A Review on Existing Tecgnology of Electrospinning at Large Scale

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Abstract: Electrospinning is a simple and economical method for the fabrication of polymer nanofibers. But low yield of electrospinning has limited this technology to develop from laboratory level to larger-scale/industrial level and hence the applications of nanofibers. This paper describes several methods for electrospinning nanofibers at large-scale, including multi-needle electrospinning, Nanospider technology, hollow porous tube spinning, NES, magnetic fluid spinning technology, and bubble electrospinning.

Keywords: large-scale; electrospinning; multi-needle; multi-jet

1. Introduction

The rapid warming of nanotechnology research sparked interest of in-depth study of researchers around the world to prepare electrospinning nanofibers. At present, electrospinning has become the most important and most effective way to make nanofibers. Electrospinning technology can be used to obtain the nanofibers with diameters in nano-scale and electrospun fiberous webs with small pores, high porosity, large surface area and good permeability, and the resultant products have potential applications in the filter materials, biomedical materials, clothing materials, sensors and so on.

With the rapid development of nanotechnology, the demand for nanofibers and their products is also growing, therefore the output of the conventional electrospinning is not able to meet the needs from various application fields any more. Therefore, the methods which can improve the yields of the electrospun nanofibers are particularly in need currently.

2. Research status of electrospinning

In the conventional electrospinning device the spinning fluid is driven into the orifice of single-nozzle connected with high-voltage power supply, forming micro-nano fibers which are finally received on the grounded receiving screen. Thus the randomly deposited continuous fibers form a thin film (US patent 1975504).The single needle/nozzle electrospinning device can effectively prepare a variety of uniform nanofibers, but the efficiency of its preparation is relatively low. Therefore, conventional Electrospinning technology cannot massively produc nanofibers and is still at the laboratory stage.

In order to improve the yield of electrospinning, it is desirable to develop highly efficient multi-needle / multi-nozzle electrospinning device[1-2]. Many related researches at home and abroad are carried on to achieve the industrialization of electrospinning technology. For example, the concentric nozzle [3], juxtaposition nozzles [4], multi-nozzles [5] and so on, were used to produce the nanofibers of hollow-type, sheath-core type or multi porous channel type instead of a single-nozzle. The plane receiving device could be in the forms of tube [6], drum-cylinder[7], rolling cylinder [8] etc. In addition, nonwadays the climate control technology [9], vibration technology and external magnetic field [10] and other auxiliary facilities could be introduced to the electrospinning process. So far, the existing Electrospinning technology could meet the requirements for high efficiency and large-scale production.

U.S., Czech Republic, Japan and Korea walked in the the forefront of the world in the field of industrializing electrospinning technology. But, the key technologies they used in different electrospinning approaches were still confidential.

3. Mass electrospinning methods

3.1. Multi-needle electrospinning

- Ding [11] used the device of multi-needle spinning to improve the production and uniformity of mixing electrospinning fiberous webs. In a spinneret, some needles were injected polyvinyl alcohol (PVA) solution, while other needles were injected cellulose acetate (CA) solution. In this method, mixed nanofibers webs could be generated. The mixing ratio of the two components could be controlled by adjusting the number of needles containing different solution components.
- Tomaszew ski [12] used nozzle arrangement of linear, elliptical and circular form for electrospinning. and among them, the circular arrangement of spinning nozzles (Figure 1) resulted in the most efficiency and best quality, with its output proportional to the number of spinning nozzles.

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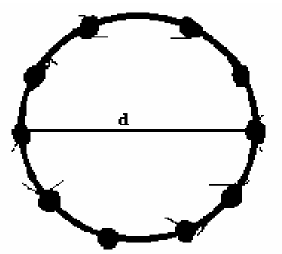


Figure 1 circular arrangement of the spinneret

- Kim et al [13] employed five needles and an auxiliary electrode for electrospinning (Figure 2). The auxiliary electrode could reduce the interference from the electric fields between the nozzles to improve the spinning yields and the quality of fiber webs.

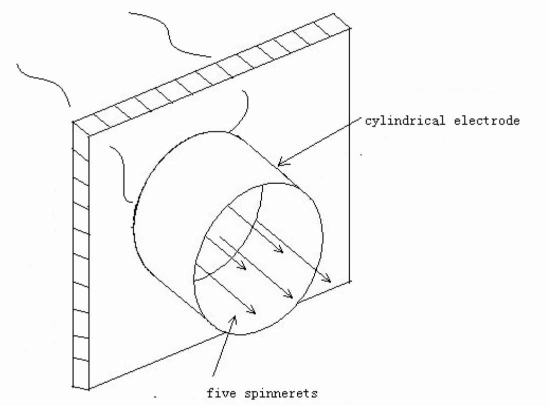
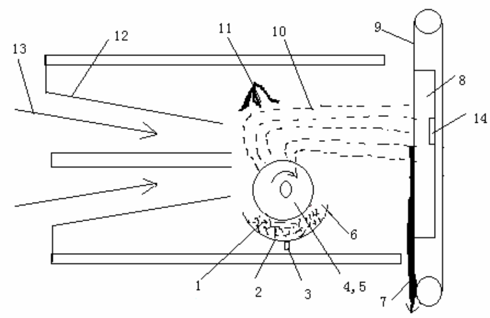


Figure.2 five nozzles with auxiliary electrode

- A new type of electrospinneret reported in a patent [14] can be used for electrospinning at large scale, which can be easily and simply added to all existing electrospinning machines to achieve mass production of electrospun nanofibers/webs, and finer fibers could be obtained than the existing electrospinning equipment.

3.2. Mass Production of Nanofibers via Needleless Electrospinning Technology

- Elmarco Company in Czech Republic cooperated with Liberee University to develop Nanospider line in 2003. They used the strong electrostatic field that was generated between the charged electrode 5 and the counter electrode 11 to spin nanofibers. Compared with conventional method of electrostatic spinning, Nanospider [15] prototype (figure 3) used a charged rotating electrode 5 instead of electrospinning nozzles. The bottom of cylinder 4 was immersed into polymer solution. When cylinder rotated, a certain amount of polymer solution was to form a thin layer on the top of the cylinder and numerous Taylor cones were formed in the electrostatic field. Polymer jets were ejected from Taylor cones and solvent was evaporated. Dry air flow helped the resultant nanofibers to drift away from the charged electrode. At last, nanofibers were collected to the metal screen and their diameters ranged from 50nm to 200nm in diameter. This device could process water-soluble or water-insoluble polymer and the yields are 1~5 g/min /m. Furthermore, this device simplified the conventional electrospinning process, greatly improving the production efficiency of electrospinning.



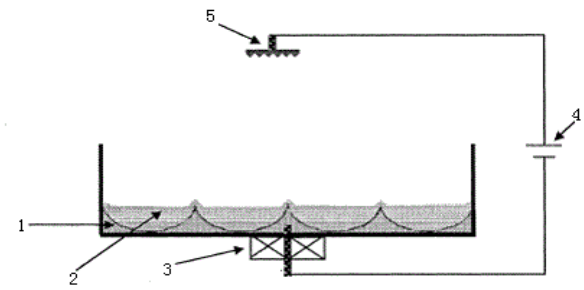
1 spinning solution 2 solution reservoir 3 solution inlet 4 cylinder 5 charged electrode 6 solution outlet 7，10 nanofiber web 8 vacuum chamber 9 transportation device 11 counter electrodes 12 the source of dry air 13 dry air 14 vacuum source

Figure.3 Schematic of Nanospider prototype

- Dosunmu etal.[16] proposed a porous tubular device of electrospinning in 2006. This new type of electrospinning technology took the place of the conventional spinning head, which used compressed air to extrude surplus polymer out of the hollow porous tube. Then Taylor cones were formed on the outer surface of the tube. Finally, multiple jets are generated under the action of electric force. In this method, the average diameter of fibers ranged from 300nm to 600nm and the yield is 250 times the single needle electrospinning method. This spinning method has the advantage of large-scale production. But there are still some problems, such as randomly scattered multi-jets, uncontrollable jet directions and so on.

- Subsequently, J.S.Varabhas et al [17] made a further improvement of the porous tubular device and drilled some small holes in the tube to effectively control the jets and to collect fiber. In this method, the average diameter of fibers ranged from 0.3 to 0.6 micron and the productivity was 3~50 times the conventional electrospinning. Xiaoping Huang et al [18] invented a new electrospinning method referred to as Needleless Electrospinning (NES).This method made use of hydrodynamics principle and traditional spinning electrodes were replaced with the rotating metal cylindricaler with smooth or notched surface.The diameter and length of the rotating cylinder could be adjusted to control the yields. It was reported that its electrospinning efficiency was 125 times that of the conventional needle electrospinning. In addition, the resultant nanofiber diameter was between 100nm and 800nm.

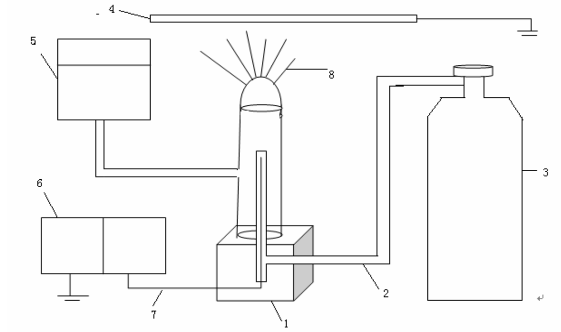
- Yarin [19] combined magnetic fluid in his research. As shown in Figure 4, the magnetic fluid generated the vertical spikes instead of the conventional Taylor cones. Two-layer solution was placed in the magnetic field to electrospin nanofibers, where the lower layer of ferromagnetic solution drove the upper layer of polymer solution, forming numerous protruded spikes. As a result, protruding spinning solution emitted the upward vertical jets under the driving of the electric field, resulting in electrospun nanofibers. Compared with conventional needle electrospinning, the problems of multi-needle arrangement and interference among needles were avoided, meanwhile the jet number per unit area increased, and hence the yield was greatly improved.



1 Layer of magnetic liquid 2 Layer of polymer solution 3 electromagnet 4 voltage source 5 counter electrode

Figure.4 Schematic of the magnetic liquid technology

- Jihuan He and Yong Liu et al.[20-21] studied a production method of bubble electrospinning (Figure 5), which could produce electrospun nanofibers at certain scale. The principle was based on the spinning process of spiders. Moreover, electrostatic field could provide drawing force at least equivalent to the mechanical stretching force generated by the spider during its spinning process. In the bubble electrospinning process, a pump was used to inject a lot of gas to polymer solution or melt, resulting in numerous bubbles in the polymer solution. Once the bubbles ruptured on the free surface of the polymer solution, numerous Taylor cones were likely generated from the solution, which is similar to multi-needle e-spinning. This approach could greatly improve the efficiency of nanofiber production.



1 tube support 2 gas tub 3 gas pump 4 collector 5solution reservoir 6 power supply 7 metal electrode 8 jets

Figure. 5 Schematic of bubble electrospinning

- Liu Yujun, and Liu Yanbo, et al. [22] invented a novel electrospinning technology that can be used for large-scale production of nanofibers, which used special spinning screen to replace the congenital needles and could control the product uniformity and yields. The electrospinning equipment was featured with the structure of special spinning mesh screen, adjustable width and length of working surface, adjustable height of spinning box as well as the adjustable fiber consolidation/receiving distance. Furthermore, the desired yields could be achieved and the fiber morphology could be controlled effectively.

4. Conclusion

The multi-needle and needle-free Electrospinning technologies have been used to realize large-scale electrosspinning. The shortcomings of jets instability and mutual interference still exist in the multi-needle electrospinning methods, which could be minimized by using the auxiliary electrode, and the special arrangement of needles. As far as needleless electrospinning is concerned, mutual interference of the jets has been excluded. But, the configurations of the jets are not easy to control, although the productivity of needleless electrospinning could be increased dramatically.

References

[1] Yang Y, Jia Z, Li Q, et al.Multiple Jets in Electrospinning. 2006:940-943.

[2] Theron SA, Yarin AL, Zussman E, et al. Multiple jets in eleetrospinning: Experiment and modeling.Polyer, 2005 ; 46(9): 2889-2899.

[3] Zhengming Huang, Guohua Dong. Multi-nozzle electrospinning device: China, 200320122276.4 [P]. 2005-3-2

[4] Yong Zhao, Zhongwei Sun, Lei Jiang. Multi-fluid composite electrospinning device: China, 200710062722.X [P] .2008-7-23

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[5] Yanmo Chen, Meifang Zhu, Yu Zhang, Weiwei Zuo, Hao Yu. An electrospinning device and its industrial applications: China, 200410025622.6 [P] .2006-1-4
[6] Denglong Chen, Min Li, Qinyuan Wu. A collector device of round tube for electrospinning: China, 200620132496.9 [P] . 2007-12-5
[7] Ya Li ng, Xian Li et al. An electrospinning device preparing alignment nanofibers: China, 200810070364.1 [P] .2009-2-11
[8] Yanmo Chen, Hao Yu, Yu Zhang , Kai Zhang. A special collection device for electrospinning: China, 200620043779.6 [P] .2007-6-27
[9] Yanmo Chen, Hao Yu,Yu Zhang , Kai Zhang. An electrospinning device of atmosphere controlled: China, 200610028790 [P] .2006-12-13
[10] Fang Chen, Xuezeng Zhao,Weijie Wang, Lizhou Dai, Tao Huang. An electrospinning device of magnetic fluid: China, 200610010181.1 [P] .2007-12-19
[11] DING B, KMURAA E, SATOA T, et al. Fabrication of blend biodegradable nanofibrous nonwoven mats via multi-jet electrospinning [J]. Polymer, 2004, 45: 1895.
[12] TOMA SZEW SKIW, SZADLKOW SKIM. Investigation of electrospinning with the use of a multi-jet electrospinning head [J]. Fibers& Textiles in Eastern Europe,2005, 13: 22-26.
[13] Geun Hyung Kim，Young-Sam Cho, Wan Doo Kim.Stability analysis for multi-jets electrospinning process modified with a cylindrical electrode [J]. European Polymer Journal, 2006, 42:2036-2037
[14] Yuqin Wan, Jianyong Yu, Jihuan He. A new type spinneret used for electrospinning: China, 200 420 107 832 [P]. 2006-1-25.
[15] Isaac O, Lucas D, et al .The methods of production nanofibers using electrospinning from polymer and the equipment of the implementation method: China, 200480025691. 5 [P]. 2006-1018.
[16] Dosunmu OO, Chase GG, Kataphinan W, et al. Electrospinning of polymer nanofibres from multiple jets on a porous tubular surface [J]. Nanotechnology,2006, 17: 1123-1127.
[17] Varabhas JS, Chase GG, Reneker DH.Electrospun nanofibers from a porous hollow tube[J].Polyner，2008:49(19):4226-4229.
[18] Huang X，Wu D，Zhu Y et al.Needleless electrospinning of multiple nanofibers. Proceedings of the 7th IEEE，2007:823-826.
[19] Yarin AL, Zussman E. Upward needleless electrospinning of multiple nanofibers [J]. Polymer, 2004, 45:2977-2980.
[20] Yong Liu, JiHuan He. Bubble-electrospinning for mass production of nanofibers [J]. International Journal of Nonlinear Sciences and Numerical Simulation, 2007, 8: 393-396.
[21] JiHuan He, Yong Liu, Lan Xu, Jian-Yong Yu,Gang Sun. BioMimic fabrication of electrospun nanofibers with high-throughput [J]. Chaos,Solitons and Fractals, 2008, 37: 643-651.
[22] Yujun Liu, Yanbo Liu, Jinbo Yao. A electrospinning equipment used for large scale production of nanofibers: China, 200820127732 [P] .2009-7-2