

EFFECT OF FLOW RATE ON DIAMETER OF ELECTROSPUN NANOPOROUS FIBERS

by

Xiao-Peng TANG^a, Na SI^a, Lan XU^{a,b*}, and Hong-Ying LIU^a

^a National Engineering Laboratory for Modern Silk, College of Textile and Clothing Engineering,
Soochow University, Suzhou, China

^b Nantong Textile Institute, Soochow University, Nantong, China

Original scientific paper
DOI: 10.2298/TSCI1405447T

The effect of flow rate on the diameter of the charged jet in the electrospinning process is studied theoretically. The obtained theoretical results offer in-depth physical understanding and mechanism of nanoporous fibers. It also reveals that the morphology and diameter of nanoporous microspheres can be controlled by the flow rate.

Key words: *electrospinning, nanoporous, flow rate, pore*

Introduction

Because of ultra-high specific surface, nanoporous structure has been caught much attention recently as the most promising material in nanotechnology [1-8]. Nanoporous membranes can also be widely produced by electrospinning, but a single nanoporous fiber is difficult to align and process into useful materials. Recently, a general strategy for the synthesis of microsphere with nanoporosity by electrospinning was suggested in [4, 5], the porous sizes having uniform but tunable diameters can be controlled in the electrospinning process. The presence of pores on the surface of fibers has served to enhance performance in electronic, catalytic and hydrogen-storage systems, tissue engineering, and others [1-4]. Fabrication of nanoporous fibers always involves solvent evaporation [6-8].

This paper theoretically studies the effect of flow rate on the diameter of the charged jet in the electrospinning process. There is good correspondence between the theoretical results and the experimental findings. These results show that the flow rate plays an indispensable and crucial role in the electrospinning process, which directly affects the surface morphology of the charged jet. With the increase of the flow rate the diameter of the charged jet increases.

Theoretical analysis

During the electrospinning process, the charged jet pulled from a capillary orifice is accelerated toward the target by a constant external electric field, and rapidly thins and dries as a result of elongation and solvent evaporation. Therefore, the process is a gas-liquid two-phase flow process, and the two phases that co-exist simultaneously in the fluid flow often exhibit relative motion among the phases as well as heat transfer across the phase boundary. In the proceeding sections, averaged equations governing the conservation of mass, momentum and energy are formulated based upon the consideration of averaging being performed over an arbitrary volume V , as shown in fig. 1 [9].

* Corresponding author; e-mail: lanxu@suda.edu.cn.

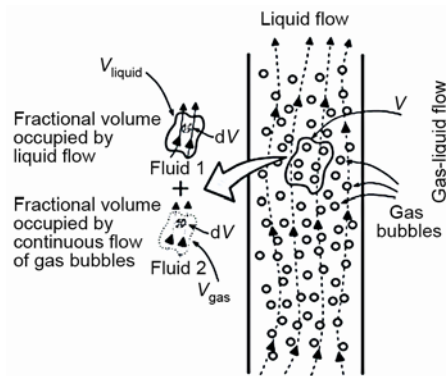


Figure 1. Schematic representation of gas-liquid flow [9]

The conservation law is pertinent to the derivation of the conservation equation of mass. From classical physics consideration, the instantaneous conservation equation of mass in the single-phase fluid flow may be derived from the consideration of a suitable model of the flow for a continuum fluid, which is also deemed to be valid for the continuous flow in each phase. The infinitesimal fluid element approach is adopted and this approach essentially prescribes an infinitesimal element, as shown in fig. 1.

Considering the enlarged elemental volume dV containing any k^{th} phase, the fundamental physical principle governing the conservation of mass is:

$$\text{The rate of increase of mass within the fluid element} = \text{The net rate at which mass enters the elemental volume} \quad (1)$$

Let us consider an one dimensional jet, and then it is convenient to choose a part of the stream tube, as shown in fig. 2. It indicates that the change in volume of the jet in the control volume during any time interval is equal to the difference between the volume of inflow and the volume of outflow during that time interval.

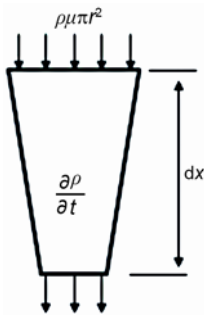


Figure 2. An elemental volume of the k^{th} phase

On the basis of eq. (1), the partial differential equation of the conservation of mass can be written as:

$$\frac{\partial \rho^k}{\partial t} + \frac{\partial}{\partial x}(\pi r^2 u^k) dx + \frac{\partial \rho^k}{\partial x} \pi r^2 dx = 0 \quad (2)$$

where $\partial \rho^k / \partial t = 0$.

$$\pi r^2 \rho^k u^k = Q^k \quad (3)$$

where Q^k is the volume flow rate of the k^{th} phase, r – the radius of the jet, ρ^k – the density of the k^{th} phase, and u^k – the velocity of the k^{th} phase.

In this process, the value of the applied voltage is a constant, and we assume the velocity of the jet keeps unchanged. Therefore, according to eq. (3), the diameter of charged jet increases with the increase of the flow rate.

Experimental verification

Poly lactide (PLA) solutions are prepared with 6 wt.% by using mixture of N, N-dimethylformamide (DMF) and $\text{CHCl}_3(\text{CF})$ with weight ratio 1/9. Electrospinning experiments are carried out with the same collective distance (15 cm) and the same voltage applied (15 kV) at the room temperature (18 °C) and 50% relative humidity in a fume hood under the horizontal configuration. The flow rate varied from 1 to 2.5 ml/h. The fiber diameters are measured using Image J software.

Figure 3 shows the effect of flow rate on the diameter of the electrospun nanoporous fibers. It can be seen that the diameter of the electrospun nanoporous fibers increases with the

increase of the flow rate. These experimental results agree with the above results obtained by applying theoretical analysis.

Conclusions

The effect of the flow rate on the diameter of the electrospun nanoporous fibers was studied theoretically. The experimental data is in good agreement with the results obtained by applying theoretical analysis. The results show that with the increase of the flow rate the diameter of the electrospun nanoporous fibers increases, and the porous sizes having uniform but tunable diameters can be controlled by the flow rate in the electrospinning process. The mechanism is worth further studying.

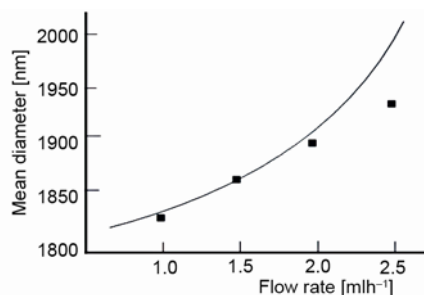


Figure 3. Effect of flow rate on the diameter of the electrospun nanoporous fibers

Acknowledgments

The work is supported financially by PAPD (A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions), Jiangsu Provincial Natural Science Foundation of China (Grant No. BK20131175), Natural Science Foundation of the Jiangsu Higher Education Institutions of China (Grant Nos. 14KJA130001 and 12KJB130002), Suzhou Science and Technology Project (Grant No. SYG201434), Nantong Science and Technology Project (Grant No. BK2014050), National Natural Science Foundation of China (Grant No. 11372205), Science & Technology Pillar Program of Jiangsu Province (Grant No. BE2013072), and China Postdoctoral Science Foundation (Grant No. 2014M551658).

References

- [1] Yang, F., *et al.*, Electrospinning of Nano/Micro Scale Poly(L-lactic Acid) Aligned Fibers and Their Potential in Neural Tissue Engineering, *Biomaterials*, 26 (2005), 15, pp. 2603-2610
- [2] Wolfrum, B., *et al.*, Suspended Nanoporous Membranes as Interfaces for Neuronal Biohybrid Systems, *Nano Letters*, 6 (2006), 3, pp. 453-457
- [3] Kumakura, M., Preparation Method of Porous Polymer Materials by Radiation Technique and its Application, *Polymers for Advanced Technologies*, 12 (2009), 7, pp. 415-421
- [4] Xu, L., *et al.*, Electrospun Nanoporous Materials: Reality, Potential and Challenges, *Materials Science and Technology*, 26 (2010), 11, pp. 1304-1308
- [5] Xu, L., *et al.*, Theoretical Model for the Electrospinning Nanoporous Materials Process, *Computer & Mathematics with Applications*, 64 (2012), 5, pp. 1017-1021
- [6] Bogwitzki, M., *et al.*, Nanostructured Fibers via Electrospinning, *Advanced Materials*, 13 (2001), 1, pp. 70-72
- [7] Megelski, S., *et al.*, Micro- and Nanostructured Surface Morphology on Electrospun Polymer Fibers, *Macromolecules*, 35 (2002), 22, pp. 8456-8466
- [8] Casper, C. L., *et al.*, Controlling Surface Morphology of Electrospun Polystyrene Fibers: Effect of Humidity and Molecular Weight in the Electrospinning Process, *Macromolecules*, 37 (2004), 2, pp. 573-578
- [9] Yeoh, G. H., Tu, J. Y., *Computational Techniques for Multiphase Flows*, Elsevier Ltd., Oxford, UK, 2010

Paper submitted: December 20, 2013

Paper revised: February 1, 2014

Paper accepted: April 10, 2014