The Influence of PVOH Concentration on the Structural Morphology and Dimension of Electrospun Nanofibers

Erni Misran[1,2], Basuki Wirdjosentono[1,3], Nasrudin M. Noor[4], Saharman Gea[1,3], Mahyuni Harahap[1,3] and Suhut Alexander Situmorang[1,3]

[1]*Cellulosic and Functional Materials Research Centre, Universitas Sumatera Utara, Medan, Indonesia*
[2]*Department of Chemical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan, Indonesia*
[3]*Department of Chemistry, Faculty of Mathematics and Natural Science, Universitas Sumatera Utara, Medan, Indonesia*
[4]*Deparment of Physics, Faculty of Mathematics and Natural Science, Universitas Sumatera Utara, Medan, Indonesia*

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Abstract: The parameters applied in electrospinning process were the main factors to produce ultrafine nanofibers for different target applications. In this study, the effect of polyvinyl alcohol (PVOH) concentration, from 12% to 16% (wt) in distilled water, on the morphology and dimension of nanofibers was investigated. Scanning electron microscopy (SEM) was used to analyze the morphology of PVOH electrospun nanofibers and Image J analysis was used to calculate the dimension of fibers. From the results, 12% and 13% of PVOH concentration produced bead shaped fibers. Meanwhile ultrafine nanofibers were produced from PVOH concentration of 14%, 15%, and 16% (wt). The diameter of ultrafine fibers increased with the increase in PVOH concentration.

1 INTRODUCTION

Electrospinning technique, with its simplicity setup of syringe pump, needle, and collector only (Figure 1), has attracted significant interest among researchers to fabricate fibers with diameters ranging from microscale (10 μm) to nanoscale (<1000 nm) (Zhuo et al. 2008). Moreover, this method provide higher surface area to volume ratio compared to other methods, i.e. template synthesis, self-assembly, phase separation and drawing techniques (Abunahel et al. 2018). Electrospun nanofibers have been applied to various applications including tissue engineering, drug delivery system, wound dressing, textile industry, cancer treatment and the fabrication of new radiation shielding material (Mirjalili and Zohoori, 2016).

Basically, the process of electrospinning uses high voltage power supply, so there is a surface charge at the end of the needle tip where the polymer solution is held by its surface tension. Due to the disturbance in the polymer surface, droplets with spherical shapes called "Taylor zone" are produced in the initiation of electrospinning process. Then, a jet of polymer solution is ejected from the tip of the needle to the collector. As the jet travels through the air, the solvent evaporates and ultrafine fibers are collected on the surface of the target (Teo and Ramakrishna, 2006). The properties of spun fibers can be controlled with three important parameters; (i) the parameters of solution, which include the concentration, molecular weight, surface tension, conductivity, and volatility of polymer solution; (ii) processing parameters, such as applied voltage, liquid flow rate, and distance of the needle to the collector; and (iii) processing environment like temperature and humidity (Harahap 2018).

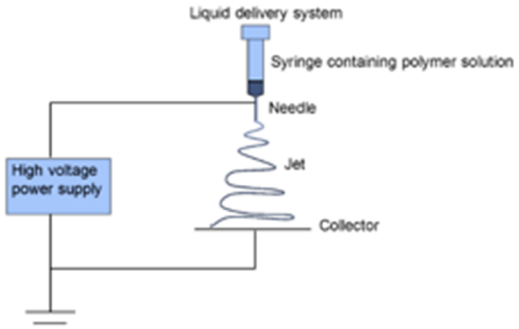

Figure 1 Electrospinning set up.

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There are more than 50 different polymers that have been reported to have undergone successful electrospinning. One of them is PVOH, a water-soluble polymer, which can also be electrospun from its aqueous solution phase (Lu et al. 2006). Many studies have reported the influence of concentration on the morphology of fibers, but there has not been any literature data available reporting the diameters. Hence, we aim to study the effect of PVOH concentration to the morphology of electrospun nanofibers, as well as their diameters.

2 EXPERIMENTAL

2.1 Materials

The material used in this study was PVOH powder, Mw = 60,000 g/mole fully hydrolyzed, purchased from Merck, Darmstadt, Germany. Before used, PVOH was dried at 80 °C for 5 h in a vacuum oven to remove the moisture content. Distilled water was used as a solvent for PVOH.

2.2 Solution Preparation

PVOH solution with various concentration of 12%, 13%, 14%, 15%, and 16% (wt) was prepared under reflux condition for 2 hours at 80 °C. After the polymer was homogeneously mixed, the reaction was put to stop and the solution was allowed to cool with continuous stirring until it reached room temperature. The solution was stored no more than three days prior to use for electrospinning.

2.3 Electrospinning Process

The electrospinning process was carried out by horizontal electrospinning (basic series electrospinning unit Brand NLI, Nanolab Instruments Sdn Bhd, Malaysia) at room temperature. The condition was set-up as follow: (i) disposable 18-G syringes; (ii) voltage was 15 kV; (iii) polymer solution feed rate was 0.2 mL/hour; (iv) needle tip-to-collector distance was 15 cm; and (v) the speed of collector was 115 rpm. Ultrafine fibers were collected on aluminum foils. The mat fibers were dried in a vacuum oven at 40 °C for 3 h to remove residual water and stored in a desiccator containing silica gel.

2.3 Characterization

2.3.1 Scanning Electron Microscopy

The morphology of the samples was analyzed by using a scanning electron microscopy (SEM) Hitachi TM3030 (JEOL, Ltd., Tokyo, Japan). The sample was coated with a thin layer of gold before analysis to reduce charging. The diameter of the fibers was calculated by using Image J software analysis.

3 RESULTS AND DISCUSSION

3.1 The Morphology

The concentration of the polymer solution is one of the parameters controlled in the electrospinning process. It has a big influence in the formation of fibers. Low concentration ($\eta<1$ Pa.s) has been reported to form sprays instead of fibers. In this condition, bead forms were also produced. Meanwhile, fine fibers would be produced with higher concentration of polymer solutions (Yang et al. 2007).

In this study, PVOH solution dissolved in distilled water was able to undergo electrospinning. The fiber formation is illustrated in Figure 2. During the process, there were no clogs at the tip of the needle. Nonetheless, the morphology of PVOH electrospun nanofibers were not the same for each concentration used. SEM images for PVOH nanofibers with concentration of 12%, 13%, 14%, 15%, and 16% (wt) are presented in Figure 3. At the concentration of 12% and 13% many beads were produced. While, concentration of 14% produced smooth fibers. The morphology of the fibers became smoother with higher concentration (15% and 16%). Polymer concentration was the main factor that affected the final morphology of fibers. If the concentration of polymer was too high, the electrospinning process could not be done due to high viscosity. However, low concentration would produce bead form fibers (Sener, Altay and Altay, 2011).

The dimension of nanofibers (Figure 3) in this study was calculated from the fiber images in SEM results by using Image J software. PVOH electrospun nanofibers had diameters of 108 nm, 100 nm, 130 nm, 129 nm, and 133 nm for the concentration of 12%, 13%, 14%, 15%, and 16% respectively (Figure 4). The higher the concentration of PVOH polymer solution, the higher the diameter of spun fibers. However, this result contradicted

other studies that reported higher concentration or viscosity of polymer solution produced smaller diameter of spun fibers (Misran et al. 2020).

Figure 2 The formation of electrospun nanofibers.

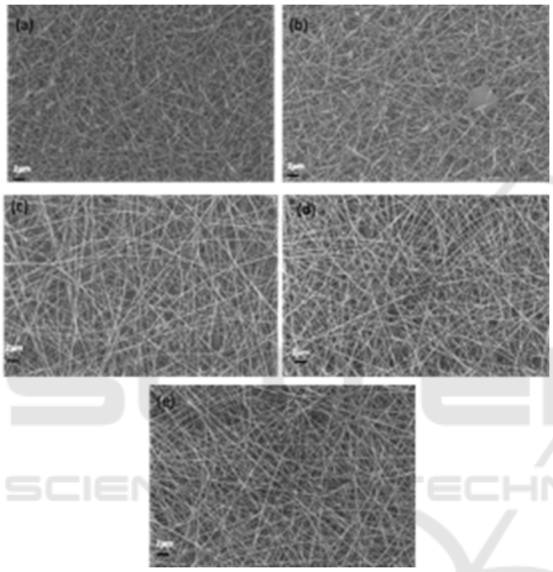

Figure 3 SEM images for electrospun nanofibers: (a) 12% PVOH, (b) 13% PVOH, (c) 14% PVOH, and 15% PVOH.

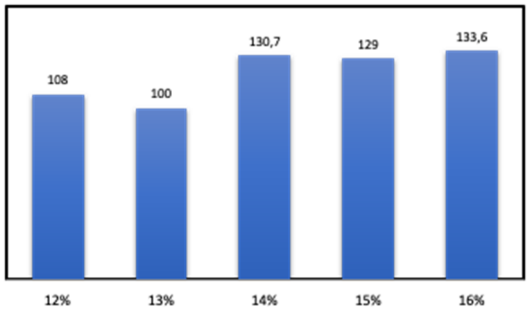

Figure 4 PVOH electrospun nanofibres dimensions with various concentration of 12%, 13%, 14%, and 15% (wt).

4 CONCLUSION

Polyvinyl alcohol (PVOH) nanofibers were prepared by electrospinning technique. In this study the concentration of PVOH varied from 12% to 16% (wt). At low concentration (12% and 13%) bead fibers were produced. While higher concentration (14%, 15% and 16%) produced fine nanofibers. The diameter of PVOH electrospun nanofibers increased from 108 nm to 133.6 nm with the increase in concentration of PVOH concentration from 12% to 16% respectively.

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