American Journal of Sciences and Engineering Research

E-ISSN– 2348–703X, Volume 8, Issue 6, 2025

Optimization of Electrospinning Parameters for the Development of Elastomeric PA6/PP Nanofibers

Moussa Mohamed [1], Balla Diop Ngom [1], Sahoby Lalaoharisoa [2], Benjamin Dierre [3], Said Soudjay [4]

[1,] *Department of Applied Physical Chemistry, Cheikh Anta Diop University of Dakar, Senegal*
[2,] *Department of Physics, University of Antananarivo, Madagascar*
[3,] *Department of Physical Chemistry, Bossuet School, France*
[4,] *Department of Nuclear Physics, University of Comoros, Comoros*

Abstract: *The fabrication of PA6/PP nanofibers by electrospinning offers innovative solutions for industry, particularly in the fields of filtration, technical textiles, and biomaterials. These nanofibers, combining the mechanical strength of PA6 and the lightness of PP, have strong potential for sustainable applications, especially in Africa, where recycling polymers like PP is crucial to reducing the environmental impact of plastic waste. This study optimizes electrospinning parameters (concentration, voltage, distance) to control fiber diameter (130–226 nm) and orientation. The results show that concentration is the dominant factor, yielding finer (160 nm) and better-oriented fibers at 12% PA6/PP and 25 kV. Statistical analysis (ANOVA) confirms the importance of the concentration-voltage interaction, while the distance plays a secondary role. Fibers obtained at 12% PA6/PP and 25 kV exhibit optimal orientation (135°), whereas at 15% and 30 kV, a bimodal orientation emerges. These advances suggest possibilities for local industrial applications, such as filtration membranes or technical textiles, while promoting recyclable materials. This approach aligns with circular economy principles, essential for African countries facing environmental and economic challenges. The process optimization thus paves the way for sustainable production tailored to regional needs.*

Keywords: *PA6/PP nanofibers, electrospinning, fiber diameters, statistical analysis*

I. Introduction

Electrospinning is an innovative technique for the fabrication of polymer nanofibers, offering unique properties suited to various industrial applications, particularly in filtration, technical textiles, and biomaterials. Among the materials used, composites based on polyamide-6 (PA6) and polypropylene (PP) are of particular interest due to their complementary properties: PA6 provides high mechanical strength, while PP contributes with its lightness and thermal stability. These nanofibers, whose diameters can be controlled at the nanometric scale (between 130 and 226 nm in this study), are promising for demanding industrial applications, such as high-performance filtration membranes or reinforcements for composite materials.

In Africa, where environmental and economic challenges are significant, the production and recycling of such polymers is of critical importance. PP, in particular, is a highly recyclable material, making it an ideal candidate for sustainable approaches in contexts where plastic waste management is a critical issue. The optimization of processes such as electrospinning for PA6/PP composites could therefore contribute to greener industrialization by reducing the environmental footprint while adding value to local resources.

 Received-20-11-2025 Accepted- 30-11-2025

This study focuses on optimizing electrospinning parameters (concentration, voltage, needle-to-collector distance) for the production of PA6/PP nanofibers. Using a Design of Experiments (DoE) and statistical analyses (ANOVA), we identify the optimal conditions for controlling fiber diameter and orientation. The results show that concentration is the dominant parameter, with a significant interaction with applied voltage. For instance, a concentration of 12% and a voltage of 25 kV yield fibers that are both fine (average diameter of 160 nm) and well-aligned (peak at 135°), whereas at 15%, viscosity limits jet stretchability. These advances are particularly relevant for African countries, where the development of low-cost and sustainable industrial processes is essential. By combining recyclable polymers such as PP with optimized electrospinning techniques, this research opens up perspectives for local applications, such as water purification or the production of technical textiles, while aligning with a circular economy model. The following sections detail the experimental methods, results, and their implications for industry and the environment.

II. MATERIALS AND METHODS

1. Materials

This study is based on two thermoplastic polymers with complementary properties: polyamide-6 (PA6) and polypropylene (PP). PA6, supplied by BASF SE, has excellent mechanical and chemical resistance, with a density of 1.084 g/cm³. Its counterpart, PP, is notable for its lightness (0.92 g/cm³) and high recyclability—features particularly valuable for sustainable applications. These two polymers were dissolved in formic acid (FA), a solvent selected for its effectiveness and purity (99%), supplied by Sordalab. With a molar mass of 46.02 g/mol and a density of 1.22 g/mL, FA enables the preparation of solutions with rheological properties suitable for the electrospinning process. The following table summarizes the key characteristics of these materials:

Table 1: Description of the polymers and solvent used

		Polymere	
N°	Properties	PA-6	PP
1	Density (g / cm ^{3})	1.084	0.92
2	supplier	BASF SE, Europe	
	Formica Acid (FA)		
3	Molar mass (g / mol)	46,02	
4	Density (g / mL)	1,22	
5	Pureté (%)	99	
6	Fournisseur	Sordalab, France	

2. Method

In this study, elastomeric solutions based on polyamide 6 (PA6) and polypropylene (PP) were prepared for use in the electrospinning process. The mass ratio between PA6 and PP was fixed at 80/20 for all formulations. Three polymer concentrations were studied: 7%, 12%, and 15%. The polymers were dissolved in a suitable solvent (noted as FA) under controlled stirring. The dissolution temperature was maintained between 40 and 60 °C to facilitate solubilization of the materials. This step ensures complete disintegration of the polymer chains in the solvent. After dissolution, the solutions were homogenized at room temperature. This homogenization was carried out over 24 hours to ensure uniform component distribution. Temperature and time control is critical to avoid precipitation or phase separation. These solutions were then used for electrospinning tests under different voltage and distance parameters. The final characteristics of the nanofibers strongly depend on the quality and stability of these preparatory solutions.

Table 2: Preparation of PA6/PP elastomeric solutions (80/20 ratio) at different concentrations

N°	**Elastomer solution** (%) PA6/PP blend (ratio 80/20)	**Dissolution of PA6 and PP in l'AF**
1	7	40–60°C under stirring Homogenization for 24 hours at room temperature
2	12	
3	15	

2.1. Electrospinning

2.1.1. Electrospinning Process

Electrospinning is a technique for producing ultrafine fibers, widely used in filtration, regenerative medicine, tissue engineering, and the development of technical textiles. This method is based on applying a high electric field between a polymer solution and a conductive collector. When the electrostatic force exceeds the surface tension of the solution, a jet is ejected from the needle tip, forming what is known as a "Taylor cone." The jet then undergoes rapid stretching as it travels toward the collector, enabling the formation of continuous nanometric fibers.

The efficiency of electrospinning depends on numerous parameters, grouped into three main categories: solution properties (concentration, viscosity, conductivity, surface tension), operating parameters (applied voltage, needle-to-collector distance, flow rate), and ambient conditions (temperature and relative humidity) [1–2]. Precise control of these variables is essential to ensure jet stability and obtain uniform, defect-free fibers. In this study, elastomeric solutions composed of polyamide 6 (PA6) and polypropylene (PP), in a mass ratio of 80/20, were prepared using a single solvent: formic acid (FA). Three concentrations (7%, 12%, and 15%) were selected to analyze the influence of polymer content on fiber morphology. The table below summarizes the experimental conditions used for electrospinning.

2.1.2. Electrospinning Operating Conditions

The main operating parameters are described as follows:

- The solvent used is formic acid, selected for its ability to simultaneously dissolve PA6 and PP.
- The polymer solution concentration was adjusted to three values (7%, 12%, 15%).
- The injection flow rate was kept constant at 0.1 mL/h.
- A 55-gauge needle was used to control the size of the emitted jet.
- Ambient temperature was stabilized at 23 °C, with relative humidity around 22%.
- Spinning time was set at 12 minutes for each sample, ensuring uniformity across tests.
- These conditions ensured the reproducibility and comparability of the fibers obtained.
-

Table 3: Experimental conditions for electrospinning PA6/PP solutions

Polymere : elastomer solution (PA6 /PP)	Polyamide 6 (PA-6) Polypropylene (PP)
Solvent	Formic acid (AF)
Flow rate (mL/h)	0,1
Needle diameter (G)	55
Ambient parameter	Temperature (°C) : 23 Humidity : 22%
Electrospinning time	12 mn

3. Design of Experiments (DoE)

Electrospinning is a process used to fabricate continuous nanofibers from a polymer solution subjected to a high-intensity electric field. However, when the processing conditions are not optimal particularly the polymer concentration and applied voltage the nanofiber morphology may be compromised by the formation of beads. These beads, typically spherical or spindle-shaped, are considered morphological defects as they reduce the homogeneity, specific surface area, and mechanical properties of the resulting nonwoven material. In polyamide 6 (PA6) and polypropylene (PP)-based systems, this phenomenon is frequently observed when the polymer concentration is too low. An insufficient concentration (typically < 8 wt% for PA6) results in low viscosity, which prevents the formation of a stable and continuous jet. The outcome is droplet flow instead of uniform stretching, leading to discontinuous and beaded fibers [3–4].The applied voltage also plays a crucial role. If the voltage is too low, the electrostatic force generated is insufficient to overcome the surface tension of the polymer solution, also promoting bead formation. Conversely, an excessively high voltage (>25 kV in some cases) may cause jet instability, leading to fibers with irregular diameters, accompanied by beads due to rapid jet breakup or incomplete solvent evaporation [5–6]. In PA6/PP blends, the addition of PP can exacerbate the issue, as PP is difficult to electrospin on its own (due to its insolubility in conventional solvents) and often reduces the overall compatibility and viscosity of the blend. Poor homogenization of the PA6/PP mixture can therefore increase the presence of beads or irregular coalescence zones on the fibers [7].

Observed effects of bead formation [8]:

- Reduction in the specific surface area of the material.
- Structural heterogeneity compromising applications in filtration or biomedical fields.
- Decreased mechanical properties due to fiber discontinuity.

Good practice includes:

- Gradually increasing the concentration until reaching a critical viscosity threshold (~10–15 wt% for PA6),
- Adjusting the voltage within an optimal range (between 15 and 20 kV),
- Using additives or compatibilizers when necessary in PA6/PP blends.

Table 4 presents a systematic design of experiments (DoE) established to investigate the electrospinning of a PA-6,6-based polymer solution. Three independent variables were selected as major input factors influencing the nanofiber morphology: polymer concentration (%), applied voltage (kV), and the needle-to-collector distance (cm).

Table 4: Design of experiments (DoE) applied to a PA-6,6 solution, based on three input variables: concentration, voltage, and needle-to-collector distance.

N°	Electrospinning parameters	Abbreviation	Units	Levels
1	Solution concentration	C	wt %	7, 12, 15
2	Distance	D	cm	15, 20, 25
3	Voltage	V	kV	21, 25, 30

Scale:

- x43,000: Image magnification (43,000 times)
- 5.0kV: Electron beam accelerating voltage (5 kilovolts)
- 100nm: Scale bar represents 100 nanometers

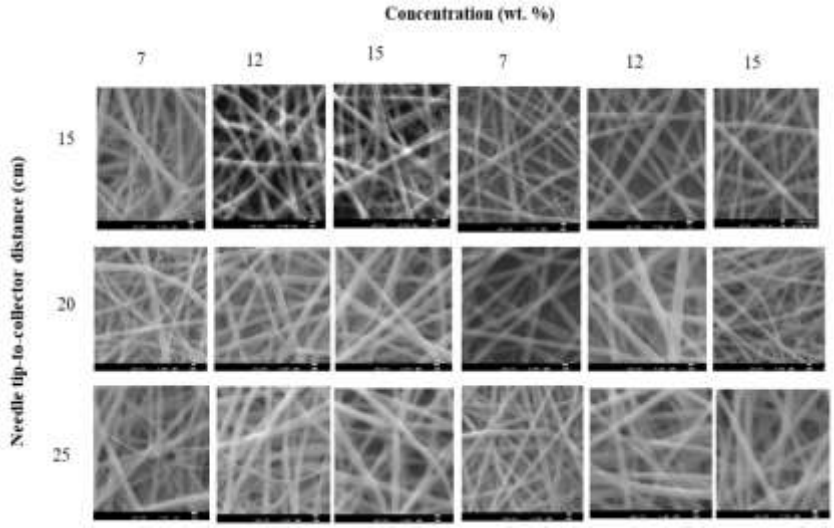

Figure 3. SEM images obtained for each experimental condition of the DoE plan.

The morphology of the nanofibers was examined using scanning electron microscopy (SEM) micrographs, along with quantitative diameter analysis using ImageJ software. This method enabled determination of the individual diameter of nanofibers present in each micrograph. Figure 3 illustrates, for each experimental condition, an SEM micrograph obtained at a magnification of 45,000x. In this figure, the images are organized systematically: horizontally by increasing polymer concentration (from 7 to 15 wt%), and vertically by increasing needle-to-collector distance (from 15 to 25 cm). The average diameters, calculated from the measurement of 64 fibers per image, and their standard deviations are reported in the DoE matrix summarized in Table 5. Electrospinning experiments were conducted according to this plan, and the results reveal that the nanofiber diameter of PA6/PP varies significantly depending on operating conditions, with values ranging from 130 nm to 226 nm. These observations confirm the major influence of polymer concentration, applied voltage, and needle-to-collector distance on the uniformity and fineness of the produced fibers.

This plan makes it possible to assess the effect of these parameters on the final characteristics of the nanofibers, particularly their mean diameter and diameter distribution. It encompasses a wide range of experimental combinations, ensuring comprehensive analysis of the optimal production conditions. The adopted approach aims to understand the synergy among the variables and to optimize the electrospinning conditions to obtain homogeneous, fine fibers that meet the desired performance requirements.

Table 5. Design of Experiments (DoE) developed for the electrospinning of PA6/PP

N°	C	V	D	Mean diameter	SD
S1	7	25	20	150	49
S2		30	25	160	41
S3		21	20	143	24
S4		21	25	134	22
S5		30	15	130	31
S6		25	25	155	53
S7		25	15	132	35
S8		30	20	148	36
S9		21	15	254	70
S10	12	30	25	227	90

S10	12	30	25	227	90
S11		25	25	114	26
S12		21	15	161	43
S13		25	15	150	29
S14		21	25	160	48
S15		30	15	226	34
S16		30	20	225	49
S17		21	20	171	40
S18		25	20	160	42
S19	15	21	20	182	52
S20		25	20	186	26
S21		25	25	199	58
S22		21	25	174	46
S23		30	20	231	70
S24		25	15	197	41
S25		30	15	226	78
S26		21	15	212	41
S27		30	25	212	70
N°	C	V	D	Mean diameter	SD

N°	C	V	D	Mean diameter	SD
S1	7	25	20	150	49
S2		30	25	160	41
S3		21	20	143	24
S4		21	25	134	22
S5		30	15	130	31
S6		25	25	155	53
S7		25	15	132	35
S8		30	20	148	36
S9		21	15	254	70
S10	12	30	25	227	90
S11		25	25	114	26
S12		21	15	161	43
S13		25	15	150	29
S14		21	25	160	48
S15		30	15	226	34
S16		30	20	225	49
S17		21	20	171	40
S18		25	20	160	42
S19	15	21	20	182	52

S20		25	20	186	26
S21		25	25	199	58
S22		21	25	174	46
S23		30	20	231	70
S24		25	15	197	41
S25		30	15	226	78
S26		21	15	212	41
S27		30	25	212	70

The morphology of electrospun nanofibers refers to the structure, uniformity, and surface appearance of the fibers at the nanometric scale. In the case of polymers such as polyamide 6 (PA6) and polypropylene (PP), this morphology is highly dependent on the parameters of the electrospinning process as well as the physicochemical properties of the polymer solution. Polyamide 6 is a semi-crystalline, hydrophilic polymer with good electrospinnability due to its ability to form homogeneous solutions with polar solvents such as formic acid. When electrospun, PA6 generates relatively smooth, continuous nanofibers with small diameters, generally in the range of 100 to 250 nm, and with good morphological uniformity [9]. Polypropylene (PP), on the other hand, is a hydrophobic polymer that is difficult to electrospin via conventional methods because it does not dissolve in common solvents. To overcome this limitation, PP is often used in blends with another more easily electrospinnable polymer such as PA6. This strategy allows for the mechanical properties of PP to be utilized while retaining the spinnability of PA6 [10]. When PA6 and PP are blended (often in a PA6/PP ratio of 80/20), the morphology of the resulting nanofibers depends on the miscibility of the two polymers, the mass percentage of the solution, the applied voltage, the needle-to-collector distance, and the solution flow rate. A well-homogenized mixture can yield composite nanofibers with diameters generally ranging between 130 and 250 nm, as shown in several experimental studies [11]. Fiber diameter variations are strongly influenced by the following factors [12–14]:

- Polymer concentration: the higher it is, the thicker the fibers due to increased viscosity.
- Applied voltage: a higher voltage leads to greater jet stretching, thereby reducing fiber diameter.
- Needle-to-collector distance: this affects the jet's solidification time and thus the morphological uniformity of the fibers.

From a morphological perspective, PA6/PP fibers exhibit a relatively smooth and cylindrical structure, free of beads, provided that the process parameters are properly optimized. Scanning electron microscopy (SEM) analysis allows for observation of their structure and precise diameter measurement using image analysis software such as ImageJ [15–17].

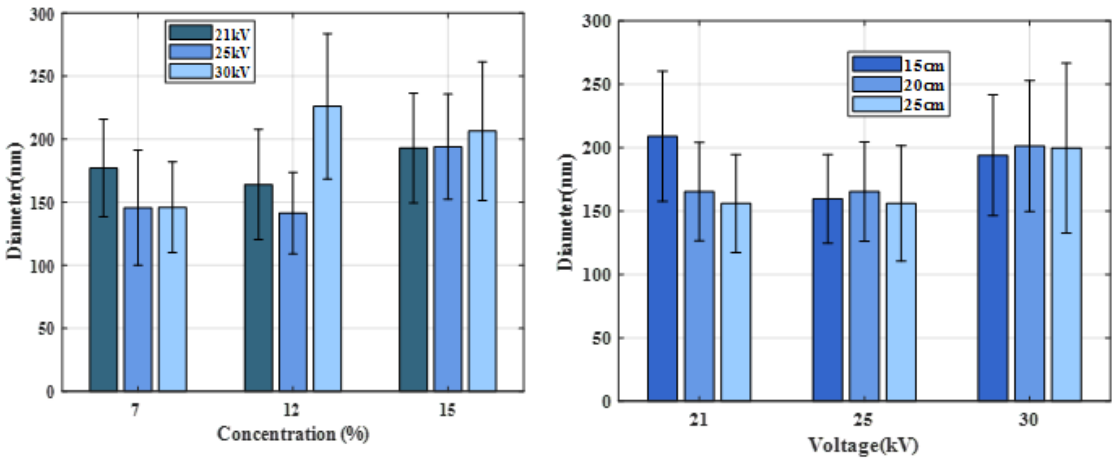

Figure 4. Effect of concentration and applied voltage on the average diameter of electrospun nanofibers

The results obtained clearly illustrate the significant influence of process parameters on the morphology of electrospun nanofibers. It appears that polymer concentration directly affects the viscosity of the solution and, consequently, the diameter of the fibers produced. A low concentration (7%) tends to generate finer but also less stable fibers, while a higher concentration (15%) promotes the formation of thicker yet more uniform fibers due to improved stretching of the electrospun jet.

The applied voltage (21–30 kV) shows a less linear but nonetheless decisive effect: a moderate voltage (25 kV) appears to result in an optimal compromise between jet stretching and morphological stability of the fibers. Beyond this, an excessively high voltage may cause excessive atomization or jet instability, resulting in fibers with irregular diameters, or even beaded fibers. As for the needle-to-collector distance, a general trend indicates that an intermediate distance (20 cm) is favorable for the production of more homogeneous fibers, likely due to a sufficient flight time allowing complete solvent evaporation. Overall, these results confirm that obtaining PA6/PP nanofibers with fine and uniform diameters depends on a balanced combination of these three parameters. These conclusions are consistent with the literature, particularly the works of Huang et al. (2003) and Teo & Ramakrishna (2006), who emphasize the importance of precise adjustment of electrospinning conditions to optimize nanofiber morphological quality [18-19].

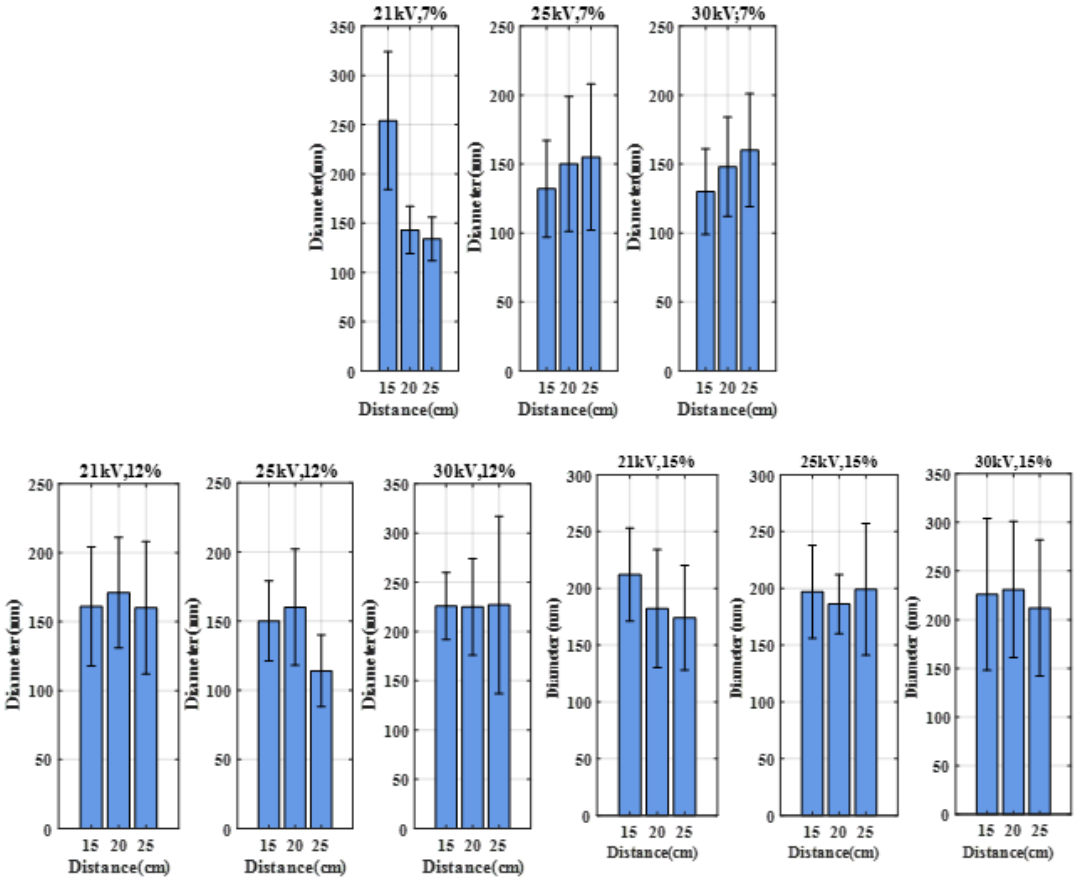

Figure 5. Effect of the combined influence of concentration, applied voltage, and needle-to-collector distance on the average diameter of PA6/PP nanofibers

The set of presented graphs illustrates the combined effect of three key electrospinning process parameters solution concentration (7%, 12%, 15%), applied voltage (21, 25, 30 kV), and needle-to-collector distance (15, 20, 25 cm) on the average diameter of PA6/PP nanofibers. In general, increasing the concentration tends to produce thicker fibers, which aligns with an increase in solution viscosity that limits jet stretching.

At constant voltage, a distance of 20 cm often results in more uniform diameters, appearing to represent a good compromise between jet stretching and solidification. At 7%, standard deviations are more pronounced,

indicating process instability at low concentration. Conversely, at 15%, fibers exhibit more regular diameters, particularly at 25 kV and 20 cm. The effect of voltage is less linear: at 30 kV, although stronger stretching is observed, instability may arise at low concentration. Overall, the best conditions for fiber stability and uniformity appear to lie around 12% to 15%, 25 kV, and 20 cm, combining good morphology with low variability.

4.2. Statistical Analysis (ANOVA)

To assess the significance of the effect of the selected parameters (solution concentration and needle-to-collector distance) on nanofiber diameter and its distribution, an analysis of variance (ANOVA) was conducted. The results obtained are summarized below.

Table 6: Analysis of variance (ANOVA) for the average diameter (nm) of PA6/PP nanofibers

No	Terme	P-Value for dia	$p \leq 0,05$	$p \leq 1$
1	C	0.0030406	+	+
2	V	0.0039355		+
3	D	0.501027		
4	C x C	0.50441		
5	V x V	0.034601	+	+
6	D x D	0.68073		
7	C x V	0.033294	+	+
8	C x D	0.83305		
9	Vx D	0.092215		+

The ANOVA reveals a highly significant influence of concentration (p = 0.003) and voltage (p = 0.004) on nanofiber diameter. The interactions C×V (p = 0.033) and V×V (p = 0.035) confirm nonlinear combined effects. The needle-to-collector distance (p = 0.501) and quadratic terms C×C (p = 0.504) and D×D (p = 0.681) prove to be non-significant. These results show that:

- Concentration is the dominant parameter
- Voltage acts as a secondary factor
- Their interaction significantly influences morphology
- Distance has a negligible effect
- Relationships are primarily linear

Therefore, optimization requires precise control of concentration and voltage, while distance can be adjusted secondarily. These conclusions provide effective guidance for setting process parameters.

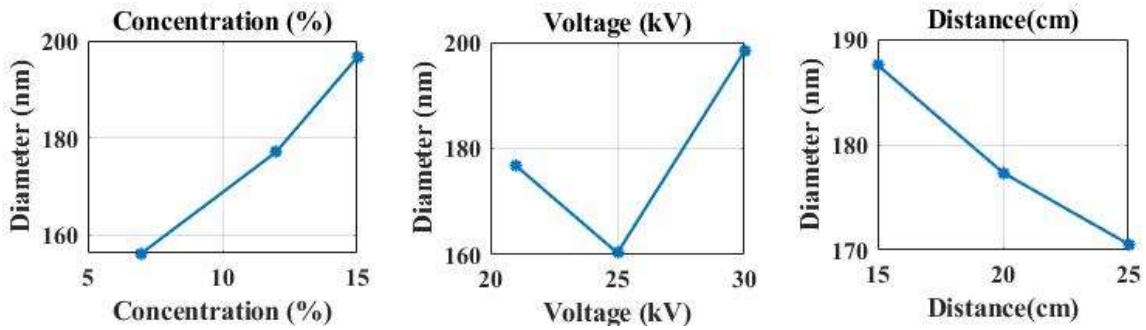

Figure 6. Main effects plot (ANOVA) of the parameters on the average diameter of PA-6,6 nanofibers

The main effects plot reveals that:

- Concentration (%) has a significant impact on nanofiber diameter, with a progressive increase in diameter (from ~160 nm to 200 nm) as the concentration increases from 6% to 16%.
- Voltage (kV) shows a less linear relationship, with diameter variations (160–200 nm), suggesting a complex effect that requires precise optimization.

- Collection distance (cm) moderately influences diameter, with a tendency toward reduction (from 190 nm to 170 nm) as the distance increases from 15 cm to 25 cm.

These results confirm that concentration is the dominant parameter, while voltage and distance require fine-tuning for optimal control of fiber morphology.

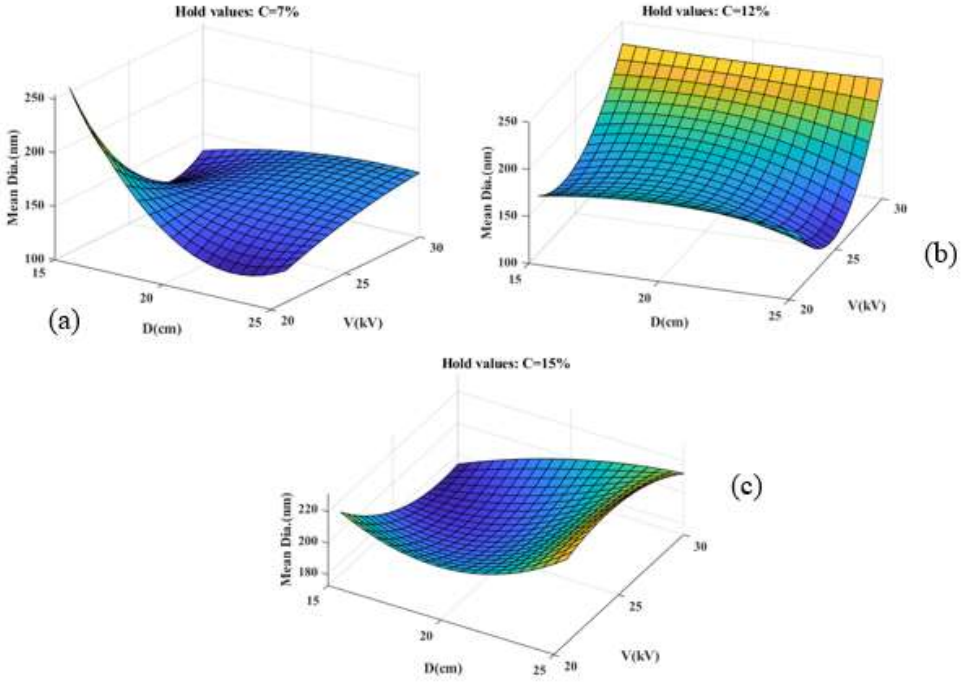

Figure 7. Response surfaces illustrating the effect of electrospinning parameters on the average diameter of nanofibers for different concentrations

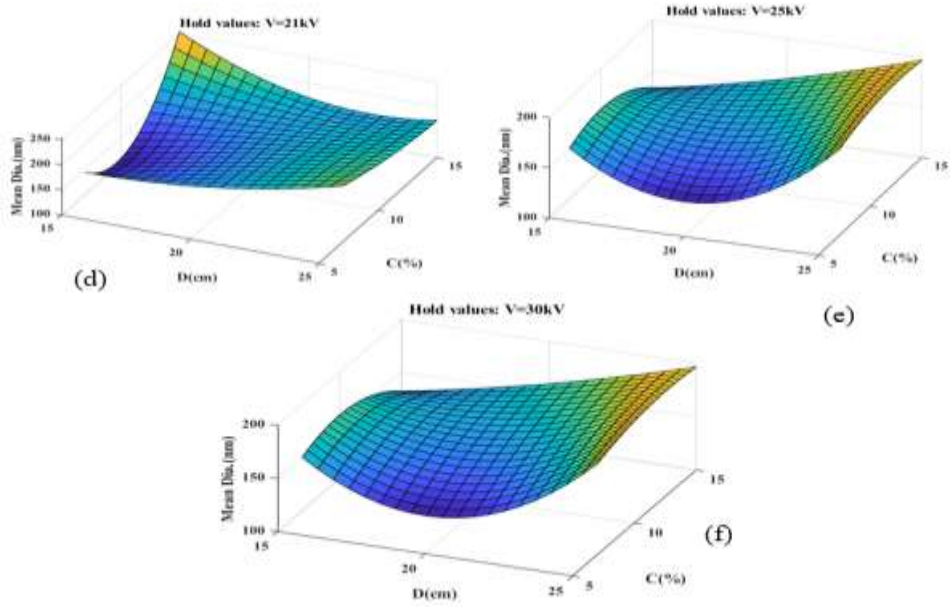

Figure 8. Response surfaces illustrating the combined effect of concentration and distance on the average diameter of nanofibers for different applied voltages

The response surfaces show the influence of the two main input parameters polymer solution concentration (C, in %) and collection distance (D, in cm) on the average diameter of nanofibers (in nm), for three different levels of applied voltage (V). These figures allow visualization of the complex interaction among these parameters within the electrospinning process. Analysis of the obtained response surfaces confirms that the average diameter of electrospun nanofibers is highly dependent on the applied voltage (V), as well as on the interaction between the solution concentration (C) and the collection distance (D). For lower voltage (V = 21 kV), the response surface exhibits marked variations in diameter, indicating increased process sensitivity to variations in the other parameters. As the voltage increases (V = 25 kV and V = 30 kV), a progressive reduction in the amplitude of variations is observed, indicating better process stability. However, combined effects are still observed: at each voltage level, fiber diameter tends to decrease as the concentration increases and the collection distance is moderate, but local minima and maxima appear depending on the experimental conditions. These results confirm that optimizing the electrospinning process requires an integrated approach, taking into account voltage, concentration, and distance to precisely control nanofiber diameter. The use of response surfaces thus makes it possible to identify optimal operating zones to obtain homogeneous fibers suitable for targeted applications

4.3. Fiber Orientation

Figure 9 below shows the orientation of fibers obtained by electrospinning as a function of PA6/PP concentration and applied voltage. This analysis allows evaluation of the influence of these parameters on the directionality and uniformity of the formed fibers.

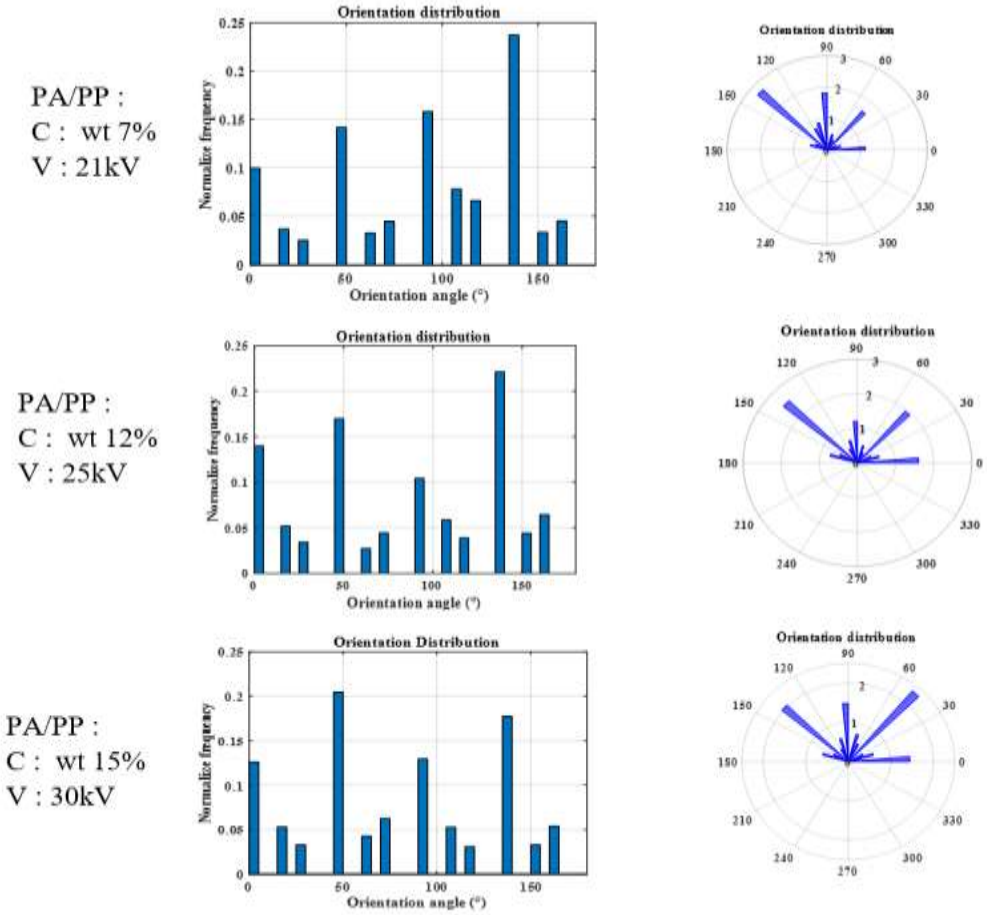

Figure 9. Fiber orientation analysis as a function of PA6/PP concentration and electrospinning voltage

SAMPLE 1 (7% PA6/PP, 21 kV)

- Histogram: The angles are fairly dispersed, but with a notable concentration around 135°.
- Polar histogram: Several moderate peaks, particularly near 135°, indicating a preferential but relatively dispersed orientation.

SAMPLE 2 (12% PA6/PP, 25 kV)

- Histogram: The distribution shows a dominant peak around 135°, more pronounced than at 7%. Less dispersion.
- Polar histogram: Strong dominant orientation toward 135°, more directional than the first sample.

SAMPLE 3 (15% PA6/PP, 30 kV)

- Histogram: Two distinct peaks: around 40–50° and 130–140°, indicating two preferential orientations.
- Polar histogram: More dispersed distribution around two main directions (≈45° and 135°), reflecting a bimodal orientation.

Table 7: Overall analysis of fiber orientation as a function of concentration

Parameter	Orientation	Dispersion	Dominant direction
7 % - 21kV	Medium	Modium to high	153°
12 % - 25kV	Strong	Low	135°
15 % - 30 kV	Bimodal	Medium	45° et 135°

The increase in concentration and voltage promotes better fiber orientation up to a certain point (12% – 25 kV). At 15% – 30 kV, although the voltage is higher, a bimodal orientation is observed, which may indicate instability or turbulence in the process, reducing uniformity. The most uniform and directional orientation is obtained at 12% PA6/PP and 25 kV, which may represent an optimal point for desired anisotropic mechanical properties.

4.4. Industrial Implications

The results of this study open concrete perspectives for the development of high value-added products in several industrial sectors. In particular, PA6/PP nanofibers optimized by electrospinning present strong potential for water filtration, technical textiles, functional membranes, and biomedical supports [20–21]. Their controlled fineness (130 to 226 nm), adjustable orientation, and homogeneous morphology meet performance requirements in applications where porosity, specific surface area, and mechanical strength are essential.

In terms of sustainability, the integration of polypropylene (PP), a recyclable and abundant material, enables consideration of low-cost and eco-friendly solutions, particularly suited to emerging countries. In the African context, this process represents a strategic opportunity to valorize plastic waste through the local manufacture of advanced materials, within a circular economy framework [22–23].

III. CONCLUSION

The objective of this study is to manufacture nanofibers and optimize the electrospinning process for PA6/PP-based nanofibers by analyzing the influence of key parameters such as polymer solution concentration, applied voltage, and the distance between the needle tip and the collector. The methodological approach adopted, based on a Design of Experiments (DoE) supported by the Response Surface Methodology (RSM), allowed for a detailed understanding of the effect of each parameter, both individually and in interaction.

The results showed that concentration is the most influential factor on the average diameter of the nanofibers, followed by voltage and distance. The optimal conditions identified namely a concentration of 12%, a voltage of 25 kV, and a distance of 20 cm enabled the production of homogeneous nanofibers with regular diameters, free of beads and major morphological defects. At 15%, a bimodal orientation was observed, indicating a certain degree of jet instability.

Furthermore, statistical analyses (ANOVA) confirmed the significance of these parameters on fiber regularity. This study also demonstrated that the careful combination of these parameters can not only improve nanofiber quality but also direct their structural organization within the resulting membrane. This work thus paves the way for industrial applications in the fields of filtration, technical textiles, and biomaterials, while also contributing to the sustainable valorization of polymers, especially in geographic contexts with high potential for local innovation.

These results align with an industrial valorization perspective for recyclable polymer materials, particularly in local contexts such as Africa, where access to sustainable and adaptable technologies is essential. By providing a solid technical basis for controlling nanofiber morphology, this research helps strengthen the bridge between scientific innovation and industrial solutions with low environmental impact.

IV. REFERENCE

[1] Ramakrishna, S., Fujihara, K., Teo, W.-E., Yong, T., Ma, Z., & Ramaseshan, R. (2006). Electrospun nanofibers: solving global issues. Materials Today, 9(3), 40–50.

[2] Bhardwaj, N., & Kundu, S. C. (2010). Electrospinning: A fascinating fiber fabrication technique. Biotechnology Advances, 28(3), 325–347.

[3] Khenoussi, N., L. Schacher and D.C. Adolphe, Nanofiber Production: Study and Development of Electrospinning Device. Experimental Techniques, 2012. 36(2): p. 32-39.

[4] Frenot, A., & Chronakis, I. S. (2003). Polymer nanofibers assembled by electrospinning. Current Opinion in Colloid & Interface Science, 8(1), 64–75.

[5] Nayak, R., R. Padhye, I.L. Kyratzis, Y.B. Truong and L. Arnold, Recent advances in nanofibre fabrication. Textile Research Journal, 2012. 82(2): p.129-147. [6] Bhardwaj, N., & Kundu, S. C. (2010). Electrospinning: A fascinating fiber fabrication technique. Biotechnology Advances, 28(3), 325–347.

[7] Heikkilä, P., & Harlin, A. (2008). Parameter study of electrospinning of polyamide-6. European Polymer Journal, 44(10), 3067–3079.

[8] Li, D., & Xia, Y. (2004). Electrospinning of nanofibers: reinventing the wheel? Advanced Materials, 16(14), 1151–1170.

[9] Huang, Z.-M., Zhang, Y. Z., Kotaki, M., & Ramakrishna, S. (2003). A review on polymer nanofibers by electrospinning and their applications. Composites Science and Technology, 63(15), 2223–2253.

[10] Demir, M. M., Yilgor, I., Yilgor, E., & Erman, B. (2002). Electrospinning of polyurethane fibers. Polymer, 43(11), 3303–3309.

[11] Bazbouz, M. B., & Stylios, G. K. (2008). The tensile properties of electrospun nylon 6 single nanofibers. Journal of Polymer Science Part B: Polymer Physics, 46(5), 485–493.

[12] Subbiah, T., et al. (2005). Electrospinning of nanofibers. Journal of Applied Polymer Science, 96(2), 557–569.

[13] Agarwal, S., J.H. Wendorff and A. Greiner, Use of electrospinning technique for biomedical applications. Polymer, 2008. 49(26): p. 5603-5621.

[14] Tan, S. H., et al. (2005). Systematic parameter study for ultra-fine fiber fabrication via electrospinning. Polymer, 46(16), 6128–6134.

[15] Shah Hosseini, N. and N. Khenoussi, Structuring of electrospun nanofiber mats by 3D printing methods. 2017: p. 73-85.

[16] Ramakrishna, S., et al. (2006). An Introduction to Electrospinning and Nanofibers. World Scientific.

[17] Andrady, A.L., Science and technology of polymer nanofibers. 2008: John Wiley & Sons.

[18] Huang, Z.-M., et al. (2003). A review on polymer nanofibers by electrospinning and their applications. Composites Science and Technology, 63(15), 2223–2253.

[19] Teo, W. E., & Ramakrishna, S. (2006). A review on electrospinning design and nanofibre assemblies. Nanotechnology, 17(14), R89–R106.

[20] Reneker, D.H., A.L. Yarin, H. Fong and S. Koombhongse, Bending instability of electrically charged liquid jets of polymer solutions in electrospinning. Journal of Applied physics, 2000. 87(9): p. 4531-4547.

[21] Zhang, R., Synthetic nano-scale fibreus extracellular matrix. J.Biomed.Mater. Res. 1999,46(1), 60-72.

[22] Doshi, J. and D.H. Reneker, Electrospinning process and applications of electrospun fibers. Journal of electrostatics, 1995. 35(2-3): p. 151-160.

[23] Martin,C.R., Membrane-based synthesis of nanomaterials. Chem.Mater. 1996,(8),1739-1746.