Polyvinylpyrollidone/Cellulose Acetate (PVA/CA) Fiber Size Prediction Using Scaling Law Model

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Polyvinylpyrollidone/Cellulose Acetate (PVA/CA) Fiber Size Prediction Using Scaling Law Model

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Abstract. The purpose of this research was to compare the diameter of the fiber produced using the electrospining method and scaling law model. The electrospinning process is a simple technique in producing nanofibers from the incorporation of various polymers. The polymer material used is Poly (vinylpyrrolidone) (PVP) with Cellulose acetate (CA) solvent. Cellulose acetate (CA) solvents using different concentrations were 6% (PC 1), 10% (PC 2) and 17% (PC 3). The process parameters used electrospinning voltage is 10 kV, the needle tip to collector distance is 13 cm and flowrate used is 3.2 µL/hour. The product of nanofibers was morphologically characterized using a digital microscope and the fiber diameter size was predicted using a scaling law model. The scaling law model predicts electrical conductivity in PC 1, PC 2, PC 3 samples are 0.004298 S/m, 0.001289 S/m, and 0.000374 S/m respectively. The results of the logarithmic comparison of Q/K to the diameter of the nanofiber produce a linear graph pattern with a decrease in the value of K resulting in the diameter of the nanofiber-based on the results of experiments that have been carried out.

1. Introduction

Nanofiber synthesis can be produced through various methods, such as: drawing, phase separation, template synthesis, self-assembly, and electrospinning [1], [2]. The several methods that have been mentioned electrospinning is the most versatile method in the synthesis of nanofibers. Poly(vinyl alcohol) [3][4], Chitosan [5], Poly(urethane), poly(lactide-co-glycolic acid), Poly(vinylpyrollidone) [6], Cellulose Acetate [7], and several other polymers have produced nanofiber through the electrospinning method. The method involves the strength of the Coulumb force that results from the use of an electric charge, which causes the polymer solution to elongate because of electric charge exposure [1], [2], [7] Factors that influence the shape of nanofibers using the electrospinning method are divided into four types: (1) structural properties of polymers (molecular weight and tactics), (2) parameters of polymer solutions (concentration, electrical conductivity, viscosity, and surface tension), spinning conditions (stress, spinning distance, flow rate, and piston geometry), and environmental parameters (temperature, atmospheric pressure, and relative humidity) [1], [2], [8], [9].

Several previous studies have used Cellulose acetate (CA) in producing nanofibers that are superior in terms of stability, biocompatibility, and hydrophilicity [10]. Cellulose Acetate (CA) can be easily dissolved and processed in a non-polar solvent so that it is suitable in the electrospinning process [11]. This shows Cellulose Acetate (CA) has a significant advantage in the electrospinning process. However, the lack of chemical affinity and low oxidability of Cellulose Acetate (CA) fiber prevents the application

of Cellulose Acetate (CA) to a wide extent. One way that more Cellulose Acetate (CA) performance can be improved by combining it with the appropriate polymer. Polyvinylpyrollidone(PVP) is a hydrophilic polymer that is widely used because it is non-toxic, soluble in water and also has good biocompatibility [12]. PVP is a non-polar and organic polymer so it is suitable to be combined with Cellulose Acetate (CA).

Nanofiber has been successfully synthesized from the results of mixing PVP/CA through an electrospinning process with a PVP molecular weight of 1,300,000 kg/mol with concentrations of 6%, 10% and 17% and CA has a molecular weight of 50,000 kg / mol. From the results of the PVP/CA electrospinning process with a concentration of 6% produces a fiber with a diameter of 872 nm and a PVP/CA with a concentration of 10% produces a fiber with a diameter of 1408 nm. Whereas PVP/CA with a concentration of 17% produces fiber with a diameter of 2110. In the production of nanofibers, the size of a stable fiber is very important. Predictions in explaining the specifications of polymeric materials are important things that must be overcome to improve the progress of the polymer industry. In understanding complex systems such as polymers, various forms of different polymer prediction models have been developed and investigations carried out for each scale [13]. One model that can predict diameter sizes is scaling law. The scaling law (SL) model combines parameters (concentration, flow rate, inertia, electrical conductivity, viscosity, surface tension) to produce a stable diameter. In this paper, we will discuss the prediction of polyvinylpyrollidone/cellulose acetate (PVP/CA) fiber size using a scaling law model.

2. Method

2.1 Material

The material used to make fiber is PVP polymer and CA. PVP has a molecular weight of 1.300.000 kg/mol obtained Sigma Aldrich. The Cellulose Acetate (CA) has a molecular weight of 50.000 kg/mol from Sigma Aldrich.

2.2 Experimental Procedure

Polyvinylpyrollidone/cellulose acetate (PVP/CA) fiber manufacturing is done by making varying PVP / CA concentrations of 6% (PC1), 10% (PC2) and 17% (PC3). This polymer solution was cleared using magnetic stirring for 5 hours at 60°C and at a speed of 200 rpm. After that, 10 ml Terumo syringes are inserted with 15 mm hole diameter, 38 mm width and 0.8 mm needle length. The PVA/CA solution is spun using electrospinning equipment (Nacriebe 601), the systematics of the electrospinning illustration is shown in Figure 1. This electrospinning equipment uses room temperature and inertia (26 ± 0.55°C, RH 40 ± 50%). The polymer uses a voltage of 15 kV and a flowrate of 5 mL/hr to collect fibers on the collector drum. The collector drum uses a rotation speed of 450 rpm and the distance between the needle and the collector is 10 cm. At the time of collection of fibers can use the camera to monitor Taylor Coneyang formed on the tip of the syringe.

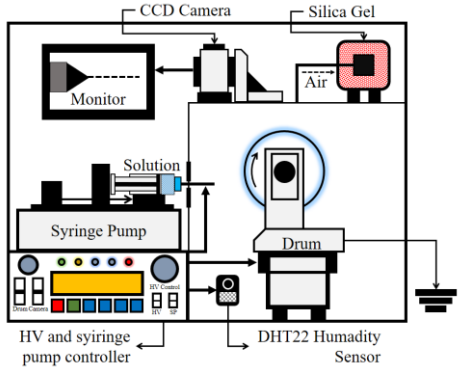

Figure 1. Schematic illustration of electrospinning [7]

2.3. Scaling Law Modeling

Scaling law (SL) is an observation of how the laws of physics work on the size of a material or a reduced device. The application of SL is widely used in solid physics. SL is needed to explain the particle sizes that make up solid and polymer materials. Based on SL, the diameter of the polymer that has been synthesized by the electrospinning method will be a function of flow rate, electrical conductivity, dielectric constant, polymer volume fraction, viscosity, solution density, surface tension, and molecular weight. Hogan (2007) [14] and Widyandari (2007) [15] explain the Scaling Law (SL) model in a theoretical prediction of the diameter of fibers and particles given by the following formula:

$$D_{drop} = G(\kappa)\left(\kappa\varepsilon_0 \frac{Q}{K}\right)^{\frac{1}{3}} \quad \text{.....(i)}$$

$$G(\kappa) = -10{,}9\kappa^{-\frac{6}{5}} + 4{,}08\kappa^{-\frac{1}{3}} \quad \text{.....(ii)}$$

Description of the equation:

D_{drop}	=	droplet diameter	K	=	electrical conductivity (S / m)
ε_0	=	permeability (8.85 x 10-12 C2 / Nm2)	Q	=	flow speed (µL / min)
κ	=	dielectric constant	$G(\kappa)$	=	dimensional function

Equation (i) for prediction of droplet size, equation (ii) for prediction of polymer particle size. The dielectric constant value has been determined while the value of viscosity, droplet size, and polymer particle size is predicted. The evaluation results are then used to show that with the control of the polymer solution and the appropriate process parameters will produce polymer particles with stable size and controlled properties that can be produced.

3. Result and Discussion

3.1 PVP/CA Nanofiber

The manufacture of Polyvinylpyrollidone/cellulose acetate (PVP/CA) fibers is produced using electrospinning by utilizing an electric field to produce coulomb forces so that it can gently pull fibers from the polymer in micrometers and nanometers. When a high DC voltage source is connected to the needle as a positive electrode and the collecting drum as a negative electrode, which is initially very neutral charged it experiences polarization due to the influence of the potential difference between the two electrodes[1], [16]. The charges in this solution will be spread evenly including on the surface of the solution. The collection of these charges will experience a Coulomb force due to the repulsion between charges according to equation (iii)[17]. Moreover, will produce an electric force due to the electric field of the two electrodes in accordance with equation (iv) [17]. This process is suitable for producing fibers that use large, small and complex molecules. In addition, this process does not require the use of chemical coagulation and high temperatures.

$$\vec{F_c} = \frac{kq_1q_2}{r_{21}^2} \quad \text{.....(iii)}$$

$$F_{electric} = q\vec{E} \quad \text{.....(iv)}$$

In the electrospinning process, there are basic properties to produce fiber including viscosity, surface tension, solution conductivity and electrostatic forces. Three balanced forces including the electrostatic force of the high electric field (F_C), the hydrodynamic force of the booster pump (F_H) and the surface tension force ($F\gamma$) influence the formation of the fiber[6], [7]. When the electrostatic and hydrodynamic forces exceed the threshold value of the surface tension, the jet will come out and fibers will form on the collector.

3.2 Morphology and Fiber Distribution

In the electrospinning process the electrical conductivity of the solution plays an important role in controlling the structure of nanofibers. In addition to the electrical conductivity of stout solutions, the literature states that the impact of the quality of the solvent on the electrospining process is able to

control nanostructures. In experiments, that have been carried out using PVP polymer materials with solvents using CA[18]. The volume ratio of the PVP / CA ratio is 7: 3 for all samples with different CA solvent concentrations. In the process of electrospining the thickness of the polymer solution determines the conductivity of the solution.

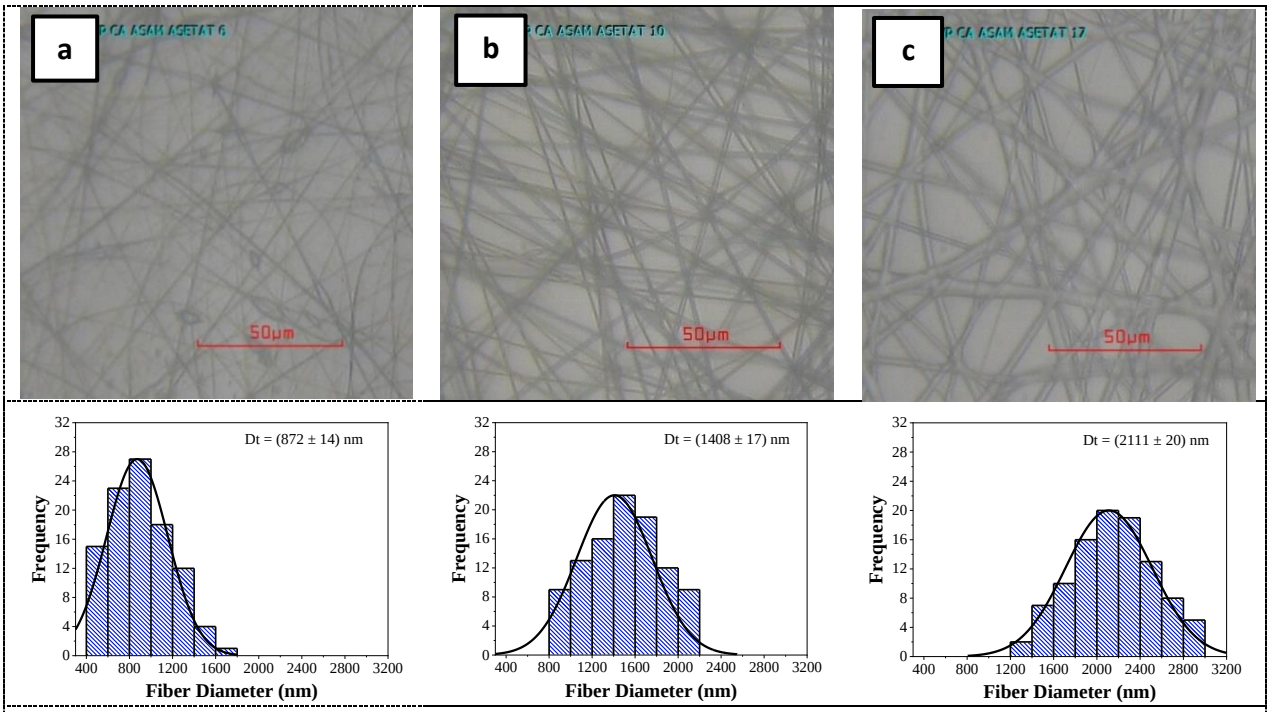

Figure 2. Morphology and diameter distribution of nanofiber (a) PC1 (b) PC2 dan (c) PC3 nanofiber.

In figure 3 shows the fiber distribution of PVP / CA solutions with 3 different concentrations. PC1 with a concentration of 6% produces nanofibers with a diameter of 872 nm and PC2 concentrations with a concentration of 10% and PC3 with a concentration of 17% produces nanofibers with a larger diameter of 1408 nm and 2111 nm. The morphology of the different nanostructure structures that results from the electrospinning process is very dependent on the parameters of the solution[19]. Morphological results of PVP / CA fiber distribution using a digital microscope with 400 times magnification with a scale size of 50µm. In the picture PC1 is a distribution of nanofibers in a bead structure with a fiber distribution of 14 nm. PC2 images produce morphology in the form of fibers with a standard deviation of 17 nm and PC3 images produce morphologies in the form of fibers with a standard deviation of 20 nm. The nanofiber of optimum produced with the electrospinning method at a concentration of 17% w/w is free-bead fiber. This research is in accordance with the results of previous studies [6,7], that the increased polymer concentration produces free-bead fiber.

3.3. Fiber Size in the Scaling Law Model

Table 1. Results of PVP / CA Samples

Sample	κ	K (S/m)	Q (μL/min)	Q/K (μL/min)/(S/m)	Log Q/K	D (μm)	Droplet size (μm)	Log D
PC1	5 – 78	0,004298	0,05	11,63177	1,0657	0,872	0,78 – 2,17	-0,05948
PC2	5 – 78	0,001289	0,05	40,5819	1,6028	1,408	0,93 – 2,59	0.148902
PC3	5 – 78	0,000374	0,05	160,8943	2,1238	2,110	1,28 – 3,22	0,34439

Based on table 1 the results of the calculation of the fiber diameter for all experiments with a comparison of the value of the flow rate with electrical conductivity. Based on Figure 3, the shape of the circle is the data of experimental results predicted by the size of the Polyvinylpyrollidone/cellulose acetate (PVP/CA) PVP/CA fiber using equation (1) and equation (2). Based on Figure 3. Squares, and triangles are empirical data obtained from the results of previous studies, Widyandari (2007) using polymer-pigment-composite nanoparticles and using pure polymers and also shown theoretical lines showing approximate diameter sizes of fibers based on equation (1) and (2) [15], [14], [20].

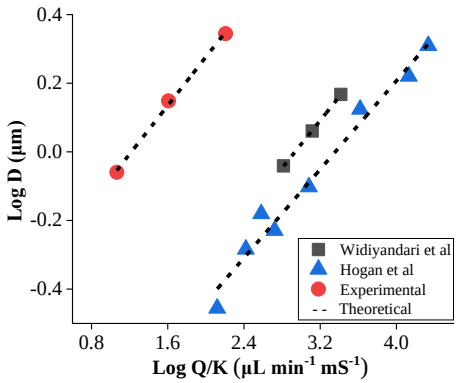

Figure 3. Relationship of logarithm of droplet diameter from two empirical data and theoretical calculation of comparison of solution flow rate and electrical conductivity

In Figure 3 it was found that the experimental data in accordance with the theoretical model $\kappa = 5$ to 78 8 were used, as $5 < \kappa < 78$ for all solutions. More than double the predicted Q / K logarithm, the fiber diameter calculated based on the polymer solution is in very good condition with the prediction from the equation. (1); thus SL can be used to predict and control the size of the polymer fibers produced. by adjusting the parameters of the atomization process (flow rate, electrical conductivity, and dielectric constant). Polyvinylpyrollidone/cellulose acetate (PVP/CA) fiber size prediction using the scaling law model in PC1 sample shows the logarithm value of (flow rate per electrical conductivity) is 1.0657 and the logarithm value of the fiber diameter is -0.05948. In the PVP / CA sample with a concentration of 10%, the logarithmic value of the flow rate per electrical conductivity is 1.6028 and the logarithm value of the fiber diameter is 0.1486 and the PVP/CA sample with a concentration of 17% shows the logarithmic value of the results (rate flow per electrical conductivity) is 2.1238 and the logarithm value of fiber diameter is 0.32428. From these results it can be concluded that the greater the logarithm of the flow rate per electrical conductivity (Q / K), the greater the logarithm of the fiber diameter.

4. Conclusion

The electrospinning method and the scalling law method have succeeded in the production and prediction of nanofiber PVP/CA fibers. The nanofiber of optimum produced with the electrospinning method at a concentration 17% w/w is free-bead fiber, with the process parameters of electrospinning voltage is 10kV, the needle tip to collector distance is 13 cm and flowrate used is 3.2 µL/hour. The diameter of PC1, PC2, and PC3 nanofibers produced from electrospinning methods were 872 nm, 1408 nm and 2111 nm, respectively and the fiber diameter size was predicted using a scaling law model are 872 nm, 1408 nm and 2111 nm, respectively. The results showed that the diameter of the nanofibers from the experiments using the electrospinning method is the same as the results of the prediction using the scaling law method.

Acknowledgments

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