DESIGN OF ELECTRODE FOR COAXIAL ELECTROSPINNING

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Abstract

The paper deals with the design of a new effective electrode for coaxial electrospinnig process. This concept is based on a circular symmetric design enabling formation of a double polymeric layer. The layer is created by overflowing of one solution over the other. Subsequently, the double layer is exposed to critical voltage in the DC electrospinning process to create core/ shell nanofibers. The electrode geometry has been designed using the FEM analysis of the electrical field. As a result, appropriate distribution of the electric field on the electrode surface has been found. The manufactured electrodes have been verified experimentally. The results of both the analysis and experiment have proved, the design meets requirements for an appropriate location of Taylors cones on the polymeric surface and thus increases potential for production of coaxial nanofibers.

Keywords: Weir spinner, electrospinning, coaxial, electrostatic analysis

1. INTRODUCTION

There are many ways of nanofibers production [1] and the electrospinning is one of significant methods. This technique is applicable for many types of materials, therefore it is widely used and very popular in different industrial fields, e.g., textile, medicine, machinery [2]. The electrospinning is based on application of a high voltage electrical field that elicit electric forces to produce fibers with a range of diameters from about 200 - 400 nm. Parameters of nanofibers vary with applied voltage and the type of electrospinning technology. Based on the electric current type, the DC electrospinning and AC electrospinning can by distinguished. The standard setting for DC electrospinning requires a positively charged electrode and a negatively charged collector. If the electrospinning technology is based on the usage of AC voltage, the voltage is applied to the electrode only. This method has been already tested for coaxial spinning electrodes [3]. For both DC and AC methods a variety of electrodes can be used, based on the required type of nanofibers produced or on the productivity of the device [4]. In case of coaxial electrospinning a special type of spinning electrodes are needed. The geometry of electrode has to enable creation of two separate layers of polymeric solution [5]. The layers consist of two different polymers, where each of them has a dissimilar function in the final structure of core- shell nanofibers during the electrospinning process.

At the very beginning of the core-shell nanofibers development a needle coaxial spinning electrode (**Figure 1a)** was invented [6]. This equipment has been primarily intended to produce nanofibers for laboratory use due to its low productivity and arduous controlling during the process. The first attempt to invent more sophisticated device (**Figure 1b**), which is based on the use of needless technology, was at Technical university of Liberec in 2009 [7] under the name „Weir spinner“. The next form of the needless electrode called „Cylindrical coaxial spinning electrode“ (**Figure 1c**) [8] originates from this type and it was developed in 2013. The basic principle of the described electrodes (**Figure 1**) is, that the polymer storage bath consisted of the inner and outer chambers, which contained different polymer solutions. As a result of larger layers of polymers, both of these types are more productive in the comparison to the needle coaxial electrode. However, these electrodes are sensitive to manufacturing disproportions and adjustment of electrode positions.

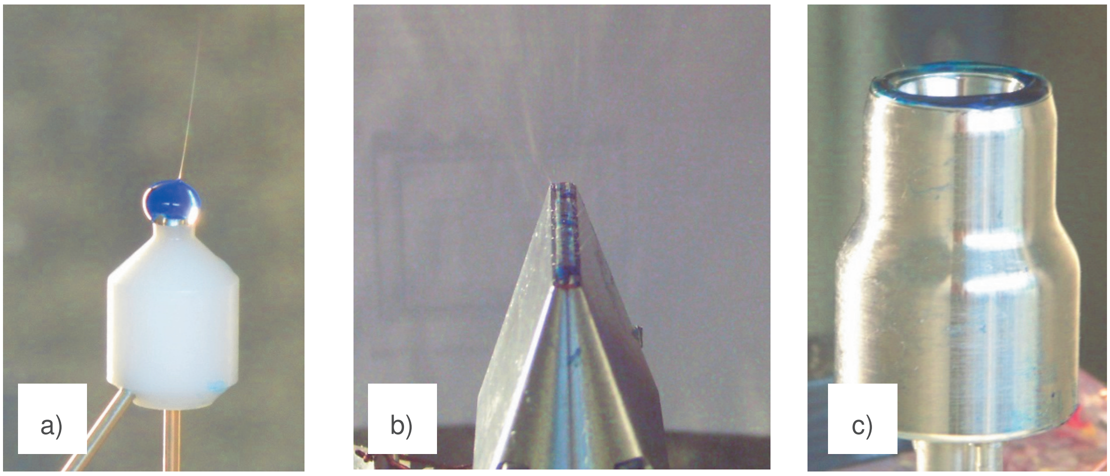


Figure 1 Types of coaxial electrodes

2. ELECTRODE DESIGN

In order to eliminate the above mentioned disadvantages a new electrode for core- shell nanofibers has been invented. The design of the electrode is also based on the overflowing effect. However, polymeric solutions are transported from the center in the radial direction towards to the electrode orifice. It enables to increase the electrospinning area and thus increase the productivity. The electrode design has been formed on the basis of findings from previous studies [8], and it is named the T-electrode. An appropriate and stable liquid surface formation is the fundamental requirement for bi-component nanofibrous layers of the core-shell type, see the T-electrode, **Figure 2-left**. In **Figure 2-right** there is the detailed view of the electrode head with the shell layer (1) overflowing over the solution of the core layer (2). In the initial concept of the electrode occurred technological problems due to manufacturing inaccuracies and improper shape of the upper disk (3). It produced hydraulic resistance that prevented the creation of a suitable shape of the shell layer. Consequently, it caused undesirable mixing of solutions, non-uniformity in dosage, where some spots were insufficiently supplied by solution and another were overdosed.

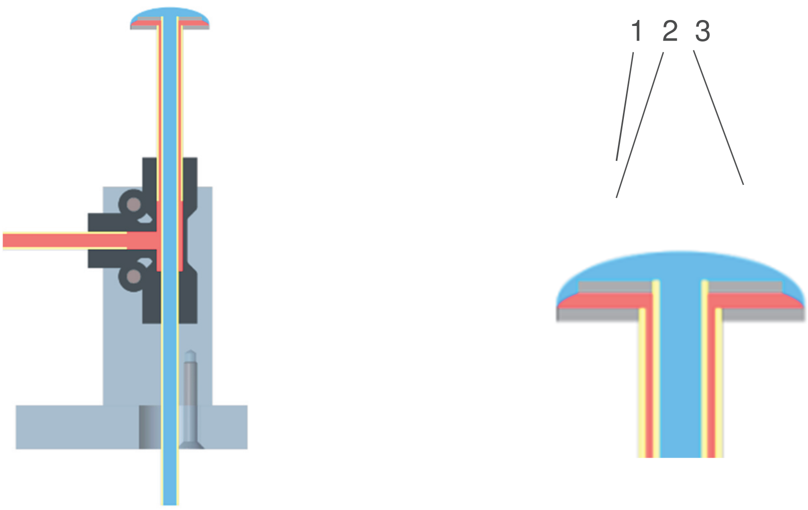


Figure 2 The basic design of coaxial electrodes

Figure 3 shows the development of T-electrode spinning heads. Case a) shows the original design, wherein the mutually parallel disks have a constant thickness. There had been a problem with the process stability and with the location of the maximum electric field, therefore, the T-electrode was modified. On the base of simulations, there was the appropriate bevel created on the upper disk. This modification ensures the desired position of the maximum electrical field and moreover smooth forming of a bi-component layer.

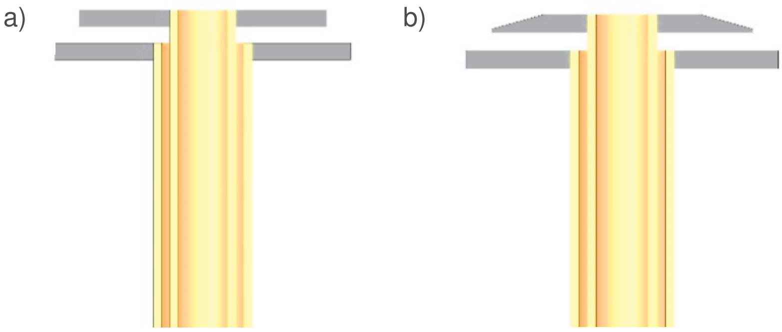


Figure 3 Types of coaxial electrode heads

3. SIMULATION

The aim of the simulation was to determine the intensity distribution of the electric field on the liquid surface (polymer solution) depending on the geometry of the electrode head. The Taylor cones, from which nanofiber jets evolve, are presumed to form in the location with the highest intensity. The geometry of polymeric layer used in simulations is derived from the previous experiments. The exact shape has been created according to the images from electrospinning process. For all presented simulation results the same polymeric layer geometry was used.

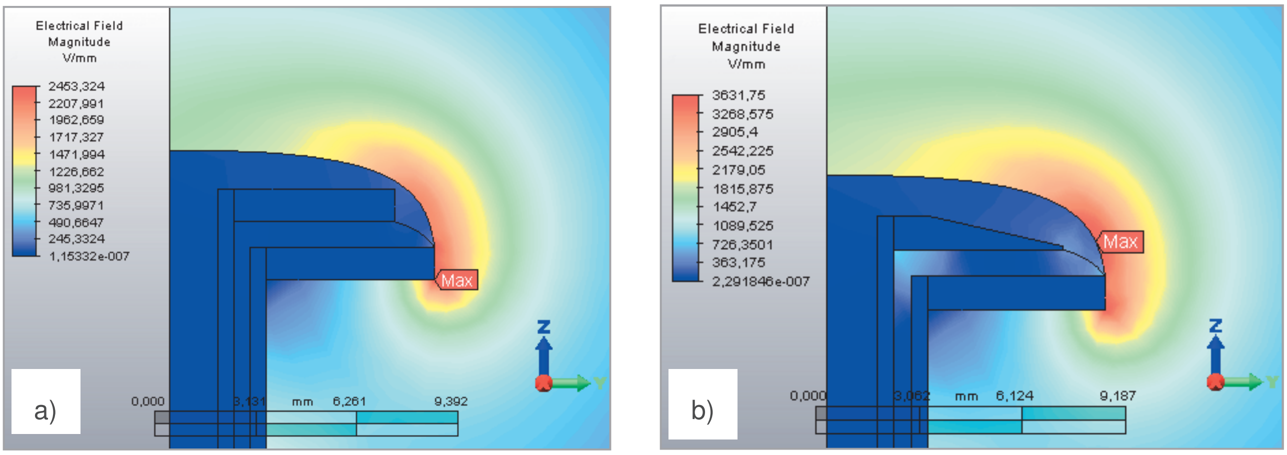


Figure 4 Simulation results

Figure 4a shows a simulation of the intensity distribution of the electric field of the original design T-electrode (**Figure 3a**). This simulation indicates an inappropriate location of the highest intensity on the bottom edge of the T-electrode. The bottom edge of the electrode is not suitable for spinning, for several reasons. One reason is non-uniform liquid layer formation on the edge of the electrode. Another reason is that this location is undesirable for mixing polymeric solutions. Therefore, it is necessary to move the maximum intensity into the area, where the shell solution is located above the core solution. This requirement is needed to ensure suitable conditions for forming core-shell bi-component fibers.

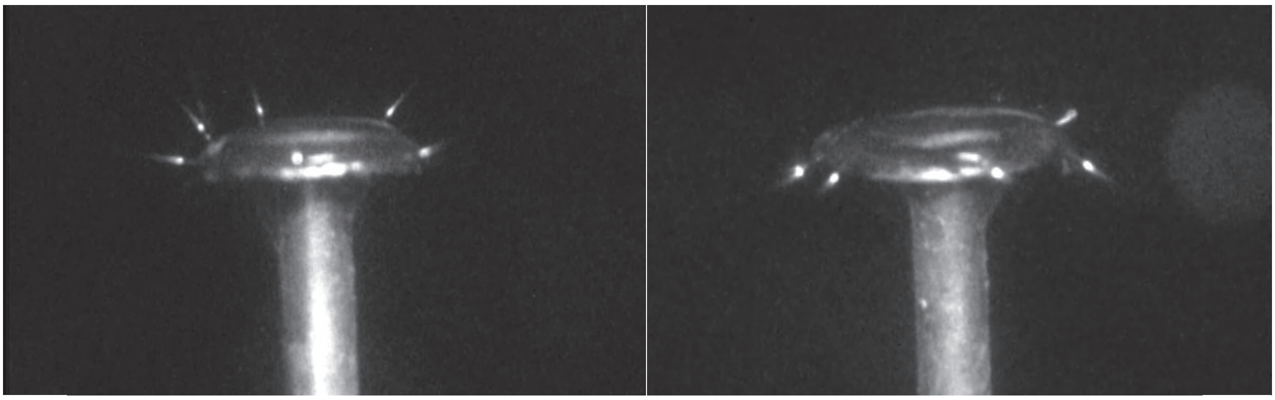
Figure 4b depicts the simulation results of the electric field intensity distribution of the T-electrode modified design (**Figure 3b**). Due to the shape modification of the upper disk it was achieved relocation of the maximum electrical field to the appropriate place of the polymeric double layer, where arise of Taylor cones is required. This adjustment should provide smooth implementation of bi-component fibers production and higher efficiency. As illustrated, a high intensity of electrical field at the lower edge of the lower disk remains, it but no longer has the maximum value, as in the previous case.

4. EXPERIMENT

The original electrodes and also the modified one were tested. For the experiment polymer solution 12wt% polyvinyl alcohol (PVA) as the polymeric shell was used. The core material was 4wt% PVA. In both cases, the distilled water solvent was used. Core material was doped with the Prussian blue pigment $Fe_7(CN)_{18}$. Dosing of polymer solutions was ensured by peristaltic pumps. The feeding rate of the core material was set at 1.5 ml/h. The core material was delivered at 0.2 ml/h. Recorded laboratory conditions where temperature 24 °C and humidity 29%. T-electrode was charged positively to 27 kV. Voltage of -15 kV was applied to the collector. For the process visualization UV CoroCam, Uvirco, South Africa was used. The first tested electrode was the type with the 18 mm lower disk diameter and the upper one 15 mm (see **Figure 3a**).

The gap between the disks was 0.8 mm. During testing of the original electrode it was found that due to improper geometry the core material had tendency to mix with the shell material. The electrospinning process is not stable and occurs dripping of polymer solutions and spinning mainly from the lower edge of the T-electrodes, see **Figure 5a**.

The modified electrode (see **Figure 3b**) was tested under the same process conditions as the previous one. The lower disk diameter, with the optimized shape, was 17 mm. The upper disk diameter was 16 mm. The gap between the disks was the same as in the previous case (0.8 mm). Due to the changes in the geometry, the desired location of maximum electric field was ensured and moreover improved overflowing was achieved. Taylor cones recorded by UV CoroCam were observed in the location where suitable overflowing of the shell over the core occurs, see **Figure 5b**.



a) b)

Figure 5 Experiment results

Moreover, in these tests it was found that it is possible to observe an appropriate area of the T-electrode, without significantly affecting the spinning process. In **Figure 6a** the situation of T-electrode prior to exposure to the electric field is given. The **Figure 6b** depicts the same situation when exposed to the electric field, where it is already possible to observe Taylor cones. Both figures were acquired by the microscope camera- DigiMicro Mobile, Dnt, Germany.

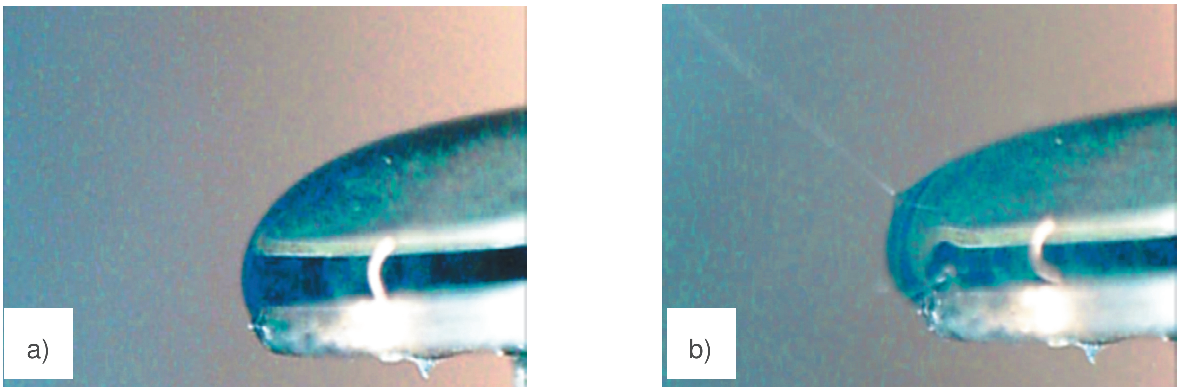


Figure 6 Liquid layer

5. CONCLUSION

The both types of coaxial electrodes for DC electrospinning have been successfully analyzed and tested. As a result of T-electrode modification, reducing of the influence of the hydraulic resistance was achieved. Consequently the polymer supply was stabilized to provide a suitable shape of the layers for spinning. Due to the new geometry of the upper disk, the maximum intensity of electrical field was relocated to the required area.

In the experiment, there were compared two different T-electrodes (see **Figure 2a, 2b**). The Records from the UV CoroCam proved the simulations results and helped to identify the occurrence of Taylor cones on the electrodes. With regard to the spinning technology, it is obvious from the result that the modified T-electrode is more suitable for the process. Moreover, a significant contribution also lies in an easier electrode setting and stability of the technological process. Ongoing tests of coaxiality are going to determine the ratio of coaxial/ non-coaxial fibers in a structure.

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