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Effect of Syringe and Collector Polarity on Electro Spinning of Polyacrylonitrile Nanofibers

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ABSTRACT: In this study, two power supplies having positive or ground and negative or ground electrode output ends were used separately for electro spinning. Contingent on type of power supply and electrode connection, electro spinning led to different fiber diameters and deposition zones. The syringe was associated to a high voltage end while the collector was grounded. Regardless of power supply used, finer fibers with a larger deposition area were obtained compared to that using the same setup but with a converse electrode connection. With an increase in the applied voltage, fiber deposition zone, and efficiency increased for all electrode connections. Grounded nozzles provide much better control over fiber deposition than the reverse electrode connections. Limited element modelling was used to analyze the electric field profile in the electro spinning region. It was exposed that high electric force was mainly located in the part that was charged with a high voltage electrode, which could explain the differences in fiber thickness and deposition area.

KEYWORDS: polyacrylonitrile nanofibers (PAN); polarity; electro spinning; electrode connector; deposition zone; electric force.

I. INTRODUCTION

Collector polarity on electro spinning process has syringe and ground to produce polyacrylonitrile nanofiber by using charges positive and negative. Electro spinning is a technique that produces nano fibers through an electrically charged jet of polymer solution. Electro spinning has shown excellent flexibility to produce continuous fibers of diameter ranging from 2 nm to more than a few micrometers with controlled fiber diameter and morphology from various polymeric materials^[1].

The solvent vaporization from the filament in the meanwhile results in dry or semidry nanofibers, which are deposited randomly on the collector forming a nonwoven nanofiber web. Considerable research has been performed to understand the effects of various parameters such as conductivity, addition of additives, solution concentration, viscosity, surface tension, flow rate, collection distance, molecular weight of polymer and collector geometry, applied voltage on electro spinning process, fiber diameter, and morphology^[3]. However, less attention has been paid toward the influence of

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power supply and electrode connection on fiber diameter, deposition, and productivity. The disordered swing nature of electro spinning makes it difficult to control the fiber deposition. Efforts toward controlling the deposition area have been made recently. It has been found that the areal density of nanofiber mat increased linearly with deposition. Methods have been developed to control the fiber deposition area, for example by placing charged rings in the electro spinning zone ⁽⁴⁾. However, all those works were based on the electro spinning setup with a positively charged high-voltage nozzle and a grounded collector. Little has been reported on using a negatively charge high voltage nozzle for electro spinning.

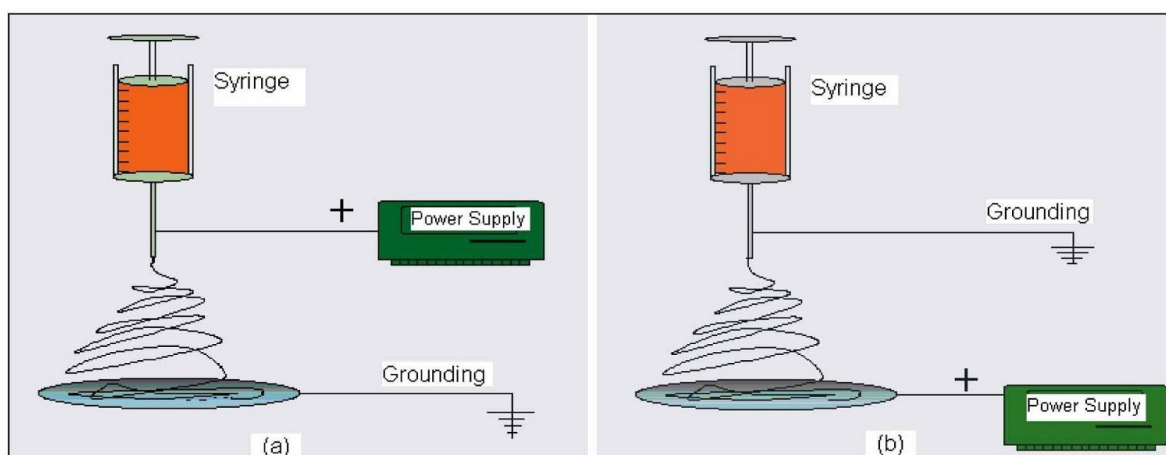


Figure 1: Basic electro spinning setup and electrode connections

II. EXPERIMENTAL AND CHARACTERIZATION

Material and feature of Polyacrylonitrile (PAN, Mw = 150,000) obtained from Aldrich was used as received. The PAN solutions were prepared by dissolving PAN in N,N'-dimethyl- formamide (DMF) at 80°C. Fiber morphologies were observed under a scanning electron microscope (Neo- scope). The fiber diameters were calculated based on the SEM images using image analysis software (Image Pro+ 6.0). At least 100 measurements were taken for each sample. The deposition area of nanofiber webs was also calculated by the same software based on the photographs taken by a high resolution digital camera. Five measurements were taken for each sample and electro spinning was carried out continuously for 1 h for each condition. The electric fields, were calculated by a finite element method using the program. The weight of aluminum foil and electro spun nonwoven mat was determined with an analytical balance.

III. RESULTS AND DISCUSSION

Setup and electrode connections two high-voltage power supplies positive ground (PHV-G) and negative ground (NHV-G) were used separately in this study to examine the effect of power supply and electrode connection on electro spinning and fiber morphology. Physically, the two power supplies have the same equivalent circuit, except the way to connect to the framework ground. For the PHV-G, the high-voltage lead is positive, and the negative end is connected to the framework ground. However, NHV-G has a negative high-voltage output and its positive end is connected to the chassis ground. Figure 1(b)–(e) reveals the electrode connections. By assessment of the power supply NHV-G in the two connection modes produced nanofibers with a deposition area of 629 cm² and 122 cm² for the connection modes NHV-G and G-NHV. Despite the considerable difference in the deposition area, nanofibers were produced at the same production rate of about 0.56 g/h. Based on the weight and the deposition zone, the areal density

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of the nanofiber webs was measured and found to be 0.0864, 0.4991, 0.0894, and 0.4765 mg/cm² for the connection modes PHV-G, G-PHV, NHV-G, and G-NHV

IV. EFFECT OF APPLIED VOLTAGES

Figure 4(a) shows the effect of the applied voltage on the regular fiber diameter obtained from all electrode connection modes. By keeping all other operating parameters the same, increasing the applied voltage led to decreased average fiber diameter. The fibers obtained from the connection modes PHV-G and NHV-G, in which the nozzle was charged with the high-voltage electrode, were finer than those from the reverse connection modes (G-PHV and G-NHV) within the applied voltage range. The type of power supply showed little effect on the fiber diameter.

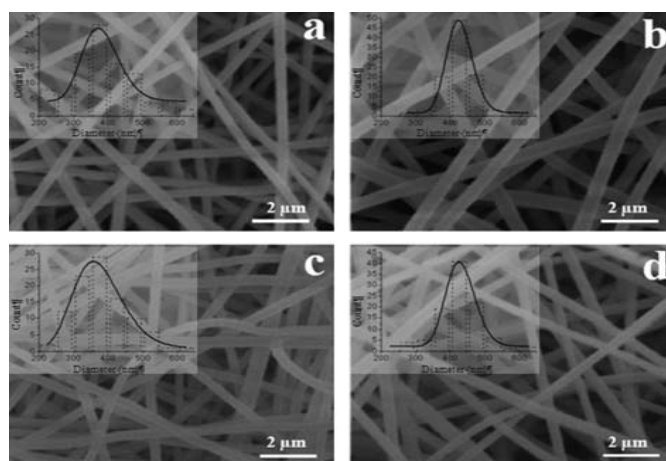


Figure 2. SEM images of nanofibers electro spun from (a) PHV-G, (b) G-PHV, (c) NHV-G and (d) G-NHV electrode connections. (PAN solution = 10 wt%, flow rate= 1.0 ml/h, spinning distance= 15 cm and applied voltage= 16 KV)

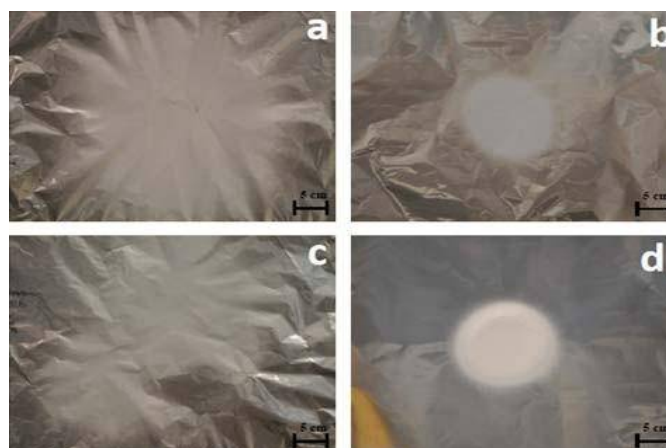


Figure 3, Photographic images of nanofibers electro spun on aluminum foil using different power supplies and electrode connection modes; (a) PHV-G, (b) G-PHV, (c) NHV-G and (d) G-NHV. (PAN solution = 10 wt%, flow rate= 1.0 ml/h, spinning distance= 15 cm and applied voltage= 16 KV)

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V. SPINNING DISTANCE

For the converse connection modes, the electro spinning distance was adjustable over a wider range 5–35 cm. The type of power supply had very little effect on the fiber diameter. Figure 5(b) shows the effect of spinning distance on the deposition area. Increasing the spinning distance from 7 to 30 cm led to increase in the fiber deposition area approximately from 365 to 1325 cm² for the connection with a high- voltage charged nozzle, but for the reverse connection modes, a downward trend was observed, approximately from 150 to 72 cm².

VI. POLYMER CONCENTRATION AND FLOW RATE

Figure 6 shows the effect of polymer concentration and flow rate of the polymer solution being processed on the average fiber diameter. Increasing the polymer concentration and the flow rate both led to increased fiber diameter. For the high-voltage charged nozzles, the range of flow rate could be adjusted between 0.1 and 6.0 ml/h. When the flow rate was lower than the low limit, no fibers were formed, while when the flow rate was higher than the upper limit, the polymer solution started dropping off the nozzle tip. For the grounded nozzles, the flow rate was adjustable in a narrower range between 0.1 and 2.0 ml/h. It was also noted that the polymer concentration and the flow rate did not have obvious effects on the fiber deposition area.

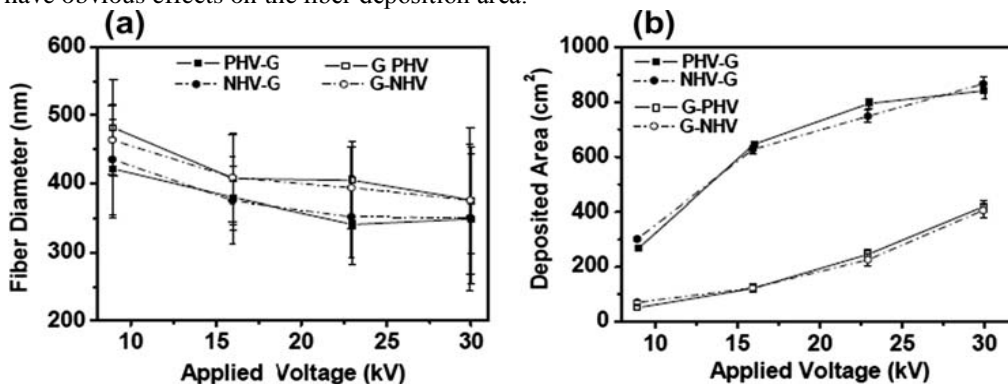


Figure 4. Effects of applied voltage on (a) average fiber diameter and (b) deposition area (PAN concentration = 10 wt%, spinning distance = 15 cm, and flow rate = 1.0 ml/h) modes. Again, the power supply type showed very little influence on the deposition area.

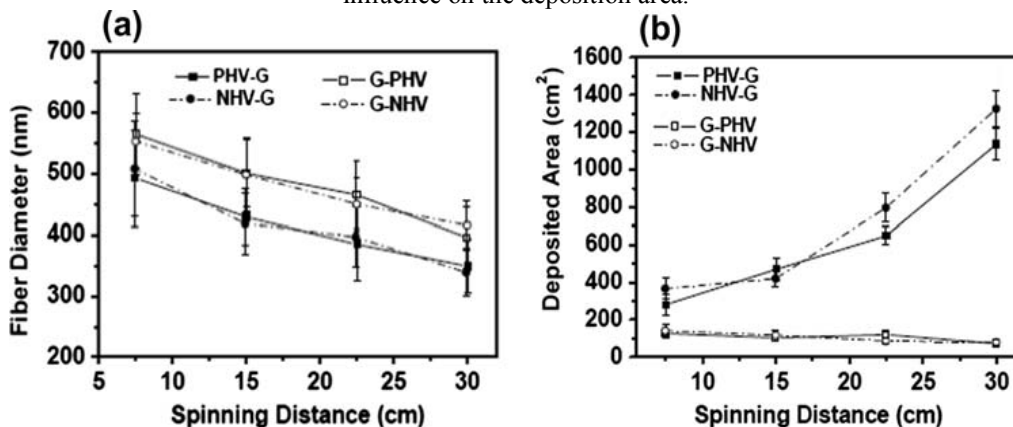


Figure 5. Effect of spinning distance on (a) fiber diameter and (b) nanofiber deposition area (PAN concentration = 10 wt%, applied voltage = 16 kV, and flow rate = 1.0 ml/h).

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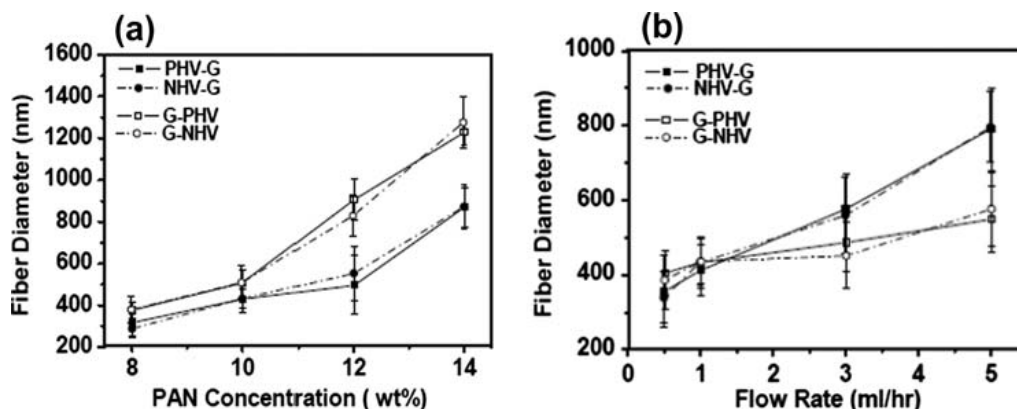


Figure 6. Effects of (a) PAN concentration and (b) flow rate (PAN concentration = 10 wt% on average fiber diameter. (Applied voltage= 16 kv, flow rate = 1.0 ml/h and spinning distance = 15 cm)

VII. PRODUCTIVITY

Figure 7 shows the effect of applied voltage and PAN concentration on the nanofiber productivity. At a low voltage, the setup with a grounded nozzle had a smaller fiber production rate compared to that having a high-voltage charged nozzle (Figure 8(a)). However, when the applied voltage was increased to above 15 kV, the setup with a grounded nozzle had higher productivity, and the productivity reached the highest value at the applied voltage of 23 kV.

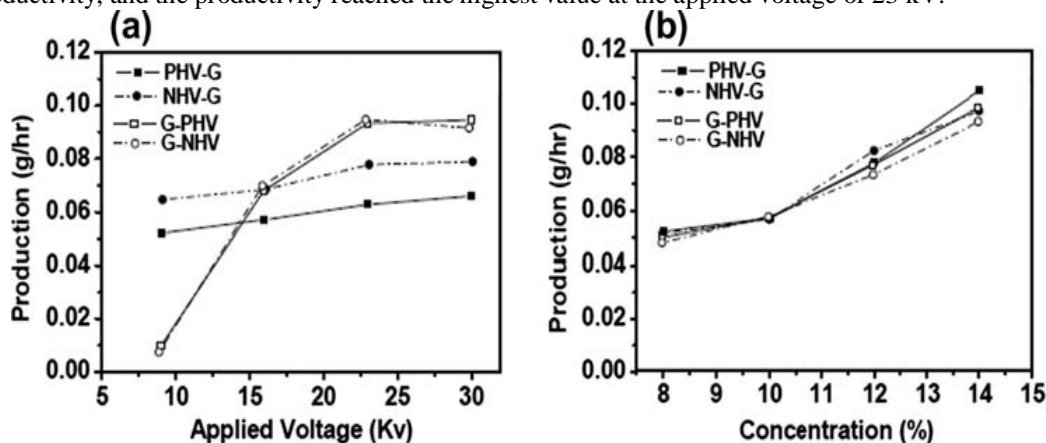


Figure 7. Effects of (a) applied voltage on productivity of nanofibers (PAN concentration = 10 wt%, spinning distance = 15cm and flow rate =1.0 ml/ h) and (b) PAN concentration on productivity of nanofibers. (Flow rate = 1.0 ml/h, spinning distance = 15 cm and applied voltage = 16 kV.)

To validate above experimental results, the electric field profiles around the nozzle surface and in the electro spinning zone (from the nozzle tip to the collector) were calculated by a finite element. Figure 8 shows the electrical intensity profiles of the four connection modes. The high voltage for the electro spinning setups with a high-voltage nozzle was more concentrated on the nozzle area (Figure 8(a) and (b)), while the high voltage for the setup with a grounded nozzle was concentrated around the collector, as shown in Figure 8(c) and (d).

Since the electric field is the main driving force in electro spinning, a polymer solution charged by a higher electric field force can generate jets more easily and the jets are stretched under stronger forces, thus producing finer fibers. It is easy to understand that electro spinning can take place when a high voltage is charged to the nozzle while the collector is grounded.

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For the setup with the reversed connection, the high voltage collector can actually induce the polymer solution, a dielectric fluid, on the grounded nozzle tip to form opposite charges. With the action of the electric field, the charged solution droplet behaves similar to that for the setup with the nozzle being connected directly to the high-voltage end of power supply^[8]. The uneven distribution of electric field intensity in the electro spinning zone could be used to explain the difference in fiber disposition area for the high-voltage charged and the grounded electro spinning setups. When the high-voltage end is connected to the nozzle, the polymer jet receives an intensive electric field action around the nozzle. When the charged jet travels toward the collector, the electric force is reduced due to the much lower electric field intensity. As a result, the jet receives smaller influence from the electric field when it travels toward the collector. The chaotic whipping movement leads to the deposition in a large area on the collector. On the contrary, the jets in the reversed electrode connection interact with the completely different electrical field. The jet receives stronger electric force while approaching the collector, which suppresses its chaotic movement leading to reduced deposition area.

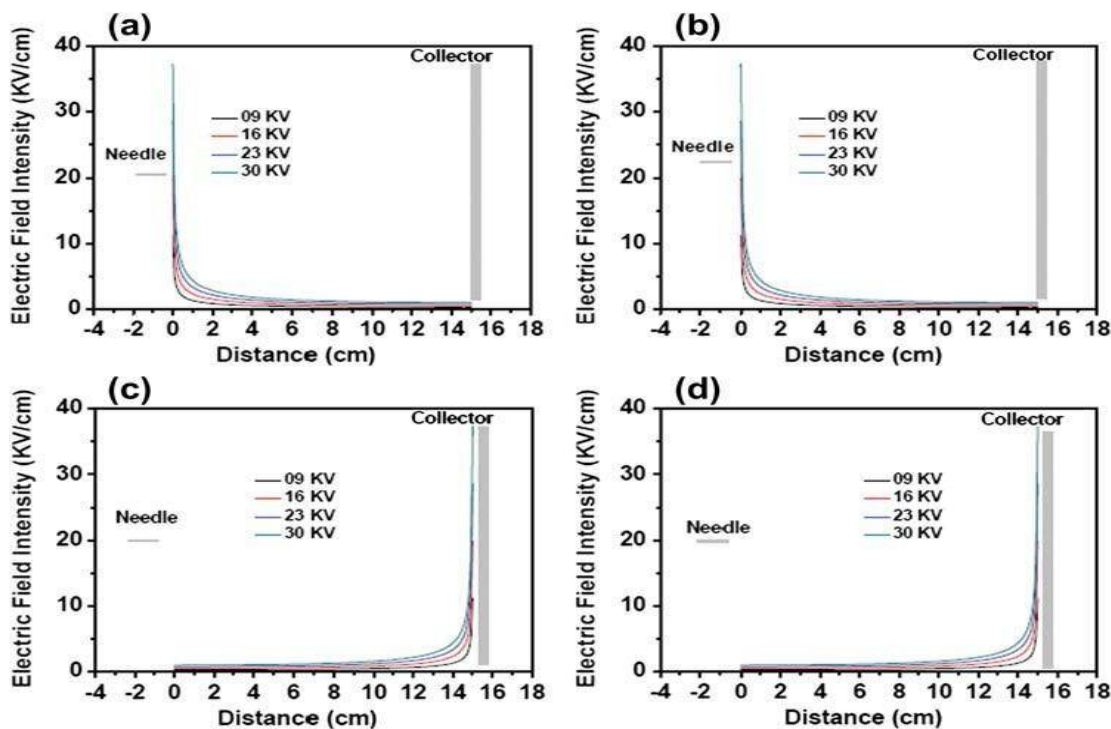


Figure 8. Effects of applied voltage on the electric field intensity profile, (a) PHV-G, (b) NHV-G, (c) G-PHV and (d) G-NHV (needle (0,0), collector (0,15), applied voltage = 16 kV

IX. CONCLUSIONS

By either increasing the applied voltage or decreasing the spinning distances, finer fibers resulted for all the electrode connections under the same operating circumstances. The type of power supply did not have a significant effect on the fiber morphology and critical voltage. The production of the grounded jets at a low applied voltage is less. However, when the applied voltage was increased to 15 kV, the production degree for the grounded nozzles was even greater than the setup with the high-voltage electrode connected nozzle. Limited element analysis of the electric field profile revealed that the high electric field intensity was mainly located in the part that was charged with a high voltage, which could explain the differences in the fiber diameter and deposition zone.

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