

POLYMER LIQUID MEMBRANE FOR NANOFIBER FABRICATION

by

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This paper finds that a polymer liquid membrane can be effectively used for nanomaterials fabrication using a blowing air and an electronic force. Polyvinyl alcohol solution is used to produce membrane on a rotating ring, which passes through periodically the solution, the membrane is deformed into a bubble by the blowing air under the presence of an electrostatic field. The experimental data show that the receptor distance affects the fiber size greatly.

Key words: bubble electrospinning, thin film, membrane, law of Laplace

Introduction

Blowing bubbles always give kids much fun. A liquid membrane is formed when a ring takes away from a soap solution, and a blowing air can produce many colour bubbles. It is really even more fascinating that its principle can be used for nanofiber fabrication, and the fiber size can be effectively controlled by adjusting the temperature of the blowing air.

In our previous works, polymer bubbles are used for nanomaterial fabrication including nanofiber, nanoparticles, and nanofilms [1-6] by the bubble electrospinning, where spun bubbles are produced on the solution surface by a gas tank. Hereby we design a new experimental set-up as illustrated in fig. 1. A polymer liquid membrane is produced by a metal ring rotating through the polymer solution, and the membrane is pulled forward by a blowing air to form a bubble. When the bubble is ruptured, multiple jets are ejected to produce micro/nano fibers. A high speed blowing air can also be used as an acting force to accelerate the multiple jets. As a result, polymer jets are attenuated rapidly by the blowing air, the resultant fibers are collected upon a screen as a nonwoven mat. The spinning process can be remarkably enhanced under the presence of a high electrostatic field. Furthermore the fibers can be twisted by a vortex blowing air to produce mi-

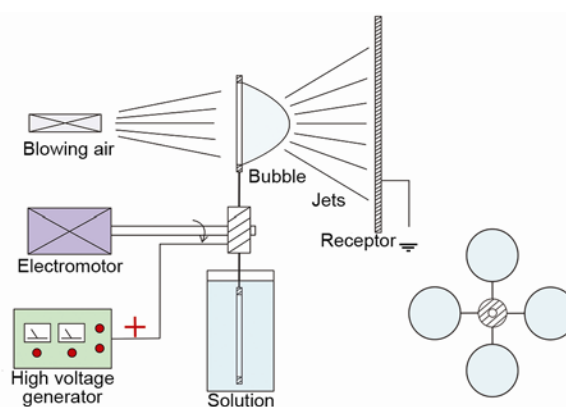


Figure 1. Experimental set-up

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cro/nano yarns. We call this new invention as the membrane spinning, which uses thin polymer film or membrane for fiber fabrication.

Membrane change

The thin polymer liquid membrane will be deformed into a hemisphere bubble by blowing air acting on the membrane. Assume that the original thickness of the membrane is h_0 , and the average thickness of the bubble is h . According to the mass conservation, we have:

$$\pi r^2 h_0 = 2\pi r^2 h \quad (1)$$

where r is the radius of the ring. That means the thickness of the formed bubble reduces to half of the thickness of the original membrane, and it can be further attenuated until the bubble is broken. The thickness attenuation is very helpful for micro/nanofiber fabrication.

During the membrane change by a blowing air, its surface tension also changes. According to the Young-Laplace equation [7, 8], the surface tension of a hemisphere bubble can be expressed as:

$$\sigma = \frac{1}{4} r \Delta p \quad (2)$$

where σ is the surface tension, and Δp – the pressure difference. According to eq. (2) it is extremely easy to control the spinning process by adjusting the ring radius (r) and the pressure of blowing air.

Using the state equation, eq. (2) can be written in the form [7, 8]:

$$\sigma = \frac{1}{4} r R (T_i \rho_i - T_o \rho_o) \quad (3)$$

where R is the gas constant, T_i and T_o are the absolute temperatures inside and outside of the bubble, respectively, and ρ_i and ρ_o are densities of the air inside and outside of the bubble, respectively. The surface tension of the bubble can also be effectively adjusting the temperature of blowing air.

Experiment

In this study polyvinyl alcohol (PVA)/phase-change material (PCM) solution is used in our experiment to produce liquid membrane. The receptor distance varies from 4 to 20 cm, and the SEM graphs are shown in fig. 2. The average diameters of fibers are 441 nm, 372 nm, 344 nm, 347 nm, 454 nm, and 440 nm for the distances of 4 cm, 8 cm, 10 cm, 12 cm, 15 cm, and 20 cm, respectively. The minimal diameters are 153 nm, 183 nm, 203 nm, 139 nm, 210 nm, and 440 nm, respectively (fig. 3).

Discussion and conclusions

When a bubble is broken, multiple charged jets are formed. The initial jet diameter depends upon the thickness of the broken film [3]:

$$d_0 = 4h \quad (4)$$

where d_0 is the initial diameter of the charged jet, which is formed from a strip of thin film due to surface tension, and h – the thickness of the film.

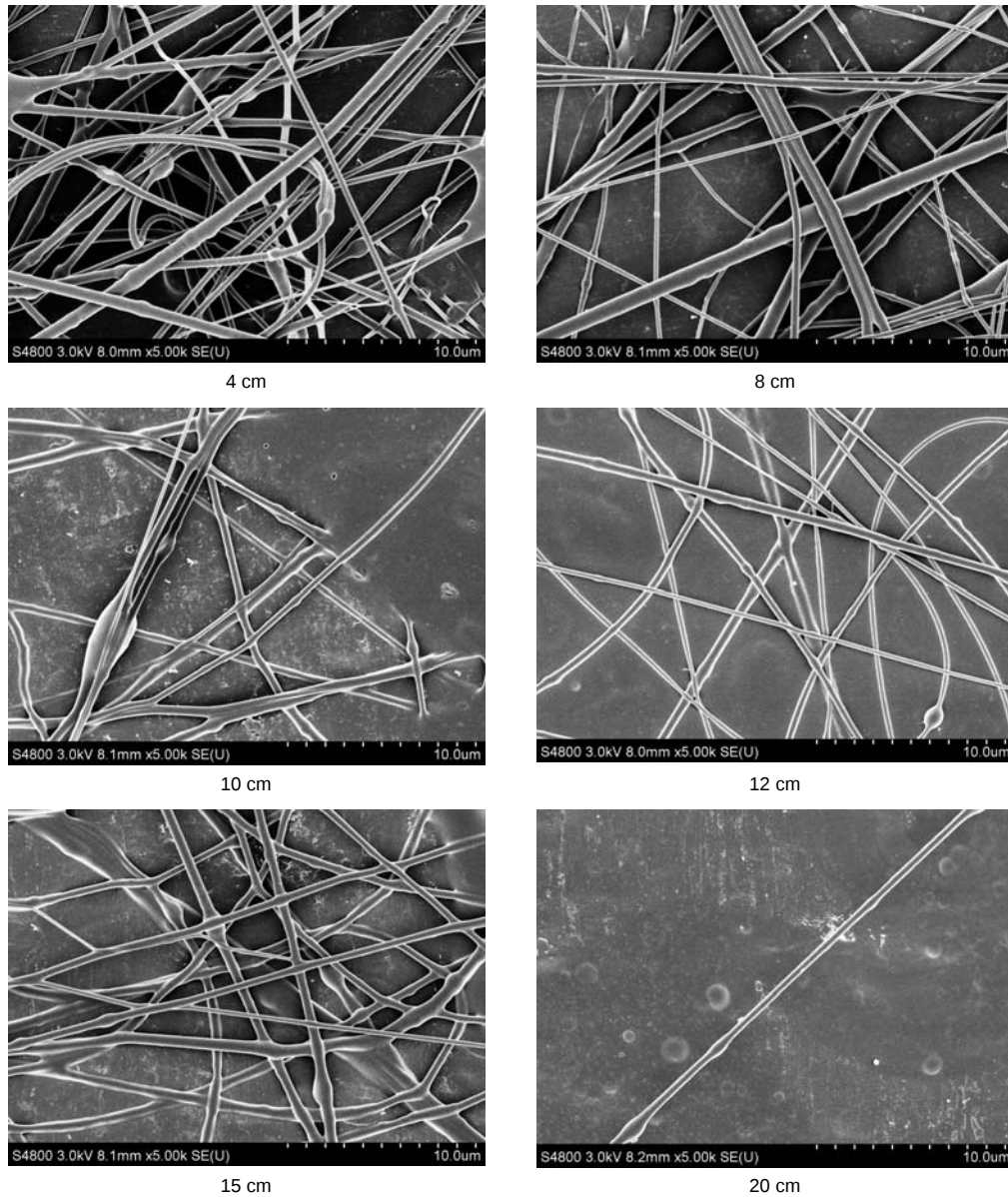


Figure 2. SEM figures of PVA/PCM fibers under different receptor distances

The jet will be accelerated by the electronic force. The force balance of the charged jet gives [9]:

$$u \frac{\partial u}{\partial z} = \frac{1}{\rho} \frac{\partial \tau}{\partial z} + \frac{2\sigma E}{\rho r} + \frac{2k(V-u)^2}{\rho r} \quad (5)$$

where u is the velocity, ρ – the liquid density, σ – the surface charge, r – the radius of the jet, E – the applied electric field, τ – the viscous force, and V – the speed of blowing air.

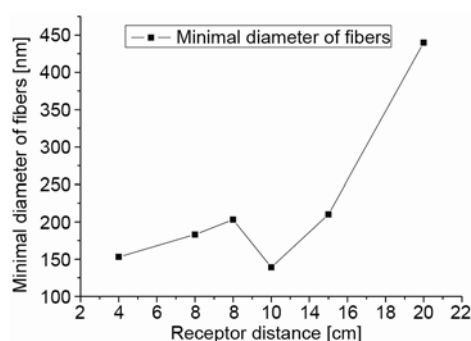


Figure 3. The minimal diameter of the PVA/PCM fibers vs. receptor distance

For a shorter receptor distance, a higher electric field (E) is predicted. According to eq. (5), a higher velocity of the jet is obtained. According to the conservation of mass:

$$\pi r^2 \rho u = Q \quad (6)$$

where Q is the flow rate, a higher velocity of the jet results in smaller fibers, this agrees well with experimental observation as given in fig. 3.

This paper suggests, for the first time, a novel membrane spinning technology to produce micro/nano fibers using polymer liquid membrane. It can be considered as a modified bubble electrospinning.

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