ELECTRIC WIND PHENOMENA DURING AC COLECTORLESS ELECTROSPINNING

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Abstract

This paper describes the electric wind phenomena occurring during colectorless altering current (AC) electrospinning. It will be shown that this phenomenon is the significant element for electrospinning generated from an alternating voltage power source. AC electrospinning is a highly productive novel method for the creation of various nanofibrous formations with specific properties. The electric wind enables easy manipulation of the nanofibrous mass rising from the electrode (in the form of smoke), which doesn´t require any collector. Investigation of this phenomenon is shown using two different methods. The first one uses a hot-wire anemometer for the collection of air speed data above an spinning electrode. The second one uses video analysis of the high-speed video camera data. Visual record of the working process allows the formulation of an hypothesis explaining mechanism of nanofibrous smoke transport away from the spinning electrode without using any additional source of wind or mechanical drawing. It is seen that, in a 3-4 cm distance from the electrode, coulombic forces are creating and accelerating the mass of the nanofibers. When the nanofibrous smoke exceeds this distance, the fibers are drifting away from the electrode in speeds that are comparable with measured electric wind values. This paper was created with financial support from TA ČR used in project - TA04010237.

Keywords: nanofibers, electric wind, AC electrospinning

1. INTRODUCTION

Electric wind [1, 2, 3] is a physical phenomenon that occurs near metal electrodes in high-voltage electric fields. It can be amplified by reducing the size of the electrode, or by the sharpening of the electrode edges. This means that the electric wind is part of electrospinning process and it can´t be reduced or removed. If we start with a more traditional process, [3] driven with direct current (DC), electric wind can be measured, observed or felt with skin (provided that the process is powerful enough). During this process, it mildly helps with the transport of polymer jets from liquid surface to the collector, but it´s not a necessary element in the process. This type of electrospinning process is primarily driven by Coulombic forces. The charged polymer in the liquid surface, spinning jet, or in the nanofibrous mass is transported towards the grounded or oppositely charged collector. It is possible to spin without the collector (Figure 1 - left) but because the polymeric material is charged with the same polarity (which acts as the repulsive force), the liquid surface is disintegrated in a short period of time and the nanofibrous mass uncontrollably exits the spinning area in all directions.

The situation is different in the case of alternating current (AC) electrospinning [4]. It will be shown that in this process, electric wind works as a major cause for movement of the nanofibrous mass (Figure 2 - right) that can be effectively described as nanofibrous smoke. In comparison with the DC system, AC uses two different polarities. One is positive and other is negative. Charges alternate at certain frequencies, which can be set. In our work, we employed a standard 50 Hz frequency with harmonic behaviour. This wave behaviour enables us to work with the nanofibrous smoke because the electric charge neutralizes itself in a short distance from the liquid surface (3-4 cm).

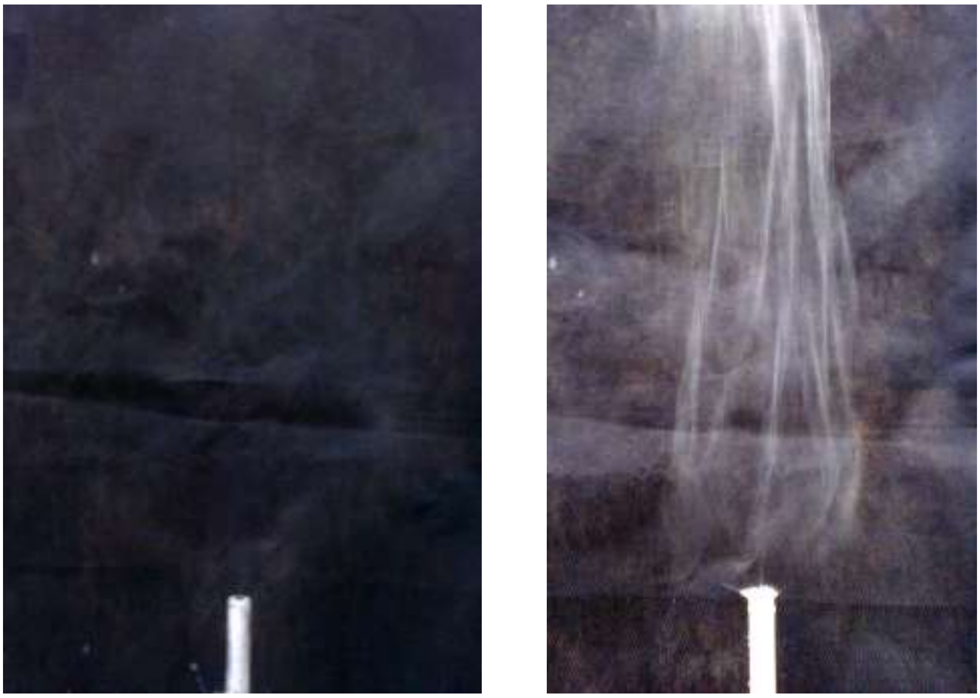

Figure 1 – Picture comparing colectorless DC (left) and AC (right) electrospinning proces

2. APPROACH

In our work, measurement of the electric wind was recorded with a hot-wire anemometer and high-speed camera. The anemometer collected data from different heights above the electrode without actual electrospinning. Measurements were taken in different positions along the x axis. The high-speed camera observed the phenomenon of AC electrospinning from the liquid surface of the cylindrical electrode and the transport of the nanofibrous smoke to a certain distance.

2.1 Materials

During the high-speed camera experiment, polyvinyl butyral (PVB) dissolved in ethanol was used as a polymer system for electrospinning. PVB Mowital® B 60 H was provided by the company Kuraray America with average molecular weight 60.000 amu. A 10% mixture of PVB and ethanol was prepared for the experiment.

2.2 Equipment

Aluminium 4 cm long electrode in rod shape with outer diameter 10 mm and inner diameter 4 mm was used as an electrode for the electrospinning. As a power supply, ABB KGUG 36 high-voltage transformer was applied. The conversion ratio of this transformer was 36000/230V. Accurate dosing of polymer was secured by New Era NE-1000X pump. For measurement of electric wind velocity anemometer Testo 425 was used. For video capturing, Olympus i-SPEED 3 high-speed camera system was applied with light source ILP-1 with discharge lamp of 120 W and F-mount lens connection.

2.3 Software

For video analysis we used Olmypus i-speed software suite. Software version – 3.0.2.9.

3. EXPERIMENT

In our experiment we used two methods of measuring electric wind during AC electrospinning process. The first one used a hot-wire anemometer. The experiment was set as follows. An aluminium electrode with cylindrical shape and a diameter of 10 mm was connected to a high-voltage power source. Voltage was set to the highest possible – 36 000 V in effective value. Above the electrode (**Figure 2** - left) was placed a hot-wire anemometer in distance of 25 cm. From this position we measured 10 different air speed velocities in certain time intervals. From this data, we calculated the average value and standard deviation. Then we measured different velocities in different positions between 25 cm and 70 cm, always increasing by 5 cm. After this measurement, two others were made with a change in X axis position. From this data, we made a 3D graph, which shows airflow speed in third (v) axis. The reason why we did not measure airflow speed closer to the electrode was purely an attempt to not endanger the anemometer.

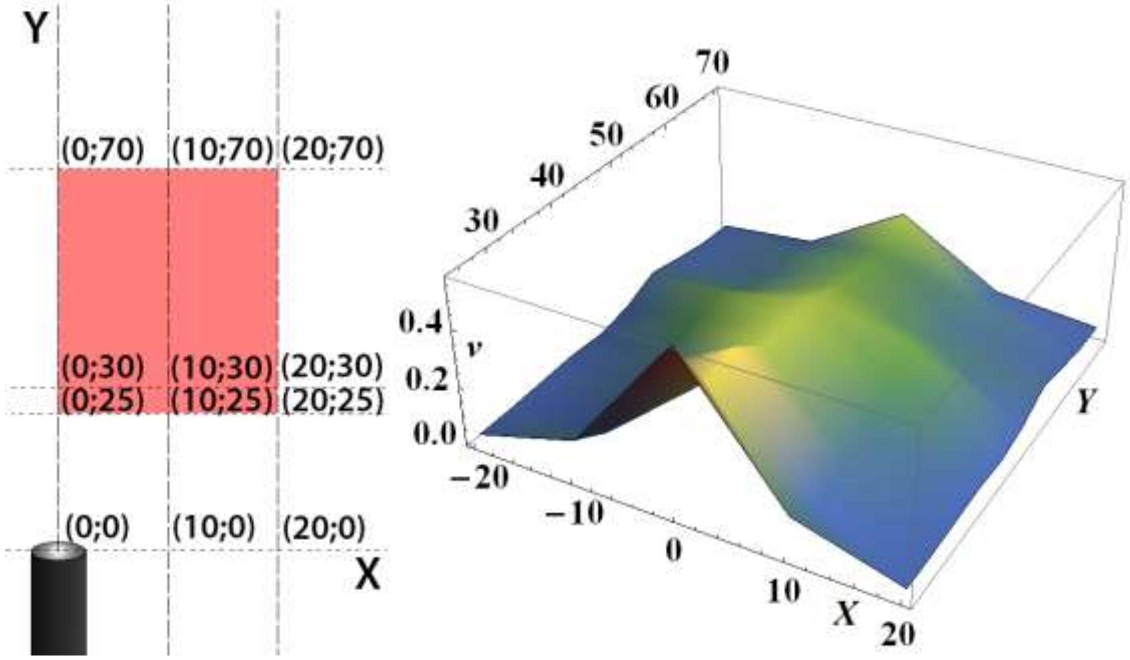

Figure 2 – Anemometer measurements in different positions (left) and resulting air speed velocities (right).

On the picture (Figure 2 - right) we can clearly see that the highest velocity of airflow is at the axis of the electrode. If we observe the other two parallel axis at distances of 10 cm and 20 cm, we can with no doubt see a rapid declination of airflow speed with the exceptions of the 50 cm distance (Y), in the case of the 10 cm distance (X) and the 55 cm distance (Y), in case of the 10 cm distance (Y).

The second method of the air-speed measurement used a high-speed camera. The software i-speed suite allowed us to track some distinct point (usually some defect) in the nanofibrous smoke and then calculate the time and speed of the traveling particle. In picture (**Figure 3** - left) the example of particle trail can be seen. The distance between the liquid surface and the last tracking point is 11 cm. Clearly, it can be seen (**Figure 3** – right), that between the liquid surface and a 3 cm distance, airflow speeds are much greater than between 3 cm and final point. In this region the primary mechanism for driving nanofibrous mass forward are coulombic forces. After this point coulombic forces vanish (or are drastically reduced) and the nanofibrous smoke continues moving forward in a speed which is comparable with speeds measured with the anemometer.

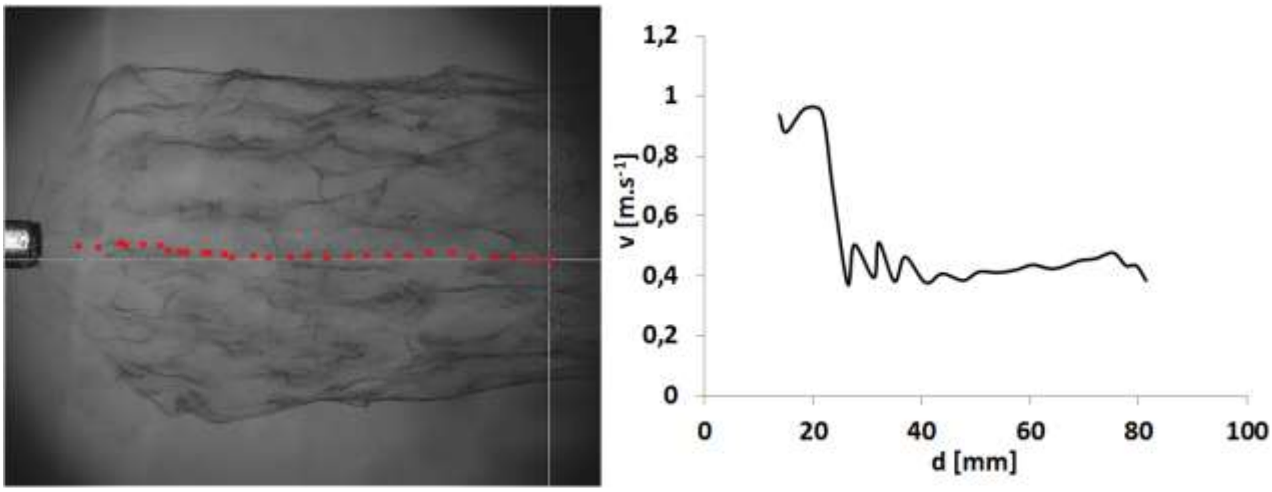

Figure 3 – Electric wind driven particle trajectory (left) with speed function of traced points (right) where *d* describes distance from the liquid surface of the electrode and *v* describes speed of the nanofibrous mass in certain point.

CONCLUSION

Two different methods for air-speed measurements around AC powered electrodes were used in this work. The first one used visual analysis and explored the transport of nanofibrous material between liquid surface on the electrode and 11 cm distance. The second one used a hot-wire anemometer and measured air-speed between a 25 cm and 70 cm distance from the liquid surface. It is seen that there are two different velocities of nanofibrous mass transport, probably caused by two different mechanisms. It is clearly seen that between the liquid surface and a 3 cm distance, the nanofibrous mass is accelerated by coulombic forces and its speed ranges between 20 $m.s^{-1}$ (the speed of material exiting the polymeric jet) and 1 $m.s^{-2}$. This part of process is slowed by the atmosphere around electrode, the mass of polymeric material and the dilution of the charge. After this 3 cm distance, electric wind generated from electrode takes the lead and will transport the nanofibrous mass further away from the electrode. It is seen that the importance of electric wind combined with the neutralisation of electric charge during in the AC spinning process is much greater than in DC spinning, and allows easy manipulation of the nanofibrous smoke.

ACKNOWLEDGEMENTS

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