto \eta^\alpha \quad (1)$$

where d is the diameter of the electrospun fiber, η is viscosity, and α the scaling exponent. The exponent value might differ between different polymers, for acrylic solution, Baumgarten [9] found that fiber diameter increased with solution viscosity in the form

$$d \propto \eta^{0.5} \quad (2)$$

Many experimental observation and theoretical analysis show that viscosity has a power relation with concentration:

$$\eta \propto C^\beta \quad (3)$$

where C is the solution concentration, β is the scaling exponent.

A simple analysis on Kenawy *et al.*'s experimental data on Brookfield viscosity data for PEVA and PLA in chloroform shows that the relation between viscosity and concentration can be expressed in the form [10]:

$$\eta \propto C^4 \quad (4)$$

Combining the scaling relationships (1) and (3) we obtain a new allometric law between the diameter of the electrospun fibers and the solution concentration:

$$d \propto C^\delta \quad (5)$$

where δ is the scaling exponent, which differs greatly between different polymers and the same polymer with different molecules or the same molecules with different properties.

Experimental Verification

Experimental set-up used for electrospinning is shown in Figure 1. A high voltage power supply is used for electrospinning, the voltages range from 0 to 50 kV, the voltage used in the experiment is about 20 kV. Polyacrylonitrile (PAN) solution was poured in a syringe attached with a capillary tip of 7 mm diameter. The original flow rate was 2.8 ml/h, and the distance between the capillary tip and collector is constant, 8 cm.

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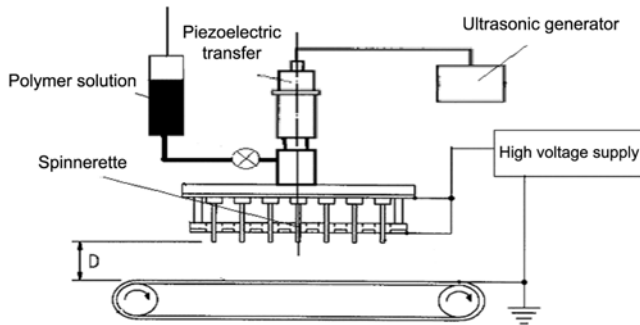


Figure 1. Schematic of polymer electrospinning (no vibration is applied).

Material

Polyacrylonitrile(PAN) with a molecular weight of 70,000 was supplied with Sinopec Shanghai Petrochemical Company Limited, and N,N-dimethylformamide (DMF) was purchased from Shanghai Chemical Co..

Solution Preparation

PAN from 9 wt% to 20 wt% was, respectively, added to DMF, and the obtained solution was stirred magnetically for one hour under the temperature of 80 °C.

Results and Discussion

Our experimental results on PAN in DMF are showed in Figure 2 and Figure 3. SEM microphotograph [17] of electrospun PAN fibers is illustrated in Figure 4.

We found that fiber diameter linearly depends on solution concentration (see Figure 2):

$$d \propto C \tag{6}$$

From Figure 3 we find that the solution viscosity is allometric with its concentration which agrees well our

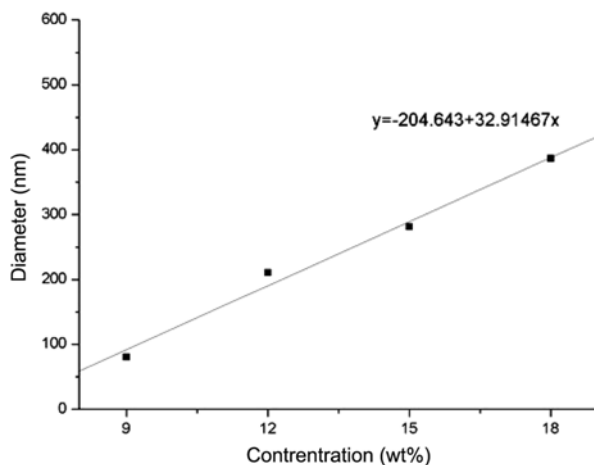


Figure 2. Relationship between diameter of electrospun polyacrylonitrile (PAN) nanofiber and its concentration.

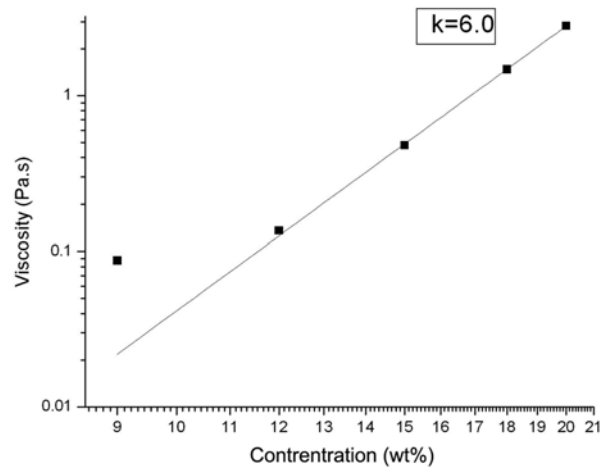


Figure 3. Relationship between viscosity and concentration $\eta \propto C^6$.

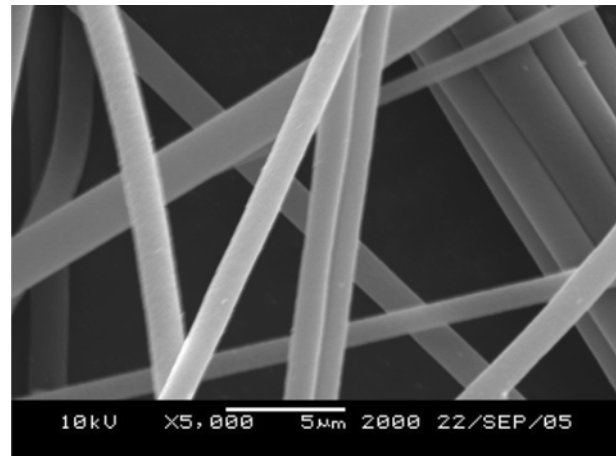


Figure 4. SEM microphotographs of electrospun PAN fibers.

theroretical prediction. This is due to the entanglement of macromolecules in resulted solution, when concentration increases, more molecules are entangled, leading to an allometrical law from Figure 3:

$$\eta \propto C^6 \tag{7}$$

Demir *et al.* [11] showed experimentally the dependence of the average fiber diameter on solution concentration in a power law relationship for electrospun polyurethane fibers: $d \propto C^3$. So the scaling exponent in (5) differs greatly between different polymers and the same polymer with different molecules or the same molecules with different properties.

Conclusion

In this paper, PAN is used to study the effect of concentration on electrospun nanofibers. Our analysis shows that the diameters of electrospun nanofibers are greatly affected by solution viscosity, and solution viscosity has an

allometric relationship with its concentration.

The experimental data verifies excellently our theoretical prediction. The relation between diameter of electrospun PAN nanofiber and solution concentration is in the form: $d \propto C$, and relationship between solution viscosity and its concentration is in the fom: $\eta \propto C^6$.

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