Electrospinning of High-Molecule PEO Solution

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ABSTRACT: Electrospinning is a simple but powerful method for making nanofibers that can then be collected to create porous mats. We expand the range of this technique by making nanofibers from macromolecules with a molecular weight of 3,000,000, namely poly(ethylene oxide) (PEO). Gelation of PEO blocks its spinning by traditional electrospinning. PEO was mixed with pure alcohol, and in specific concentration 10 wt % and under vibration condition, the mixed solution behaves like polymers for electrospinning, the average diameter of the obtained nanofibers is about 100 nm. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 103: 3840–3843, 2007

Key words: electrospinning; macromolecule; nanofiber; vibration technology

INTRODUCTION

Electrospinning is a simple but powerful method for making very thin polymer fibers.[1–4] McKee et al. expanded the range of this technique by making fibers from small molecules, namely phospholipids.[5] In this article, we expand its application to macromolecules, poly(ethylene oxide) gel (PEO gel), which cannot be electrospun by traditional electrospinning. To overcome the difficulty, a facile strategy for preparing electrospun nanofibers by vibration technology was suggested in Refs. 4 and 6. Viscosity can be reduced greatly under a suitable frequency of vibration,[7] as a result moderate voltage is needed to produce fine nanofibers that is commonly observed during conventional electrospinning procedure at elevated voltage.[4,6] The novel strategy produces finer nanofibers than those obtained without vibration,[4] and this article shows that the technology can produce nanofibers which cannot be done by traditional electrospinning.

Effect of viscosity on diameter of electrospun fiber

Experiment data[8] and theoretical analysis[9–13] show that viscosity affects much on the diameter of electrospun fibers, and it was shown that the fiber diameter depends allometrically on solution viscosity in the form[12]:

$$d \propto \eta^{\alpha} \tag{1}$$

where d is the diameter of the electrospun fiber, η is viscosity, and α is the scaling exponent. The expo-

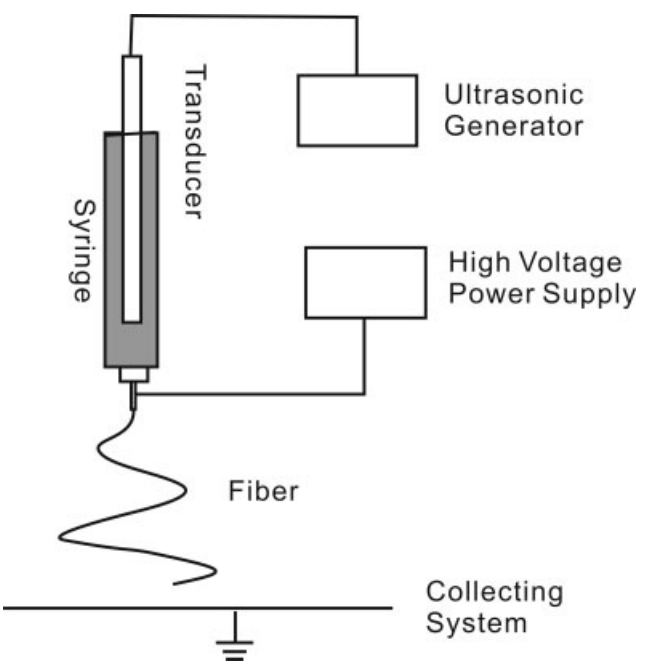

Figure 1 Schematic of vibration technology in polymer electrospinning (this apparatus was patented: Wan, Y.Q., Zhang, J., He, J.H., Yu, J.Y. CHN Pat. 200420020596.3, to use this principle to prepare electrospun fibers, transfer agreement must be made).

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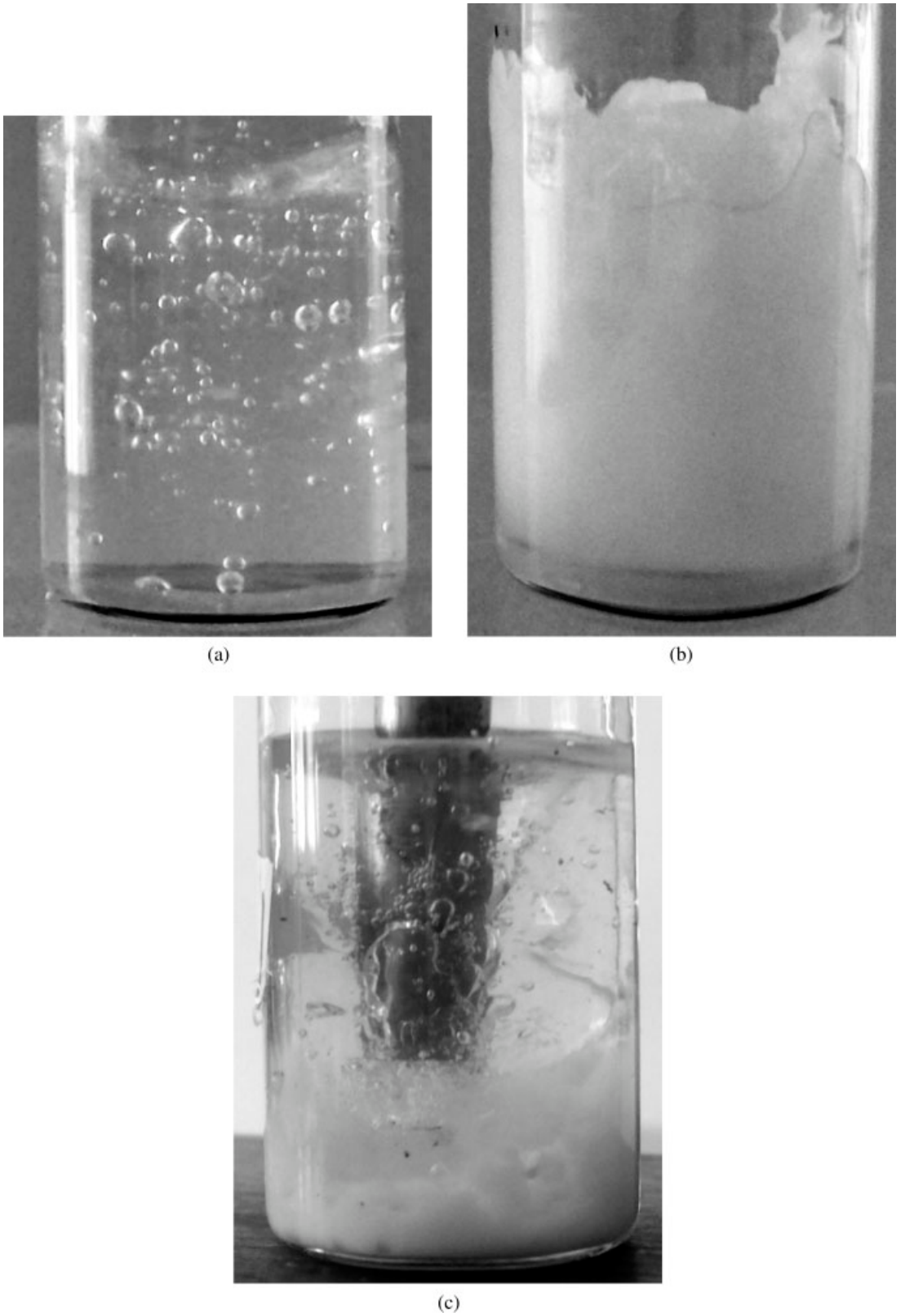

Figure 2 10% PEO solution. (a)10% PEO solution (gel), (b) coagulated solution A, (c) solution B under ultrasonic vibration.

nent value might differ between different polymers. For acrylic solution, Baumgarten[8] found that the scaling exponent is about 1/2.

The viscosity of the polymer solution can be dramatically reduced by vibration technology, leading to finer nanofibers. The viscosity scales allometrically

with oscillation frequency[6]:

$$\eta \propto \omega^{-\beta} \quad (2)$$

where β is a scaling exponent that varies with the polymer's characteristics. For PMMA solution at 239°C, Ibar's experiment showed $\eta \infty \omega^{-2/5}$. Our experiment revealed $\eta \infty \omega^{-7/10}$ for PAN/DMF solution.

From relations (1) and (2), we have the following power law[6]:

$$d \propto \omega^{-\delta} \quad (3)$$

where δ is the scaling exponent that varies among different polymers.

When an additional vibrating force is applied to conducting polymer solutions or melts, dramatic reduction in viscosity occurs. So the oscillation leads to finer electrospun fibers than those electrospun without oscillation.

EXPERIMENTAL

Material

Poly(ethylene oxide) (PEO) with a molecular weight of 3,000,000 was supplied with Shanghai Lian Sheng Chemical and pure alcohol was purchased from Shanghai Chemical.

Instrumentation

Ultrasonic generator SFSA-1(Shenbo Ultrasonic Device) was used to apply ultrasonic vibration on solution at 400 kHz. Electrospinning experimental was carried on with a setup shown in Figure 1.

PEO was added to pure alcohol at concentrations 10 wt % and stirred magnetically for 1 h under 30°C. To study its electrospinability, we divided the obtained PEO solution into two parts and poured into two bottles, labeled as solution A and solution B, all in coagulated state with very poor flow properties [Fig. 2(a)]. Because of the poor flowability of the coagulated solution, solution A could not be electrospun. When a vibration was added to solution B [Fig. 2(c)], flowability of solution B is increased. A high voltage was then applied to the vibrating solution B and a charged stream was finally ejected.

Electrospun fiber diameter and morphology were analyzed using a JSM-5600LV scanning electron microscopy (SEM). Fifty measurements on random fibers for each electrospinning condition were preformed and average fiber diameters are reported.

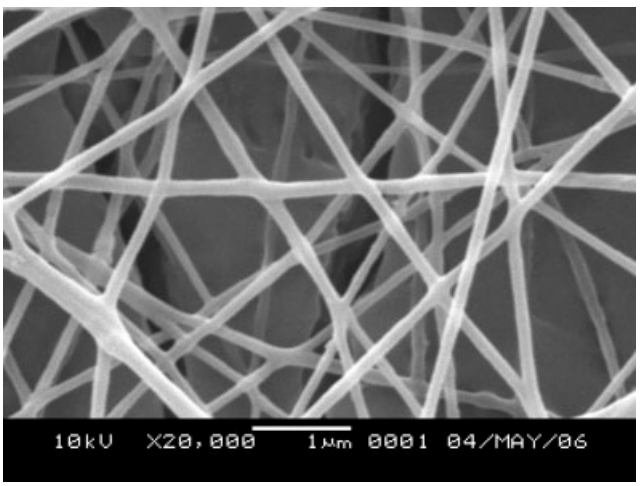

Figure 3 10% PEO electrospun nanofibers, the average diameter of the nanofibers is about 100 nm.

Electrospinning process

Solution B was placed in a 20 mL syringe. The positive lead of a high voltage power supply (F180-L; Shanghai Fudan Middle School Affiliated Factory) was connected to the 7-gauge syringe needle via an alligator clip. A grounded metal target was placed 8 cm from the needle tip. The polymer solution flowed by its gravity without an original flow rate given, and the voltage was maintained at 15 kV. At same conditions without vibration, solution A cannot be electrospun because of its poor flowability.

RESULTS AND CONCLUSIONS

Pure alcohol was added to PEO, and stirred magnetically under 30°C, the solution became a gel, and the obtained solution (gel) was too viscous to flow [Fig. 2(a)].

As solution(gel) A became cooler, PEO separated from alcohol and coagulated [Fig. 2(b)]. When an ultrasonic vibration is added to the separated solution B, the coagulated PEO is dissolved again [Fig. 2(c)].

Solution (gel) B under ultrasonic vibration was poured into the syringe where a high voltage of 15 kV was added, the charged jet was ejected from the syringe needle, and electrospun PEO fibers were finally obtained (Fig. 3).

The vibration technology is successfully applied to electrospinning. Compared with the traditional electrospinning, the vibration-electrospinning has at least two main merits: (1) moderate voltage needed; (2) finer fiber obtained. And we also show in this article that vibration-electrospinning produces nanofibers which can not be done by traditional electrospinning.

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