ELECTROSPUN NANOFIBERS FOR TEXTILE APPLICATION ¬– A FINITE ELEMENT STUDY

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ABSTRACT

Electrospinning is a very popular technology nowadays for the production of different nanofiber structures. Instead of mechanical forces, electrostatic ones are applied for drawing the fibers. The low viscosity of the polymer solution and the high electric field strength makes available to produce fibers with a diameter typically between 50-500 nm. There are many other factors that affect the fiber formation, such as ambient conditions, electrode configuration including the distance of the electrodes, the surface tension and the electric conductivity of the liquid, etc.

There are many studies which try to give a theory for the correlation of the different parameters and the fiber morphology, but these are rather special experimental results than universal laws. There are fewer studies in the literature on the effect of the electric field distribution and other setup-related parameters. Because of the many stochastic parameters, electrospinning technique is still based on "trial and error" approach.

A novel method making possible a high throughput nanofiber production was invented and patented. Our aim is to investigate the deposition of nanofibers and also try to determine the areal distribution in case of the new technique. Finite element analysis gives a hand to study the electric field distribution for different electrospinning configurations and electrode geometries. Moreover it makes possible to analyze the local electric field strength hence the efficiency of fiber production can also be studied.

1. INTRODUCTION

Electrospinning has gained a high interest in the last two decades as this technique offers a simple method for producing polymer nanofibers. By adjusting the material and processing parameters a wide range of fiber diameters can be achieved typically between a few tenths of nanometers and a few microns.

The typical electrospinnig configuration works with a simple spinneret: a small metal capillary. It is connected to a high voltage power supply. The material, destined to be spun, is usually a polymer solution and is continuously fed through the capillary. When starting the process the solution forms a small droplet at the tip of the capillary. After switching the power supply on, the charges are flowing onto the surface of the (conductive) droplet. As there is a high charge concentration at the surface, the droplet is deformed to a conical shape also known as Taylor-cone. After reaching a specific limit a thin jet is emerged from the tip. The evolved jet travels to another electrode, so-called collector that is grounded. For more detailed descriptions the reader is referred to further literature [1-4].

As the solvent is continuously evaporating the jet solidifies and nanofibers can be obtained. The possible application fields are widening, including pharmaceutical, filtration, sensor, solar energy, and composite applications [5, 6]. Nowadays, these products have begun to be realized in real commercial applications.

This single capillary method has several disadvantages that hinder the industrialization efforts. Using multiple capillaries might be a feasible way, but clogging and holding the same flow and pressure conditions can be a crucial issue. Moreover cleaning of the small capillaries can cause some inconvenience for the user. There are novel methods that make possible the nanofiber formation by using free liquid surface and special electrodes [7-9]. In such case the solvent evaporates from the free surface that can also cause problems.

A novel electrospinning method that avoids the application of capillaries was developed and patented [10].The new method is called *corona-electrospinning* as the configuration shape looks similar to an ancient crown. The first paper of the method was freshly peer-reviewed in European Polymer Journal [11].

In our joint project with ESITH, Morocco, our aim is to functionalize textiles with nanofibers and/or microcapsules. These microcapsules contain phase change material that makes possible to regulate the body temperature when there is a sudden change in ambient temperature. These textiles could be mainly used as protective or sports clothing. The microcapsules are embedded into or grafted onto the surface of nanofibers. The combination of nanofibers and microcapsules are applied as a surface coating of knitted textiles, therefore it is necessary for us to make nanofiber layers in effective (productive) ways having a homogeneous thickness. Proper homogeneity and high productivity is therefore in our focus.

In this study our aim was to demonstrate the main features of the new method and also how it works. The high throughput – compared to single capillary system – was realized and formerly pointed out. Besides the earlier morphology studies it is also interesting how the fibers are deposed on the surface of the collector screen. For investigating the deposition characteristics of the fibers and the efficiency of the system finite element analysis (FEA) was applied. The electric field distributions were determined and conclusions were made.

2. EXPERIMENTAL PROCEDURES

2.1 The *corona-electrospinning* method

In the spinneret the polymeric solution is continuously fed through a narrow, but long gutter bounded by a metal electrode having sharp edge, instead of using a capillary. This special electrode is connected to high voltage and many self-assembled Taylor-cones are formed along this sharp edge. The spinneret itself is rotating that helps the homogeneous distribution of the forming cones and jets along the circular gutter. The generated nanofibers can be collected on a grounded collector screen or on a textile substrate placed right in front of it. The process works without open liquid surface and the solution flows continuously eliminating the problems of other needleless methods. The designed rotating spinneret prototype is a simple construction, easy to clean and maintain and furthermore the technology can easily be industrialized. With the first, small size prototype we could reach a productivity of 200 ml/h in specific cases [12].

The concept of *corona*-electrospinning can be seen in Figure 1a. In the upper part the solution is distributed along the thin gutter (between parts 2 and 5). The metal electrode which is usually cylindrical (other shapes can also work) have a sharp edge for creating charge concentration. In the engineering implementation of this concept, the solution is fed through a hollow shaft (by using syringe pump) having appropriate roller bearings and sealing to avoid the leakage. The design of one of the first prototypes can be seen in Figure 1b.

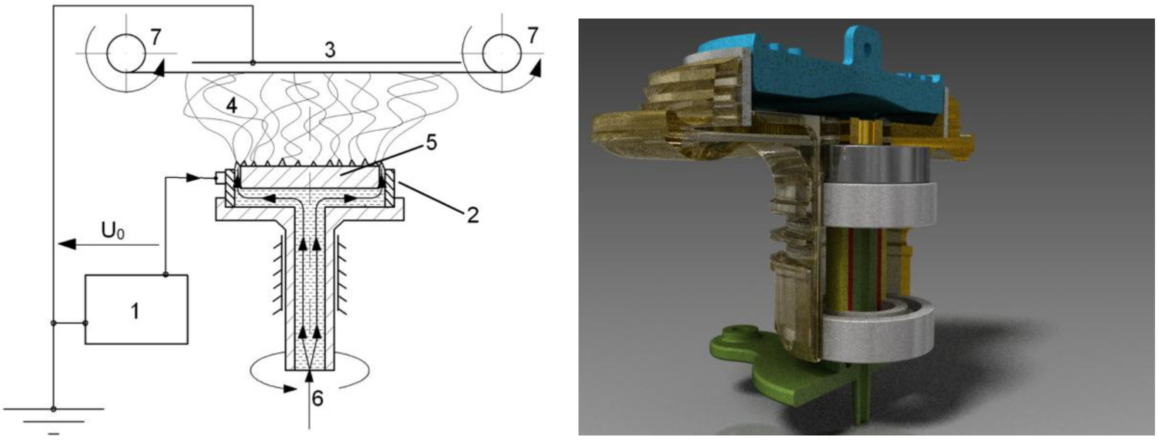


Figure 1: *Corona*-electrospinning setup. a) Schematic figure of the *corona*-electrospinning setup. 1: high voltage power supply, 2: circular electrode having sharp edge, 3: grounded collector screen, 4: fiber formation space, 5: lid, 6: solution feed, 7: traction of the collector textile […] b) design concept of the spinneret

The fiber morphology is quite similar to that of the single capillary method. Figure 2 shows a SEM image of the formerly produced polyacylonitrile (PAN) nanofibers. In this former study for electrospinning a high voltage of 45 kV, a spinneret – collector distance of 120 mm was used. Nanofibers having a diameter of 350 nm in average were obtained.

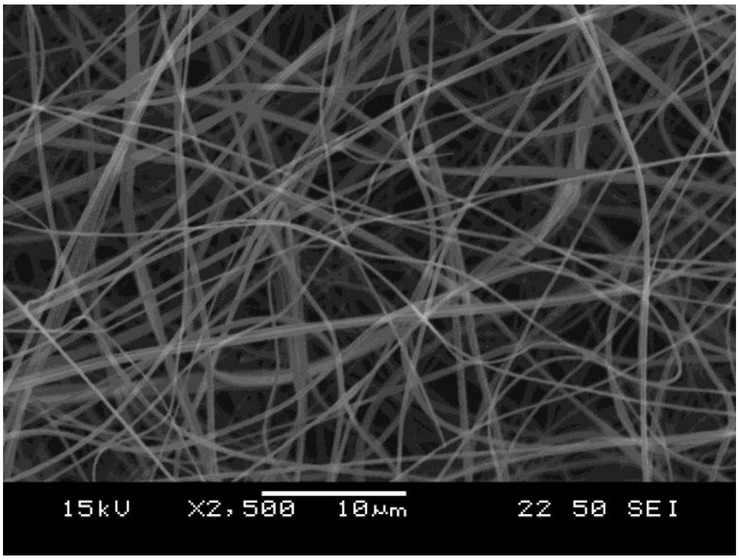


Figure 2: Nanofibers electrospun form polyacrylonitrile by corona-electrospinning

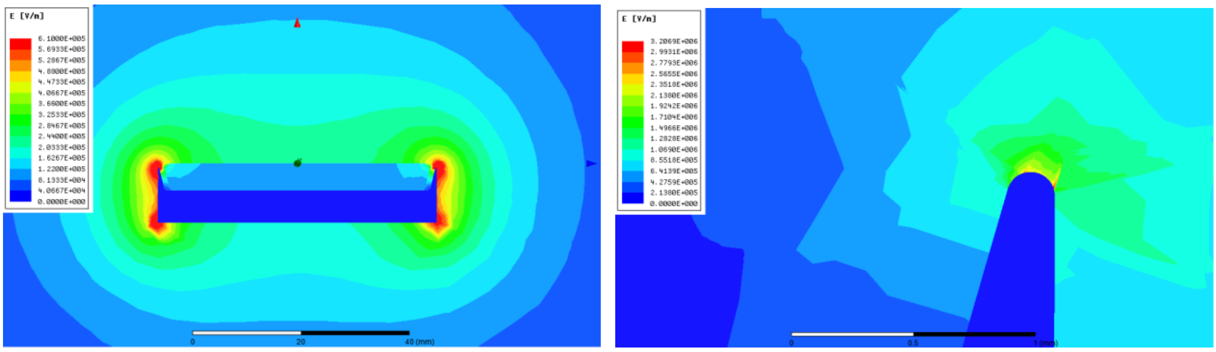
2.2 Finite Element Analysis

For determining the field strength intensity of the process finite element analysis (FEA) was applied. Different electrode configurations were designed and modeled. The charge concentration of the edge was simulated by applying high voltage on the spinneret and grounding on the plate collector electrode. The field strength distribution was also investigated for different electrode geometries. For the FEA simulations Ansys Maxwell software was used and conclusions were made.

3. RESULTS AND DISCUSSION

The finite element results of the first model can be seen in Figure 3 representing the total electric field strength distribution when the spinneret is under high voltage. Note that only the top part of the spinneret is modeled and a parallel grounded plate electrode was applied at a distance of 100 mm. The results are focusing on the spinneret part and therefore the upper part (horizontal collector electrode) was cut from the top of the image for better visibility. For modeling the main material was set to aluminum while the lid (inner part) was set to an insulating polymer material (PE).

The remarkable inhomogeneity of the electric field distribution, which is a nature of all electrospinning method, can be an advantage. It can be seen that a charge concentration appears exactly at the edge where Taylor-cones and fibers are destined to be spun. It makes this method efficient as there is a high charge concentration that facilitates fiber formation. On the other hand it can lead to further issues as fiber deposition on the collector electrode is not homogeneous.



a) b)

Figure 3: The electric field distribution of corona-electrospinning’s spinneret. a) whole spinneret, b) magnified view of the edge

During the real tests it turned out that the forming fibers are diverging because of the repulsion between them caused by the same positive charges (Coulomb-repulsion) that cannot be neglected. When applying the textile substrate with continuous traction speed for collecting the fibers it was found that the forming stipe of nanofibers had a width of approximately 300 mm. In the middle part there were less fibers deposed while at the edges there were a thicker layer. It can be a problem when coating different textile substrates. The FEA made possible to model different electrode shapes. For studying this, the angle of the electrode edge was changed and the results were evaluated (Figure 4.)

It can be seen in the image that the electric field can be controlled by the shape of the electrode part itself. This feature can be useful for controlling the fiber deposition. It is assumed that the fibers began to travel in the direction perpendicular to the equipotential lines. Based on these results it seems to be favorable to construct the geometry of the last figure causing more converging fibers. In the next step the forming fibers are also planned to be put in the model for gaining more precise extimations.

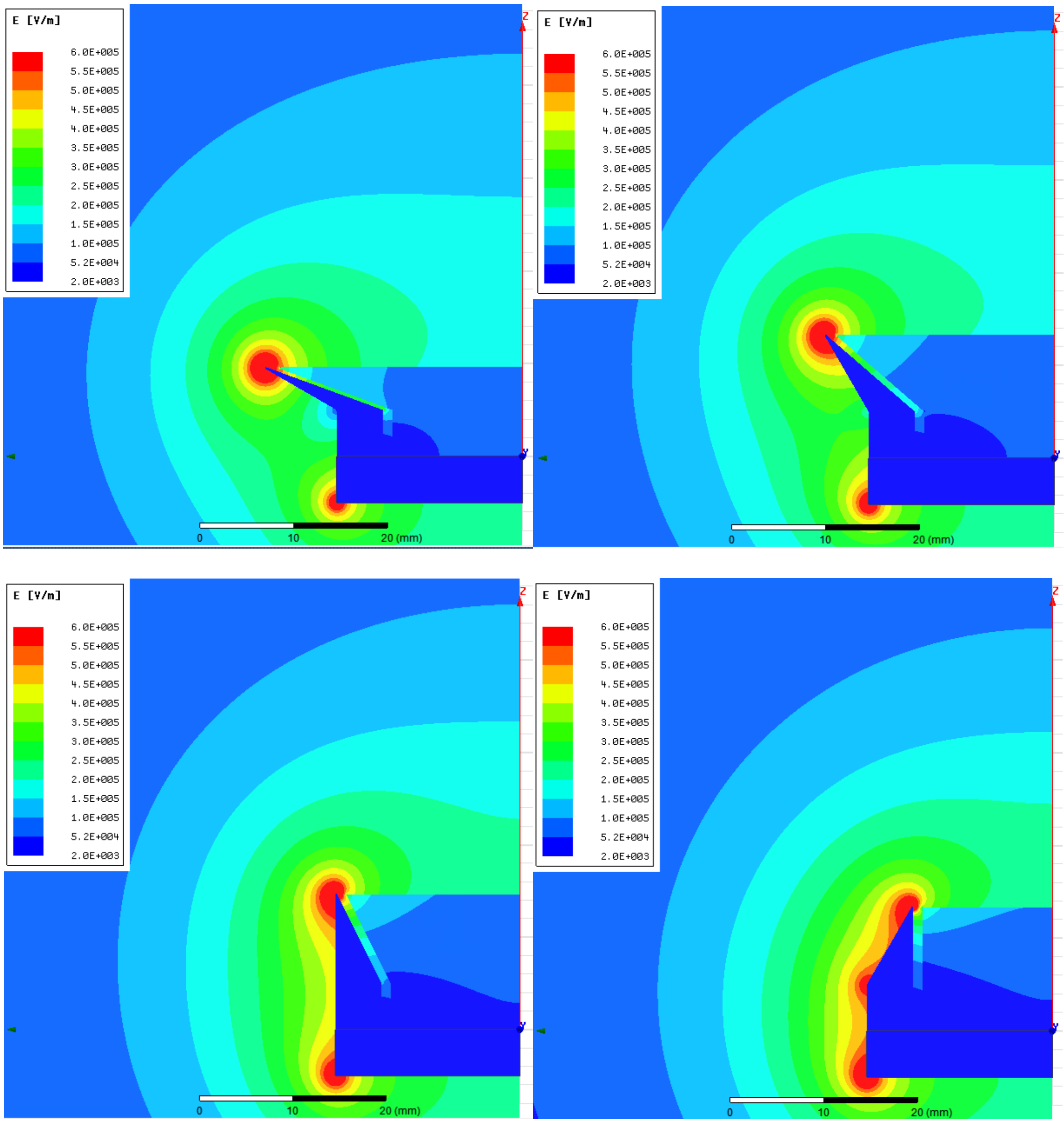


Figure 4: The electric field strength distribution of different geometries

4. CONCLUSIONS

A new electrospinning setup was invented. In this study it was demonstrated that a high charge concentration occurs along the applied sharp edge that facilitates fiber formation. The FEA models reveal that by adjusting the geometry of the spinneret itself the local electric field distribution can be controlled. This gives a hand in reaching better homogeneity of the areal density. Our future aim is to build a new prototype based on these results and to compare the results to former ones.

5. REFERENCES

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