A Quantitative Study on Simultaneous Effects of Governing Parameters in Electrospinning of Nanofibers using Modified Neural Network using Genetic Algorithm

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ABSTRACT

In this article, modified neural networks using genetic algorithms were employed to investigate the simultaneous effects of four of the most important parameters, namely; solution concentration (C); spinning distance (d); applied voltage (V); and volume flow rate (Q) on mean fiber diameter (MFD), as well as standard deviation of fiber diameter (StdFD) in electrospinning of polyvinyl alcohol (PVA) nanofibers. Genetic algorithm optimized neural networks (GANN) were used for modeling the electrospinning process. The results indicate better experimental conditions and more predictive ability of GANNs. Therefore, the approach of using genetic algorithms to optimize neural networks for modeling the electrospinning process has been successful. RSM could be employed when statistical analysis, quantitative study of the effects of the parameters and visualization of the response surfaces are of interest, whereas in the case of modeling the process and predicting new conditions, GANN is a more powerful tool and presents more desirable results.

KEYWORDS

Electrospinning, Empirical Modeling, Genetic Algorithm Optimized Neural Networks (GANN), Response Surface Methodology

1. INTRODUCTION

Electrospinning is able to produce continues nanofibers from polymer solutions or melts in high electric fields (Chowdhury & Stylios, 2010). Due to its properties such as very small diameter, large surface area per mass ratios, high porosity along with small pores sizes, flexibility and superior mechanical properties, electrospun nanofiber have numerous application in diverse areas (Nurwaha, Han, & Wang, 2013).

Employing a model to express the influence of electrospinning parameters enables us to obtain a simple and systematic way for presenting the effects of variables and thereby enabling the control of the process. Furthermore, it allows us to predict the results under new combination of parameters. Hence, without conducting any experiments, one can easily estimate features of the product under unknown conditions (Gu, Ren, & Vancso, 2005; Ziabari, Mottaghitalab, & Haghi, 2010).

DOI: 10.4018/IJCCE.2017010102

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Design of the polymeric nanofibers to meet specific needs for useful applications requires a thorough knowledge of the electrospinning parameters and their effect on nanofiber diameters and morphologies (Chowdhury & Stylios, 2010).

An empirical model therefore tells us to what extent the output of a system will change if one or more parameters increased or decreased. This is very helpful and leads to a complete understanding of the process and the effects of parameters (Yördem, Papila, & Menceloğlu, 2008).

Affecting the characteristics of the final product such as physical, mechanical and electrical properties, fiber diameter is one of the most important structural features in electrospun nanofiber mats. Podgorski et al. (Podgórska, Balazy, & Građanić, 2006) indicated that filters composed of fibers with smaller diameters have higher filtration efficiencies. This was also proved by the work presented by Qin et al. (Qin & Wang, 2006). Ding et al. Ding, Yamazaki, and Shiratori (2005) also reported that sensitivity of sensors increases with decreasing the mean fiber diameter due to the higher surface area.

A few techniques such as orthogonal experimental design (Cui, Li, Zhou, & Weng, 2007) and using power law relationships (T. Wang & Kumar, 2006) have been reported in the literature for quantitative study of electrospun nanofiber.

As it is well known, this conventional method of experimentation involves many tests, which are time-consuming, ignores interaction effects between the operating parameters and induces a low efficiency in optimization. These limitations can be avoided by applying the Response Surface Methodology (RSM) that involves statistical design of experiments (DoE) in which all factors are varied together over a set of experimental runs (Karim, Sulong, Azhari, Lee, & Hwei, 2012; Khayet, Cojocaru, & Z. Trznadel, 2008; Khayet, Seman, & Hilal, 2010).

In fact, the statistical method of experimental design offers several advantages over the frequently used conventional method being rapid and reliable, helps in understanding the interaction effects between factors and reduces the total number of experiments tremendously resulting in saving time and costs of experimentation. Moreover, RSM can be used to evaluate the relative significance of several affecting factors even in the presence of complex interactions (Cui et al., 2007; Elsealhi, Cojocaru, G. Payo, & Arribas, 2013; Idris, Kormin, & Noordin, 2006).

However, researchers mostly paid attention to response surface methodology (RSM) technique due to its simplicity and its ability to take into account the interactions between the parameters. Sukigara et al. (Sukigara, Gandhi, Ayutsede, Micklus, & Ko, 2004) employed RSM to model mean fiber diameter of electrospun regenerated Bombyx mori silk with electric field and concentration at two spinning distances. Gu et al. (Gu & Ren, 2005; Gu et al., 2005) also exploited the RSM for quantitative study of polyacrylonitril (PAN) and poly D,L-lactide (PDLA) respectively. The only difference observed in the procedure was the use of four levels of concentration in the former case. They included the standard deviation of fiber diameter in their investigations by which they were able to provide additional information regarding the morphology of electrospun nanofibers and its variations at different conditions.

In the most recent investigation in this field, Yördem et al. (Yördem et al., 2008) utilized RSM to correlate mean and coefficient of variation (CV) of electrospun PAN nanofibers to solution concentration and applied voltage at three different spinning distances. They employed a face-centered central composite design (FCCD) along with a full factorial design at two levels resulting in 13 treatments at each spinning distance. A cubic polynomial was then used to fit the data in each case. As previous studies, fiber diameter was very sensitive to changes in solution concentration. Voltage effect was more significant at higher concentrations demonstrating the interaction between parameters.

The simultaneous effects of four electrospinning parameters (solution concentration, spinning distance, applied voltage, and volume flow rate) on mean and standard deviation of electrospun
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