Influential Factors on Formation of Nanofibers: Assessments of Electrostatic Spinning Parameters

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ABSTRACT

Nanofibers have a high specific surface area and a high porosity, and thus have been applied to many fields. Electrostatic spinning is one efficient and convenient method for the preparation of nanofibers. Two influential factors of the formation of nanofibers include processing parameters, such as voltages and velocity, and environmental factors, such as temperatures and humidity. This study uses a home-made electrospinning machine for the production. The morphology of the resulted nanofibers is examined in terms of the processing parameters, in order to provide more feasible applications. The test results indicate that the viscosity of PVA electrospinning solution becomes dense as a result of the increasing temperatures. An increasing voltage changes the morphology of nanofibers from being smooth to rugged. Moreover, the diameter of nanofibers becomes smaller when the electrospinning distance is increased.

INTRODUCTION


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There have been an increasing number of studies on electrostatic spinning. These studies have different emphasis in terms of machine design, application, polymer types, and the influences of fiber types. Nano-materials have advantages of a high specific surface area and a high porosity, which has drawn the attention of researchers. Therefore, they are suitable for different fields and can be made with different forms according to the demands. One efficient and convenient method to produce nanofibers is electrostatic spinning. The influential parameters for electrostatic spinning include electric field, velocity, and the distance between the jet and the collector plate. The morphology of nanofibers is dependent on many factors, including the viscosity and conductivity of the polymer, environmental temperature, humidity, and air flux [1-5].

Polyvinyl alcohol is a synthesis polymer that has biocompatibility, a virulence, biodegradability, chemical property, and stability forming property, and thus has been commonly used electrostatic spinning matrices for drug propagation, filtration, packaging, and for tissue engineering scaffolds[6-11]. In this study, a specified concentration of PVA solution is used, while different parameters of electrostatic spinning in terms of spinning distances, voltages, and running frequencies of spinning tip.

EXPERIMENTAL

Materials

Polyvinyl alcohol (PVA, Sigma-Aldrich Co., Ltd. US) has molecular weight (Mw) of 89000-98000, and is 99+% hydrolyzed.

Procedure

PVA powder and deionized water are blended for 24 hours and kept in the room temperature, in order to formulate a 10wt% PVA solution. The PVA solution is poured into the spinning slot for electrostatic spinning. The settings include voltages (80, 90, and 100 kV), the spinning distances between the jet and the collecting plate (10, 20 cm), and the running frequencies of spinning tip (5, 10 rpm). Different combinations of different parameters are used to produce PVA electrospun fiber membranes.

MEASUREMENTS

Viscosity

A rotational viscometer (Fungi lab, Spain) is used to measure the viscosity of PVA solutions under different temperatures.

Conductivity

A pH conductivity meter (EC500, Extech Instruments, US) is used to measure the conductivity of PVA solutions. The conductivity of PVA solution is measured five times in order to have the mean.
Scanning Electron Microscopy (SEM)

PVA electrospun fiber membranes are dried in an oven for twenty four hours in order to remove the moisture. An ion sputter (E-1010, HITACHI, Japan) is then used to coat gold over the samples for thirty seconds. A scanning electron microscope (S3000, HITACHI, Japan) is then used to measure and analyze the samples.

Image Analyses

An image analyzer (Image-Pro 6.2 illustration) is used to measure the diameter of PVA electrospun fiber membranes.

RESULTS AND DISCUSSION

Effects of Temperature on Viscosity and Electrical Conductivity of PVA Solution

Table 1 shows the viscosity and conductivity of the PVA solution in relation to different temperatures. An increase in temperature causes the viscosity to increase, but it barely has any influences on the conductivity. In comparison to an environment with a low temperature, a high temperature results in high energy, which provides the molecular chains of PVA with a high ambient kinetic energy for a high mobility. PVA solution under a high temperature thus has a low viscosity. In contrast, a low ambient temperature prevents the molecular chains of PVA from a high mobility, and therefore, the viscosity of PVA solution is increased.

| Temperature (℃) | Viscosity (cP) | Electrical Conductivity (μS/cm) |
|----------------|---------------|-------------------------------|
| 26             | 657.6         | 0.62×10³                      |
| 40             | 591.1         | 0.62×10³                      |
| 60             | 536.8         | 0.63×10³                      |
| 80             | 511.7         | 0.62×10³                      |
| 100            | 486.9         | 0.63×10³                      |

Effects of Voltages and Electrostatic Spinning Distances on Morphology of PVA Electrospun Fiber Membranes

The PVA electrospun fiber membranes are made with different combinations of voltages, spinning distances, and running frequencies of spinning tip. A running frequency of 10 rpm is excessively high, and thus the PVA solution is spattered without being able to form Taylor cones on the spinning tip. Therefore, the running frequency of spinning tip is set to be 5 rpm.

Fig. 1 indicates the SEM images of morphology of PVA electrospun fiber membranes with a specified spinning distance between the jet and the collector plate (10cm). Different formations of PVA nanofibers can be observed with their corresponding spinning voltages in Fig.1 (a-c). An increase in spinning voltage changes the surface of PVA nanofibers that is from being smooth to rugged with a bead-shaped formation. Moreover, the diameter of PVA nanofibers is also increased from 539.7±152.1 nm to 873.3±112.9 nm. Because an increasing voltage enhances
the electric field force, which facilitates the process of drawing PVA solution to the collector plate, the solvent in the PVA solution has been completely deposited without volatilization.

Fig. 2 indicates the morphology of PVA electrospun fiber membranes that is formed with a specified electrospinning distance of 20 cm. The formations of nanofibers with corresponding voltages shown in Fig. 2 (a-c) also resemble those in Fig. 1 (a-c). In response to the increasing electrospinning voltages, the surface of the nanofibers also changes from being smooth to rugged, while their diameter being increased from 412.6±105.2 nm to 681.1±22.7 nm. The phenomenon is attributed to the same causes that are previously discussed. In addition, an electrospinning distance of 20 cm results in a smaller diameter of nanofiber than 10 cm. A farther distance allows sufficient time for a high fineness of the nanofiber during the electrostatic spinning process.

Figure 1. SEM images (5.0K×) of morphology of PVA electrospun fiber membranes in relation to voltages of a) 80 kV, b) 90 kV, and c) 100 kV. The electrospinning distance is 10 cm.
CONCLUSION

This study successfully prepares PVA electrospun fiber membranes. The viscosity of the PVA solution is decreased when the temperature is low. The morphology of PVA nanofibers is associated with the electrospinning voltage, and the smooth surface of nanofibers becomes rugged when the voltage is increased. Moreover, the PVA nanofibers have a smaller diameter with a farther collecting distance between the spinning tip and the collector plate.

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