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THE DESIGN AND IMPLEMENTATION OF A DISK ELECTROSPINNING DEVICE

Norbert HODGYAI,[1] Rudolf László FARMOS,[2] Attila GERGELY[3]

Sapientia Hungarian University of Transylvania, Faculty of Technical and Human Sciences Târgu Mureș, Department of Mechanical Engineering, Târgu Mureș, Romania

[1] *hodgyai@ms.sapientia.ro*

[2] *farmos_rudolf@ms.sapientia.ro*

[3] *agergely@ms.sapientia.ro*

Abstract

The electrospinning procedure is a relatively simple and fast way of producing polymer fibers with diameters in the micrometer range. The one needle setup is commonly used due to its flexible design and effectiveness; however, this procedure has one major shortcoming; it has low productivity. The disk electrospinning design presented here combines the advantages of the corona and needleless electrospinning setups, namely the small solution surface area and high productivity. We used 33 wt% polyvinylpyrrolidone (PVP) solution to produce PVP fibers with the new design. The average fiber diameter of the produced PVP fibers was d = 446±116 nm, which is ~25 % larger compared to fibers produced with the one needle method.

Keywords: *needleless electrospinning, disk electrospinning, polymer fibers, PVP, device design.*

1. Introduction

In the last couple of decades, polymer fiber production with solution electrospinning has been a very popular method of producing fibers with sub-micrometer diameter. Polymer fibermats could be used in several applications due to the relatively simple production process and high surface to volume ratio of the produced fibermats. [1] In general the electrospinning setup has only one capillary, which limits the production rate and thus the applicability of such polymeric structures. To overcome this shortcoming of the one needle method, several proposed instrumentation designs have been developed. Apart from the corona method, all the designs require a large solution surface to be employed. This is not desirable when using low boiling point solvents due to evaporation, thus the concentration of the solution could change [2–7].

The aim of this project was to design and manufacture a disk needleless electrospinning device that uses a small solution surface in the electrospinning process, thus reducing the evaporation rate of the employed solvents.

1.1. One capillary electrospinning process

Figure 1. shows a typical one needle/capillary electrospinning setup. The setup has 3 major components: a high voltage DC power supply, a container (3), with a capillary (2) and a collector

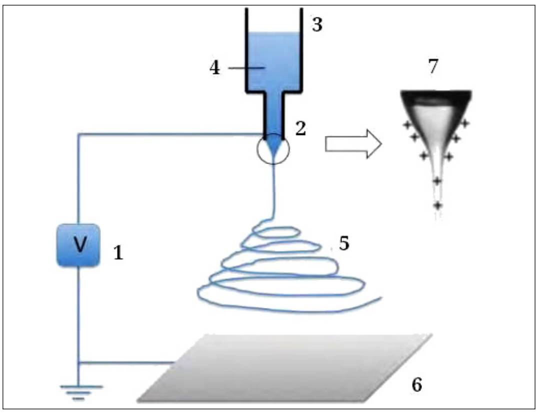

Figure 1. *One capillary electrospinning setup [11]. 1: high voltage DC power supply, 2: capillary (needle), 3: solution container, 4: polymer solution, 5: fiber producing space, 6: collector, 7: Taylor-cone.*

(6). The electrospinning process in general works as follows: the polymer solution is loaded into a syringe (container) which is connected to a needle (capillary) via tubing. A syringe pump produces a constant flow rate that transfers the polymer solution from the syringe to the needle. The needle is connected to the positive potential outlet of the high voltage DC power supply and the collector is to the ground potential.

Due to the positive potential the solution will be charged. The positive charges repel each other and when the resulting electric force exceeds the surface tension of the solution droplet, a polymer jet forms. The shape of the droplet due to the electric forces becomes cone-like - the Taylor cone. [8]. The electric field developed between the tip of needle and the collector pulls the charged polymer jet to the collector. In the process most of the solvent evaporates and solid polymer fibers will be deposited on to the collector. [1, 9].

2.2. Needleless electrospinning process

The simplest way to increase the production rate of the electrospinning process is to increase the number of capillaries. Although this approach is intuitive, the operation and maintenance of the setup is problematic. [9, 10] To overcome this shortcoming the capillary was eliminated from the setup and instead a solution surface was employed. Conductive magnetic particles, cylinders, disks, wire in a spiral shape or spheres were immersed into the polymer solution and moved or rotated. [12] This resulted in the development of several Taylor-cones on the surfaces and thus the production rate increased. The high polymer solution surface area, however, poses the risk of solvent evaporation or water uptake from the environment, thus changing the concentration and the composition of the polymer solution. This undermines the controllability of the process. [13]

Molnár et al. has developed the corona electrospinning setup that eliminates the use of large polymer solution surface, by realizing a small opening between two surfaces, where the polymer solution is pumped continuously. The schematics of the instrument can be seen on Figure 2. In this case the polymer solution is continuously pumped through cavity 6 which connects with ring 2. A cap is employed to produce the mentioned small opening between 2 and 5. The setup is rotated for a more equilibrated process. This setup thus, eliminates the use of large surface areas [14].

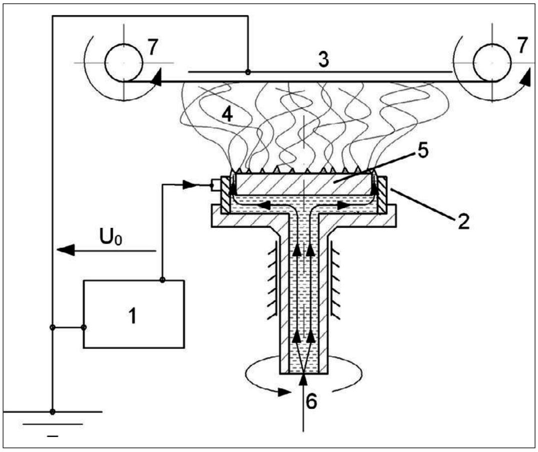

Figure 2. *The needleless corona electrospinning setup* [14].

However, one disadvantage of the design is the very precise dimensions of its components, thus fabrication cost is high

2. Experimental

2.1. Electrospinning

33 wt% polyvinyl pyrrolidone (PVP, Alfa Aesar, 58 000 g/mol) solution was prepared in 75:25 ethanol (EtOH, Merck, ACS grade): water (wt:wt) solvent system.

The process parameters for the one needle electrospinning method were determined to be: applied voltage V = 15 kV, flow rate F = 0.7 ml/h and needle-to-collector distance D = 10 cm. The used needle inner diameter was 0.7 mm.

In the case of the needleless electrospinning process the disk was rotating at 80 rpm, while the conveyer belt was used at 100 rpm at V = 20 kV and D = 10 cm. The solution was transferred to the designated cavity on the setup by the means of a syringe.

2.2. Scanning Electron Microscopy (SEM)

A JEOL JSM-5200 SEM instrument was used for the investigations at 15 kV accelerating speed. ImageJ software was used to measure the average diameter of the produced PVP fibers.

3. Results

3.1. The needleless disk electrospinning device

Our designed instrument combines the advantages of the needleless disk and corona electrospinning setups: the structure and manufacturing of the disk electrospinning setup is simple and can be easily manufactured, whereas the corona electrospinning setup employs small polymer solution surface. The working principle of the device, illustrated in Figures 3 and 4 is as follows: a thin solution layer forms on the surface of the disk that is immersed into the polymer solution and rotates. The positive potential of the high voltage DC power supply is connected to the disk, and the collector is grounded. On the edges and surface of the disk, multiple Taylor-cones form which increases the productivity of the process. The cavity, containing the polymer solution, is designed in such a way that the used polymer surface is minimized, considering the machine design criteria. The key criteria when designing the device were the low manufacturing cost, easy maintenance and cleaning and easily adjustable dimensions. Furthermore, the instrument allows the development of composite fiber mats, by means of using two separate disks that are immersed in different polymer solution. The speed of rotation of the disk spinneret and the conveyer belt can be set separately, adjusted by potentiometers.

The collector in this case is a conveyor belt that was designed in such a way that the angle could be adjusted with respect to the vertical. The use of a conveyer belt a collector could result in samples with more uniform thickness at larger quantities.

3.2. Fiber morphology and analysis

The first step was to prepare PVP fibermats with the one needle method to serve as a benchmark. The setup was discussed in detail in an earlier publication. [15]. The process parameters were set to F = 0.7 mL/h and the D = 10 cm. Under these conditions we increased the applied voltage to the point where the electrospinning process started and was stable. In our case it was V = 15 kV. Figure 5 shows the SEM images of the generated PVP fibermats.

Analyzing Figure 5.a reveals the appearance of beads that are mostly along the fibers. Based on our earlier experience the beads disappear with the increase in concentration, and at 40 wt% there are no beads. Figure 5.b shows the SEM image of the PVP fibers at x10000 magnification. The image shows PVP fibers with smooth surface and random orientation. SEM images were taken at different parts of the sample for fiber diameter measurements that resulted an average fiber diameter of d = 350 ± 86 nm. (Table 1) The histogram of the fiber diameter is shown as an inset of figure 5/b indicate a narrow distribution as well and the standard deviation.

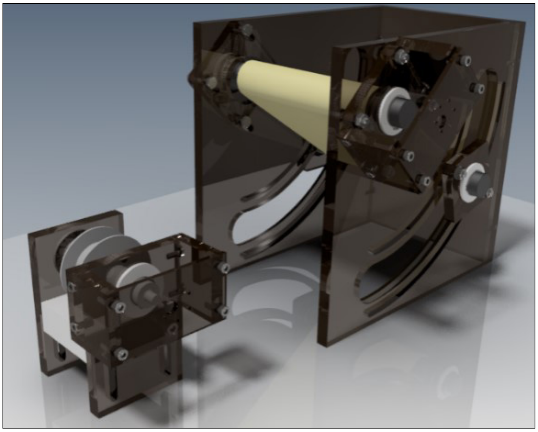

Figure 3. *The 3D model of the designed needleless electrospinning device consisting of a disk spinneret and a conveyer belt collector..*

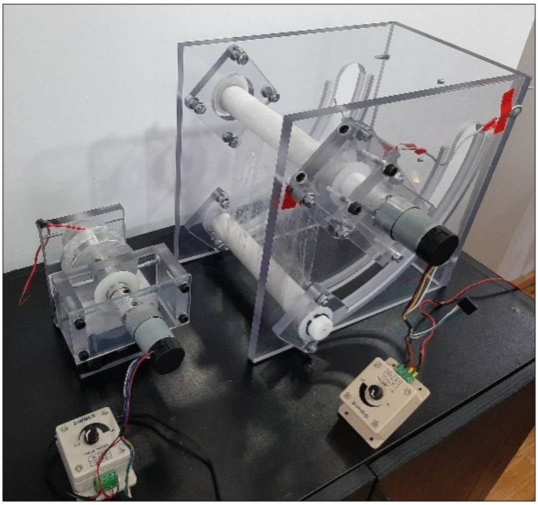

Figure 4. *The manufactured disk electrospinning device.*

Table 1. *PVP fiber average diameter and standard deviation values.*

	One needle method	Disk needleless method
d (nm)	349	446
σ (nm)	86	116

Figure 6 illustrates the SEM images of the PVP fibermats that were prepared by the needleless disk electrospinning device. Figure 6.a shows beads on the fibermats, which are mostly along

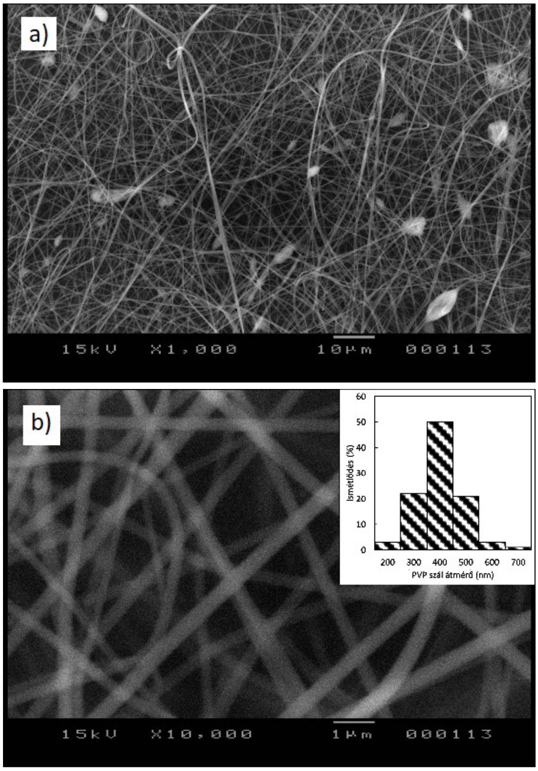

Figure 5. *SEM images of PVP fibermats produced by the one needle setup a) x1000 and b) x10000 magnification.*

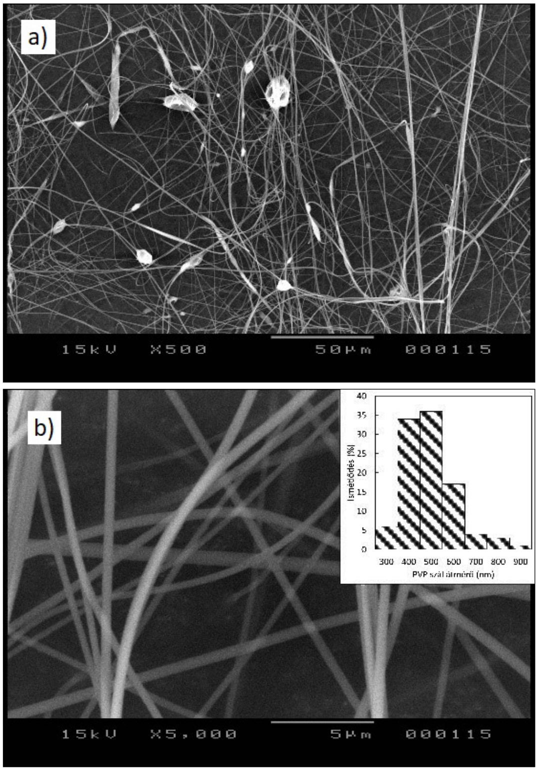

Figure 6. *SEM images of PVP fibermats produced by the disk needleless electrospinning device a) x500 and b) x5000 magnification.*

the fibers. This result is very similar to the results shown in **Figure 5.a** for the one needle method. **Figure 6.b.** shows smooth surfaced PVP fibers at x5000 magnification, similar to the one needle method. The average fiber diameter has been determined to be d = 446±116 nm.

Based on the results we can conclude that the fibermat morphology and the fiber surface characteristics are similar in both the one needle and the needleless disk electrospinning processes. The fiber diameters increased on average by 100 nm in the case of the disk electrospinning compared to the one needle electrospinning under the examined experimental conditions. In both electrospinning methods the standard deviation is approximately 25 % of the mean fiber diameter.

3. Conclusions

In conclusion, we have designed and manufactured a budget friendly, flexibly adjustable needleless disk electrospinning device that requires simple maintenance. We have produced PVP fibermats that were benchmarked to fibermats produced by the one needle method. The results show that both the morphology and fiber surface characteristics are similar, whereas the average fiber diameter increases by 100 nm, when fibers were produced with the disk electrospinning setup in comparison to the one needle method. In both cases the standard deviation of the fiber diameters was ~25 %.

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