Investigation of Parameters Affecting PAN Nanofiber Production Using Electrical and Centrifugal Forces as a Novel Method

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Abstract: Electro-centrifuge spinning is a novel, innovative, high-performance, and simple method to produce polymeric nanofibers based on using electrical and centrifugal forces. In this paper, first the electro-centrifuge method is presented and then an experiment is conducted to explore the range of centrifugal speed for the production of polyacrylonitrile (PAN) polymer nanofibers at different concentrations and voltages. Finally, the effect of important parameters such as rotational speed of the apparatus, concentration, and applied voltage on the flow rate of the polymer solution is estimated analytically and compared with experimental results.

Keywords: Nanofiber, polyacrylonitrile, electrospinning, electro-centrifuge spinning.

1. INTRODUCTION

When the diameters of polymer fiber materials are decreased from micrometers to submicron or nanometers, several physical characteristics such as very large surface area to volume ratio, and superior mechanical properties (e.g. stiffness and tensile strength) will appear [1]. These outstanding mechanical properties make the polymer nanofibers optimal candidates for many important applications. A number of applications for nanofibers include, tissue scaffolds [2-4], protective clothing, filters, nano-electronics [5, 6], high performance nanofibers [7, 8], antibacterial nanofiber membranes [9], drug delivery [10], wound dressing(wound healing) [11], and composites [12].

Although several techniques have been proposed so far for the production of nanofibers, finding effective approaches is still a challenge and many researches are underway in the field. The main methods for producing nanofibers are categorized to drawing, template synthesis, gas jet spinning, Island-in-the-sea and Electrospining.

"Drawing" is a method like dry spinning that can result in a long monofilament but only visco-elastic materials which can bear large amounts of deformation and do not break while applying great tension and stress can be transformed to nanofibers by using this method [13]. "Template Synthesis" is a method to produce nanofibers that applies porous membranes with nano-scale pores as a mold. However, it is not possible to prepare long and distinct nanofilaments by this method [14]. In Gas Jet spinning method, air-blowing force is used to apply tension and produce fibers [15]. "Island-in-the-sea" method that has been used in the past to manufacture microfibers is used recently to produce nanofibers [16]. Electrospinning has been the most successful method to produce nanofibers so far. It is a well known and prominent method based on electrostatic forces that provides possibility for spinning nanofibers from many kinds of polymers using melt or solution spinning [17, 18]. In Aero-electrospinning, an air jet surrounding the electrospinning nozzle is used to produce fine fibers [16]. Other methods for nanofiber production are phase separation [19] and self-assembly [20, 21].

Although there are many methods for fabricating nanofibres, electrospinning is perhaps the most versatile process. Materials such as polymers, composites, ceramics, and metal nanofibres have been fabricated using electrospinning directly or through post-spinning processes. To overcome various limitations of the conventional electrospinning method, researchers have come up with modifications for the set-up, including: electrospinning using a collector which consists of two pieces of conductive plates separated by a gap [22, 23], collecting spun nanofibers on a rotating thin wheel with sharp edge [24], fabricating aligned nanofibers yarn of nylon 6 by rapidly oscillating a grounded frame within the jet [25], and using a metal frame as a collector to generate parallel arrays of nanofibres [26, 27]. Matthews *et al*. [28] have applied a rotating drum to collect aligned nanofibers at a very high speed up to thousands of rpm (revolution per minute). In another approach, Deitzel *et al*. [29] used a multiple field technique which can straighten the polymer jet to some extent. Dabirian, *et al*., employed two needles which were connected to positive and negative voltages separately to produce high bulk nanofibers which can gradually be collected by a rotating drum [30, 31 and 32]. This technique was also applied to generate nanofiber yarns [30]. Luming, *et al*. [33] collected aligned nanofibers by increasing the surface velocity of the drum by using this method.

The nature of electrostatic forces is the reason for the success and effectiveness of electrospinning, because even stress is applied while the polymer string is stretching and becoming narrow. The use of mechanical methods to apply high rate of tensions to a polymer solution or melt is possible only for polymers with high extension- ability to prevent uneven transmission of tension and stress concentration. In order to apply a high rate of tension to a polymer solution or melt, methods which can apply even distribution of stress during the tension process are required. R. T. Weitz and *et al*. used of centrifuge force to produce nanofiber without nozzle; it involves the application of drops of a polymer solution onto a standard spin coater [34]. When centrifugal forces act on a substance, they affect all particles of that matter and apply an even distribution of stress. Thus, this force can be used to apply high rates of tension on a polymer solution. During the tension process, if the polymer solution has sufficient viscosity, it is stretched as a string and transformed to a polymeric fiber after drying. The viscosity of the polymer solution arises from the frictional forces between polymer chains in the solution. Since the nature of frictional forces is depended on the speed of the applied exterior forces, with an increase in this rapidity, the frictional forces between polymer chains increase. Consequently, by increasing the rate of the applied exterior forces, the polymer solutions with lower concentrations can be spun.

In this research, electrostatic and centrifugal forces are concurrently used to apply tension to the polymer solution in order to produce nanofibers. This is why the innovative method is named

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