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Analysis And Measurement Of The Charge Intensity Of The Selected Electrospinning Electrodes

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Abstract.
Polymer solutions due to their chemical and physical properties requires for efficient spinning with different intensity of the charge. This corresponds to the geometry of the design of the spinning electrode. The electrode may have geometry in the shape of a smooth cylinder to obtain a less intense charge. Contrary barbed roll or roll with strings produces locally extremely intensive charge. For selected geometry of electrodes FEM models describing the intensity and the potential of the electrostatic field have been established and the results were compared with the experimentally determined results. From a comparison of the results it is evident that on the basis of the FE model can be formed with a certain accuracy to design suitably shaped electrodes to obtain the most efficient process of production of nanofibers.

Introduction

From literature many studies focused on simulation of electrostatic field of different devices are known, less frequently on simulation is focused on electrospinning process. The reason can be found in lower performance of computers in past and also in the small amount of specialized software. Last but not least it is lack of interest about electrospinning process, which is undergoing a renaissance in last years. In [1] the simulation of electrostatic field at needle electrospinning process showed that the arrangement using more needles, concretely five was found suitable. The ANSYS/Emag.-3- software was used for the simulation. The authors introduced an electric field concentration factor (EFCF). This factor is defined as a degree of the convergence and divergence of jets to the spinning axis. Also influence of external electrical field created with cylindrical ring is studied and compared with experiments. Authors concludes that stable jets paths could be obtained independently of the numbers of nozzles in an electrospinning system and modifications can lead to higher efficiency of electrospinning process.In [2] authors describe the possibility of the creation of electrospun layers on fiber collectors with different arrangement and orientation of nanofibers in the layer. The collectors varied in distance between rods. A FEM simulation of electrostatic intensity of these collectors was performed in the Ansoft Maxwell 3D 10.0 software. It was shown, that the results of simulation are corresponding with results obtained experimentally. Also the process of deposition on the collector is explained by the help of simulation – fibers fall down on collector under rotation because of the bending and stretching forces. Authors in [3] describe modeling of electrostatic field in the process of needle electrospining. The software ANSYS was used. In the model the coherent conditions with experiment were applied including electrostatic constants of applied materials. Important result of simulation is the fact that electrostatic field intensity suddenly dropped near the needle orifice. On the basis of this result shielding net was introduced to the process. By its help the shape of the electrostatic filed was improved and process of electrospinning was optimized. Also the formula describing the relation among geometrical proportion of electrostatic machine was defined.

Materials and methods

Theory of the charge intensity

In [4-5] was stated that the general description of the distribution of electric field generated between two complicatedly shaped electrodes in the process of electrospinning is practically impossible, because the geometry affects the magnitude of the electrostatic field. Theory describes that between two oppositely charged electrodes an electric field is created having certain value of electric field intensity. This can be understood as limiting force indirectly proportional to arising charge (1). Electrostatic fields are static (time-invariant) electric fields produced by static (stationary) charge distributions. The mathematical definition of the electrostatic field is derived from Coulomb's law which defines the vector force between two point charges. On the electrode surface single charge or space field of point charges as shown in (Fig. 1) may be formed. This can be mathematically described by equation (2). Thus it is probably true, that small surface approaching the limits (point charge) and its intensity will be higher. In fact it is a similar case, which can be described in structural mechanics as the touching of two bodies generated in the initial stage of their compression [6-7].

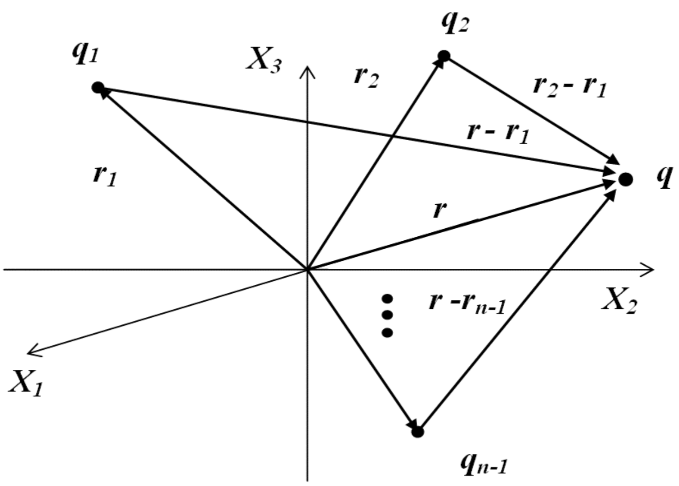

Fig. 1 Theory of the charge intensity

$$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q}, \tag{1}$$

$$\vec{F} = \frac{q \cdot q_1 \cdot (\mathbf{r} - \mathbf{r_1})}{4\pi \cdot \varepsilon_0 \cdot |\mathbf{r} - \mathbf{r_1}|^3} + \frac{q \cdot q_2 \cdot (\mathbf{r} - \mathbf{r_2})}{4\pi \cdot \varepsilon_0 \cdot |\mathbf{r} - \mathbf{r_2}|^3} + \ldots + \frac{q \cdot q_{n-1} \cdot (\mathbf{r} - \mathbf{r_{n-1}})}{4\pi \cdot \varepsilon_0 \cdot |\mathbf{r} - \mathbf{r_{n-1}}|^3} = \frac{q}{4\pi \cdot \varepsilon_0} \sum_{k=1}^{n-1} q_k \frac{(\mathbf{r} - \mathbf{r_k})}{|\mathbf{r} - \mathbf{r_k}|^3}. \tag{2}$$

where $\vec{E}$ expresses the intensity of the electric field, $\vec{F}$ is an acting force, q is point charge, ε_0 expresses the permittivity of vacuum

($\varepsilon_0 = 8{,}854187817 \cdot 10^{-12} F \cdot m^{-1}$), $\mathbf{r}, \mathbf{r}_i$ expresses a vector specifying the position of charge in space.

Analysis and measurement of the charge intensity

Analysis and subsequent measurements were carried out in production lines of Elmarco during the process of electrospinning. Production lines are able to produce nanofibers especially for air filtration. For this type of product the fiber diameter, the pressure drop of the final material and uniformity across and along the product are the most important aspects. During the spinning process the nanofibrous layer of 0.1 grams per square meter is deposited on the substrate material passing through the line by the speed of 10m/min and higher. A critical problem is the applied high voltage that ranges from 60 - 100 kV, because it affects the design of the production line (safe distance for the operator, which is determined by the voltage 5 kV / inch or by geometric arrangement of grounded elements and parts). This affects the potential distribution, resulting maximum intensity of electric field and therefore the efficiency of the production line. For the study of the electrostatic field intensity, used in the production lines for the production of nanofibers were observed and analyzed with two geometrically different electrodes. Tests were carried out with a total potential gradient 60 ± 0.5 kV, current 5mA, moisture 17.5 ± 2% and a temperature of 22.6 ± 2 ° C during 10 min. Compared electrodes are shown in Figure 2.

1) rotating cylindrical electrode, the basic principle Nanospider – spinning is carried out from free surface of the polymer placed on rotating electrode.
2) static electrode (wire), the spinning process carried out by applying a precisely defined quantity of polymer solution to the wire through the applicator head.

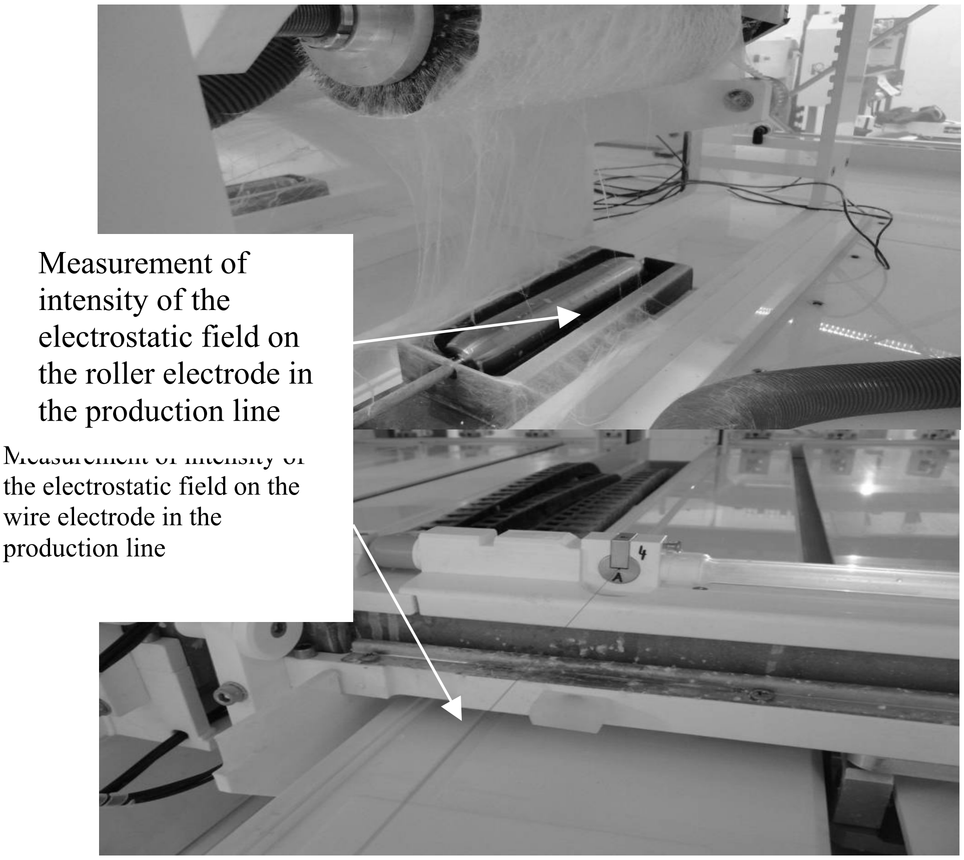

Fig. 2 Measurement and analysis of electrostatic field intensity on select electrodes

The numerical analysis were performed in the COMSOL Multiphysics, which allows the modeling of electric fields, flow in piezomaterials, compression of isotropic and anisotropic materials and other physical phenomenon. This software contains a wide variety of tools for simulation of the various problems, which are described by partial differential equations. Models were assembled with the same parameters as in [4] by the help of this the maximum electrostatic field intensity in dependence on the diameter of the electrode was evaluated.

Results and discussions

Results obtained from the FEM simulations showed that with the decreasing diameter of the electrodes the maximum intensity increases (Fig. 3), which confirms the theory of point charge distribution. According to the simulation the maximum intensity value reached with roller electrode was 320.22 statvolt / cm and 1299.5 statvolt / cm with wire electrodes, as shown in Table 1. The distribution of electrostatic field intensity in the FEM simulation is shown in Figure 4 and 5. In Figure 4 and 5 is also shown a measuring of the electric field using corocamera. Here it is seen that the cylindrical electrode shows a small number of places with arising nanofibers with visible Taylor cone. In the case of wire electrode the density of Taylor cones is substantially higher. Arising nanofibers resembled lightning (electrical discharge). This may confirm the results obtained from the numerical analysis that showed approximately 4 times higher intensity at wire electrodes.

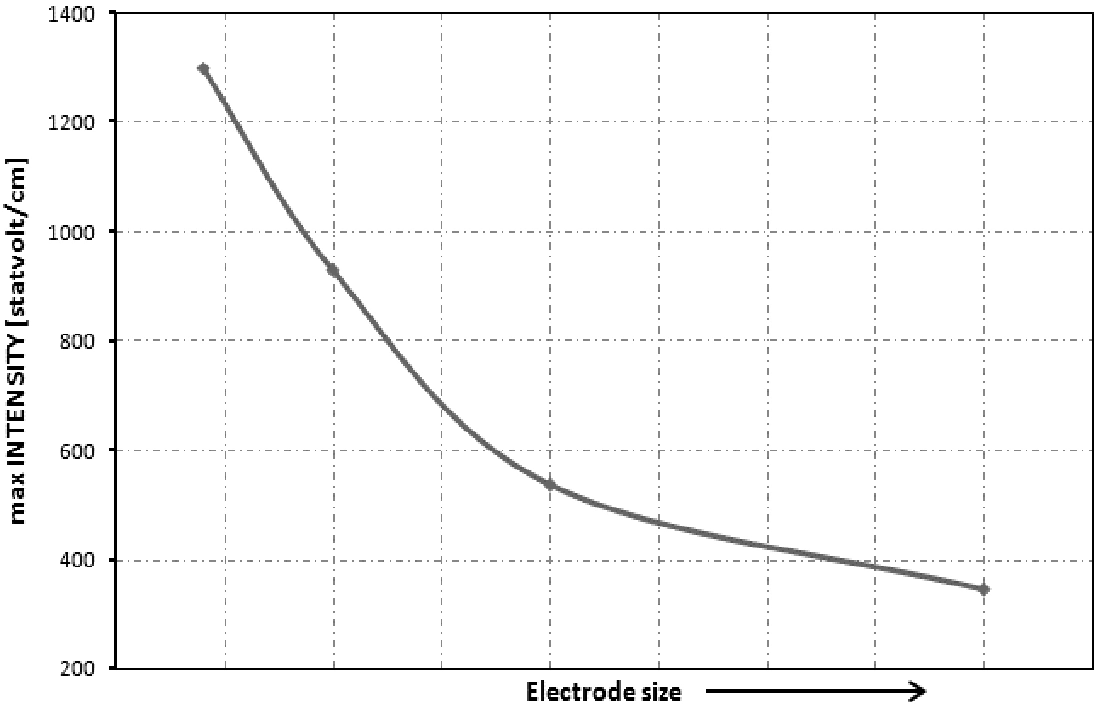

Fig. 3 Measurement and analysis of electrostatic field intensity on select electrodes

Table 1 Results of the maximum intensity of electrostatic field by FEM simulation

Time of process / Potential (10 min) (0/60kV)	FEM model - Maximal intenzity (statvolt/cm) [1)]
Cylindrical electrode	320,22
Wire cylindrical electrode	1299,5

[1)] 1statvolt=299,793 volt

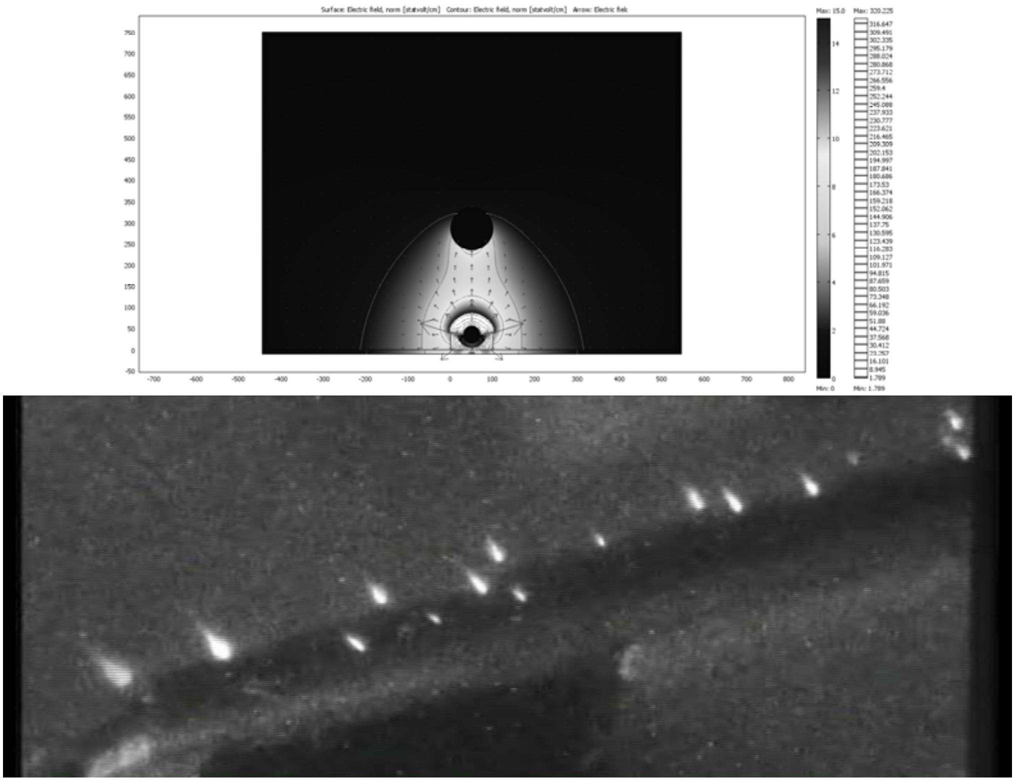

Fig.4 The intensity between two roller electrodes - FEM simulation (top), electric field scanned with the corocamera with the real roller electrode (bottom)

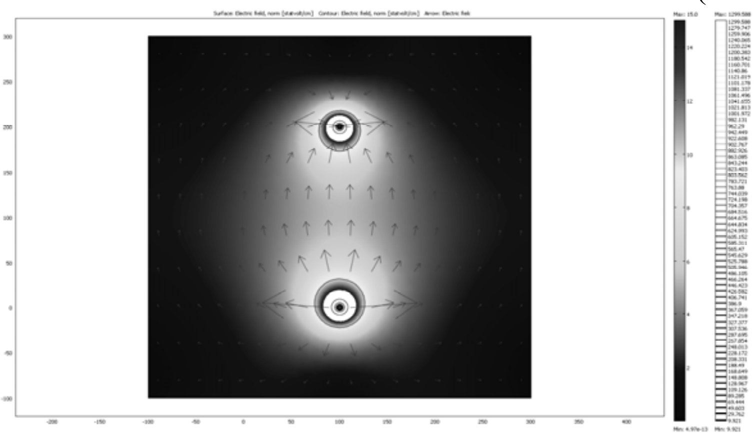

Fig.5 Intensity between two wire electrodes - FEM simulation (top), electric field scanned with the corocamera with the real wire electrode (bottom)

Conclusions

The article dealt with experimental studies and numerical analyzes of the electrostatic field intensity of selected electrodes in the process of electrospinning in production lines Elmarco. Rotating and wire electrode was analyzed and the maximum intensity of wire electrode was 4 times higher compared to rotating electrode. It was determined that with decreasing diameter of the electrode increases the maximum intensity, which confirms the theory of point charge distribution. Furthermore, experimental measurements were performed directly on the production lines by the help of corocamera. From resulting measurement it is evident that wire electrode has a higher intensity of electrostatic field, which is manifested as intense spinning, while the rotating electrode has lower intensity. These results are important for the optimization of electrospinnng process for the purpose of increasing the efficiency of nanofibres production.

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