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ORIGINAL PAPER

Optimization of rotating-jet electrospinning process using response surface methodology

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Abstract Rotating-jet electrospinning method is one of the efficient techniques for producing aligned nanofibers. This paper reports an accurate investigation on the influence of collector diameter (CD), voltage, polymer concentration (PC), and insulator length (IL) of spinneret on the degree of fiber alignment (DFA), production rate of fiber, and fiber diameter. The polymer solution was a mixture of polyacrylonitrile and *N*,*N*-dimethylformamide. The ranges of independent variables were 20–50 cm for CD, 10–22 kV for voltage, 13–19 wt% for PC, and 0.5–3 cm for IL. To minimize the number of required experiments for a complete evaluation, response surface methodology (RSM) and central composite rotatable design were applied by means of Expert Design Software. After defining the upper and lower bounds of the above independent variables in the software, 30 unique experiments were delivered. The recommended operating conditions by the software were exactly applied in the laboratory and the corresponding values for the DFA, production rate, and fiber diameter were measured. The nanofiber morphology was examined by scanning electron microscopy (SEM). By applying the least-squares method in the DX7.0.0 software, well-fitting polynomial correlations to the experimental results were obtained, and using these correlations, the influence of independent variables and responses was comprehensively studied. Finally, the best values of independent variables for optimizing the responses were determined using RSM.

Keywords Electrospinning · Rotating-jet method · Response surface methodology · Optimization

Introduction

Electrospinning is a simple and inexpensive method that has been known for the production of nanofiber for decades [1–3]. The theoretical and practical aspects of the conventional electrospinning process have been well described in literature [2]. Essentially, a conventional electrospinning device consists of a high-voltage dc power supply to create an electrostatic field, a collector (such as a flat conductive plate) with negative charge to collect elecrospun nanofibers, a feed pump to maintain a constant flow rate of a polymer solution, and a spinneret connected to the positive pole of the power supply. Due to the interaction of various electrical and viscoelastic forces of flying polymer jet, instability is initiated, propagated, and extended during the electrospinning process [4, 5]. Therefore, nanostructure mats of nanofibers are deposited over the collector. These kinds of nanofibers have just limited applications in filtration [6], drug delivery [7], tissue engineering [8], sensors [9], and catalysts [10]. However, an aligned and highly ordered web of fibers is required for some special applications, such as production of artificial nerves, very fine electronic devices, and fiber reinforcement in the textile industries [11–13]. So far, several techniques have been suggested for the production of uniaxially aligned fibers. A fast rotating cylinder was used by Boland et al. [14] as the collector to align nanofibers. In addition, Theron et al. [15] found that using a thin disk with sharp edge as the collector enhanced the electrical field strength and resulted in uniaxial nanofibers. In another relevant research, Ishii et al. [16] presented an electrospinning setup with two pieces of stainless steel collectors. They

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