Effect of Needle Diameters on the Diameter of Electrospun PVDF Nanofibers

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Abstract

Electrospinning is a technique that generates nanofibers via an electrically charged jet of polymer melt or polymer solution. The significance of this method lies in the tiniest diameter of fibers that can be produced because nanofibers provide more performance advantages in various fields and area as their diameters decrease. Different parameters of electrospinning (solution parameters, process parameters, and ambient parameters) play a vital role in determining the diameter of electrospun nanofibers. In this work, the relationship between the needle diameter and diameter of electrospun poly (vinylidene fluoride) (PVDF) nanofibers is investigated. The results show that there is a positive relationship between the needle diameter and the diameter of electrospun PVDF nanofibers.

Keywords: Electrospinning; PVDF; Nanofibers;Needle diameter; Fiber diameter

1. Introduction

Electrospinning is a method for producing fibers by pumping and lengthening polymer jets by electrostatic forces. The diameter of electrospun fibers can be ranged from nanometers scale to micrometers scale [1].

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Since electrospun nanofibers have outstanding properties (e.g. small diameters [2], ease of functionality [3], low density [4], high porosity [3], good pore structures [1], good mechanical properties [5], a variety of morphology and structure [6], and flexibility [1]), they can be used in many applications such as self-cleaning surfaces [7], filtration [8], [9], catalyst [10, 11], energy harvesting [12, 13], biomedical applications [14, 15], sensors [16, 17], and so on.

Studies have proved that the diameter of electrospun fibers is affected by the working parameters of electrospinning: (I) solution parameters (viscosity, polymer concentration, molecular weight, conductivity, and surface tension) [18, 19], (II) processing parameters (applied voltage, distance between the tip of the needle and the collector (DTC), flow rate, collectors type, and needle diameter) [20, 21], and (III) ambient parameters (temperature and relative humidity) [22, 23].

Polyvinylidene fluoride (PVDF) is a semi-crystalline polymer which can be found in different polymorphs (α, β, γ, δ, and ε) [24, 25]. It has been widely studied because of its exceptional piezoelectric and ferroelectric properties, low cost, good mechanical properties, low density, and high flexibility [26]. Therefore, it can be used in different applications such as energy harvesting [27], oil cleanup [28, 29], filtration [30, 31], and so on.

Previously, Kizildag et al. demonstrated the effect of needle diameter on the diameter of electrospun silk fibroin nanofibers. They found that there is a positive relationship between the needle diameter and diameter of silk fibers [32].

Abunahel et al. studied the effect of needle diameter on the diameter of electrospun n-Bi2O3/Epoxy-PVA nanofibers. They concluded that there is a positive relationship between the needle diameter and diameter of n-Bi2O3/Epoxy-PVA nanofibers [33].

In this study, we demonstrate the effect of the needle diameter on the diameter of PVDF fibers fabricated via electrospinning. Herein, PVDF was selected as the model as a result of its outstanding properties.

To the best of our knowledge, up to now, no studies have been systematically investigated the effect of needle diameter on the diameter of electrospun PVDF fibers. We concluded that the needle diameter plays a significant role in determining the diameter of PVDF fibers. This work can be used as a good reference for controlling the diameter of electrospun PVDF fibers by maneuvering the needle diameter.

2. Experimental

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2.1. Materials

PVDF pellets at a molecular weight of 275000 were purchased from Sigma-Aldrich, USA. Acetone (ACE) and N, N-dimethylformamide (DMF) were purchased from Shanghai Chemical Reagents Co., Ltd, China.

2.2. Methods

Electrospinning: 15% (w/v) PVDF solution with ACE/DMF at the solvent ratio of 2:1 was prepared and loaded in the plastic syringe. The polymer concentrations and the solvents used were selected to obtain nanofibers smoothly [18]. Herein, the solvent ratio was the volume ratio, and the solution concentration was the weight/volume (w/v) (g/ml). A syringe needle was used as the spinneret, which was fixed on a syringe pump (KDS 100, KD Scientific Inc., USA) connected to a high-voltage supplier (Tianjin Dongwen Co., Ltd., China). A grounded collector was used to obtain nonwoven nanofibers. All the experiments were carried out with an applied voltage of 18 kV; flow rate of 1.5 ml/h, the distance between the tip of the needle and the collector (DTC) of 18 cm, needle diameter of 0.1-0.83 mm (Figure 1). All of the samples were prepared at the relative humidity of 65% and temperature of 20 °C.

2.3. Characterization

The surface morphology of the electrospun PVDF fibers was checked under field emission scanning electron microscopy (FE-SEM, S-4800 Hitachi, Japan). Fiber diameter was determined using image processing software (ImageJ 1.45s).

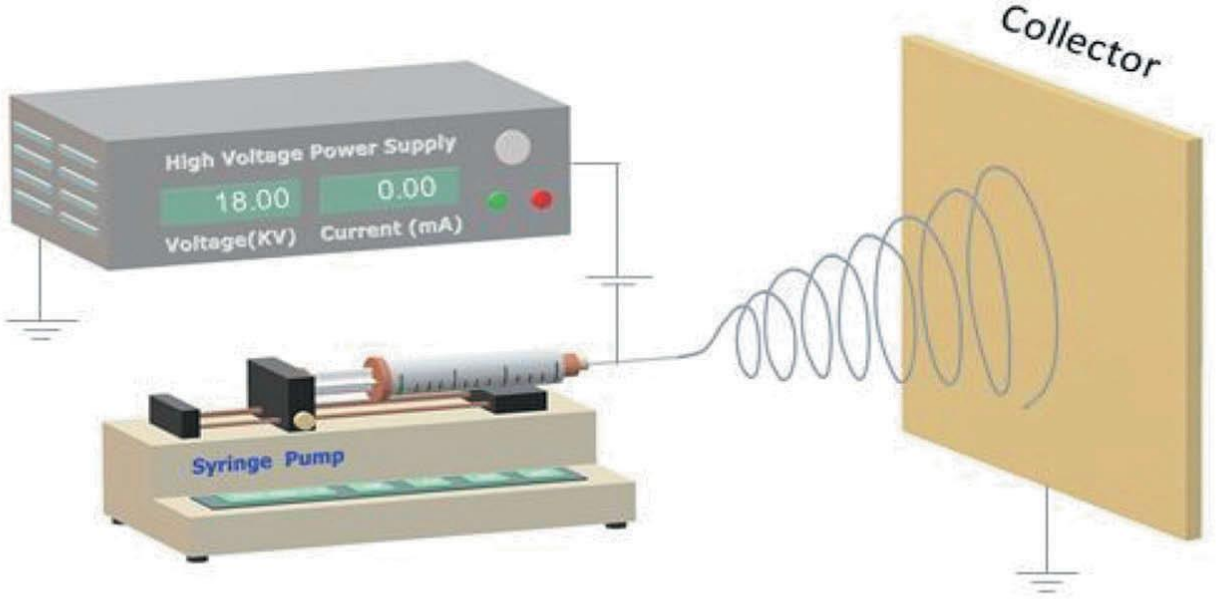

Figure 1. Schematic diagram of the electrospinning apparatus used in this work.

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3. Results and Discussion

SEM images of PVDF nanofibers generated from three different types of needle diameters are shown in Figure. 1 (A-C). Figure. 1 (A) shows the nanofibers generated from the needle with a diameter of 0.21 mm, while figure (2 A) presents nanofibers generated from the needle with a diameter of 0.41 mm, whereas figure (2 A) shows nanofibers generated from the needle with a diameter of 0.83 mm. As shown in Figure. 1 (A-C) there is a significant difference in the morphology of electrospun PVDF nanofibers between the different types of needle diameters.

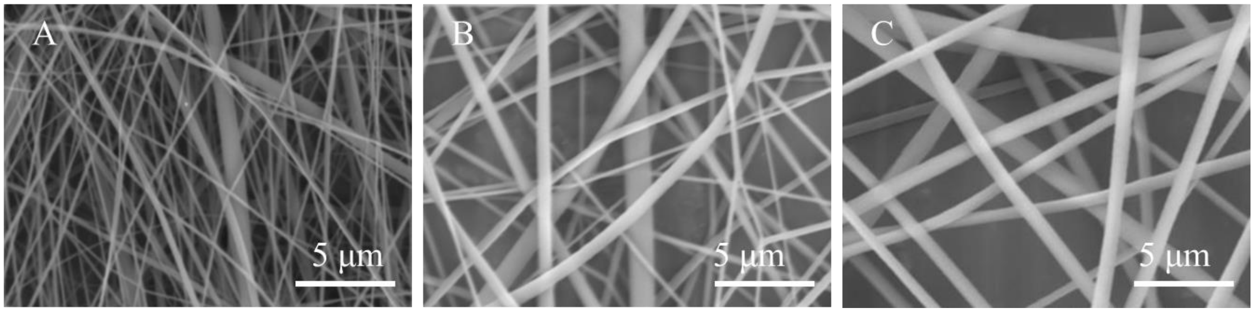

Figure 2. SEM images of electrospun PVDF nanofibers fabricated at needle diameter of A) 0.21 mm, B) 0.41 mm, C) 0.83 mm.

The results showed that beaded free nanofibers with different diameters were obtained from all samples fabricated at different diameters of needles.

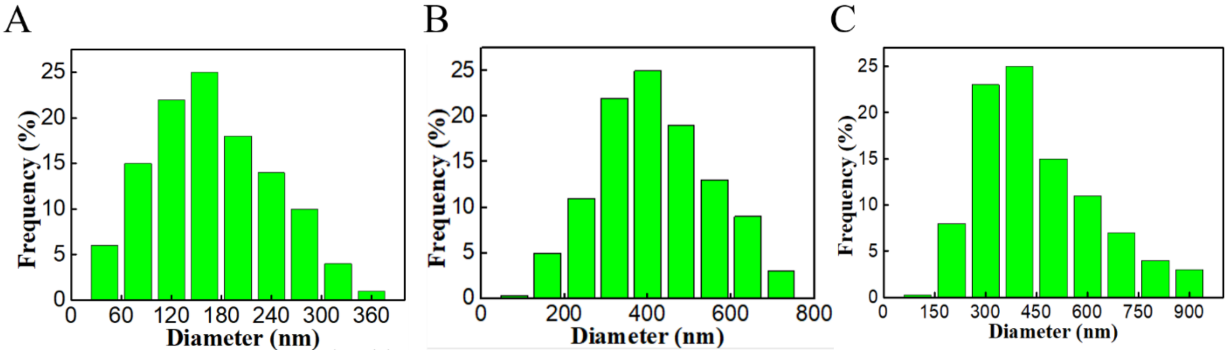

Figure 2. The distribution of electrospun PVDF nanofibers diameters fabricated at needle diameter of A) 0.21 mm, B) 0.41 mm, C) 0.83 mm.

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The diameter of nanofibers generated at a needle diameter of 0.21 mm is 155 ± 29 nm. While the diameter of nanofibers produced at needle diameter of 0.41 mm is 377 ± 38 nm, whereas, the diameter of nanofibers generated at needle diameter of 0.86 mm is 455 ± 77 nm as shown in Figure 2 and Table 1. So, when the diameter of the needle decreased, the diameter of fabricated nanofibers decreased. Furthermore, the fiber porosity increased by decreasing the diameter of the needle owing to decreasing the diameter of fibers [30].

These results could be explained as follow, at a small needle diameter, a tiny drop of polymer solution forms at the top of the needle with high surface tension compared with a large needle diameter. Polymer with high surface tension requires increasing the potential difference to overcome the high surface tension. When the high potential difference is used, the electrostatic force which is responsible for stretching the polymer jet and divides it into many smaller jets is also increased resulting in forming nanofibers with small diameters [32, 33].

Table 1. Summarizing the polymer solution, processing parameters, and fibers diameter of samples electrospun at different diameters of the needle

Polymer solution	Applied voltage (kV)	DTC (cm)	Flow rate (ml/h)	Needle diameter (mm)	Fibers diameter (nm)
15% (w/v) ACE/DMF	18	18	1.5	0.21	155 ± 29
14% (w/v) ACE/DMF	18	18	1.5	0.41	377 ± 38
14% (w/v) ACE/DMF	18	18	1.5	0.86	455 ± 77

4. Conclusion

PVDF nanofibers were obtained using different needles with different diameters (0.21 nm, 0.41nm, and 0.86 nm). The diameter of fibers was detected from the SEM images of studied samples. The results proved that there is a correlation between the diameter of the needle used and the average diameter of nanofibers obtained. The average diameter of fibers increased from 155 ± 29 nm at needle diameter of 0.21 nm, into 377 ± 38 nm at needle diameter of 0.41 mm, into 455 ± 77 nm at needle diameter of 0.86

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mm. We believe this work can be served as a good reference for generating electrospun nanofibers with adjustable diameters by maneuvering the needle diameter.

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