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A Critical Analysis On Parameters Affecting The Formation of Nano Fibers Using Electrospinning Technique

Gurpreet*

**Department of Physics, Research Scholar, Chandigarh University, Gharuan, Mohali, India*

Abstract
The ongoing improvements in innovation are to plan and make compact size gadgets with increment in productivity, less energy utilization, and viability. Manufacturing nanofibers of various polymer solutions and their expanding use in a wide scope of uses is coordinating towards this. Out of nanofibers' various manufacturing techniques; Electro-spinning is a basic, more beneficial, and ease technique. Nanofibers created by the Electro-spinning process are generally utilized in filtration, creating high conductivity materials, in medication conveyance, malignancy treatment, and so forth where explicit attributes are required. For development in these zones, nanofibers must be appropriately intended for these applications to forestall disappointment. Electrospinning is a process by which polymer nanofibers (with breadth lower than 100nm and stretches up to km) can be made utilizing an electrostatically determined stream of the polymer solution. Here the impacts of both polymer solution parameters (for example, polymer solution concentration, solution stream rate, the distance between collector and needle tip) and electrospinning process conditions (applied voltage, temperature, and humidity) on the size & morphology of nanofibers are contemplated. The goal is to consider the impacts of parameters and produce nanofibers of least breadth and imperfection free morphology by controlling the input parameters.

Keywords: *Electrospinning; Nanofibers; Fabrication; Polymer solution; Innovation*

I. Introduction

Nanofibers are of exceptionally enormous and theoretically infinite length compared to diameter [1]–[3]. Nanofibers have qualities, such as huge surface region to volume proportion, high adaptability, and surface functionalities, as shown in Fig.1.

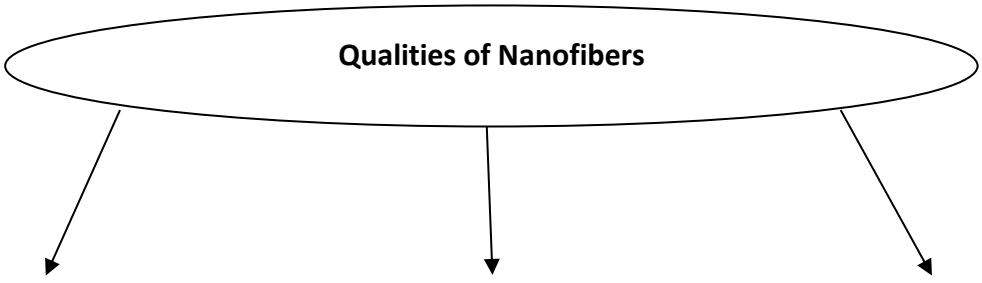

Fig.1. Outline of important characteristics of Nanofibers.

Due to these characteristics, these fibers have significant applications in medical sciences, for skin protection, for protecting the environment from facing pollution (air & water pollution), and in sensors, as shown in Fig.2. They also have very much larger energy reconstruction and storage efficiency and therefore have their utilization to make solar cells & fuel cells.

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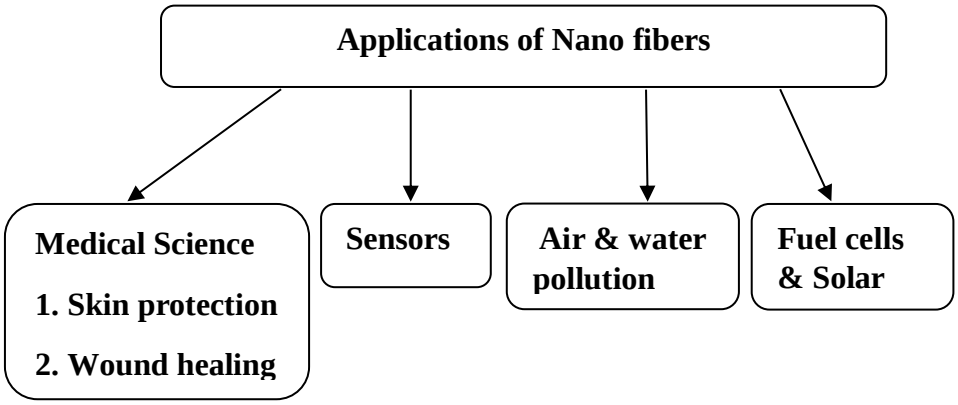

Fig.2. Showing different applications of Nanofibers with the help of a block diagram.

Nanofibers' diverse manufacturing procedures are drawing, phase separation, template synthesis, self-assembly, and electrospinning, as shown in Fig.3.

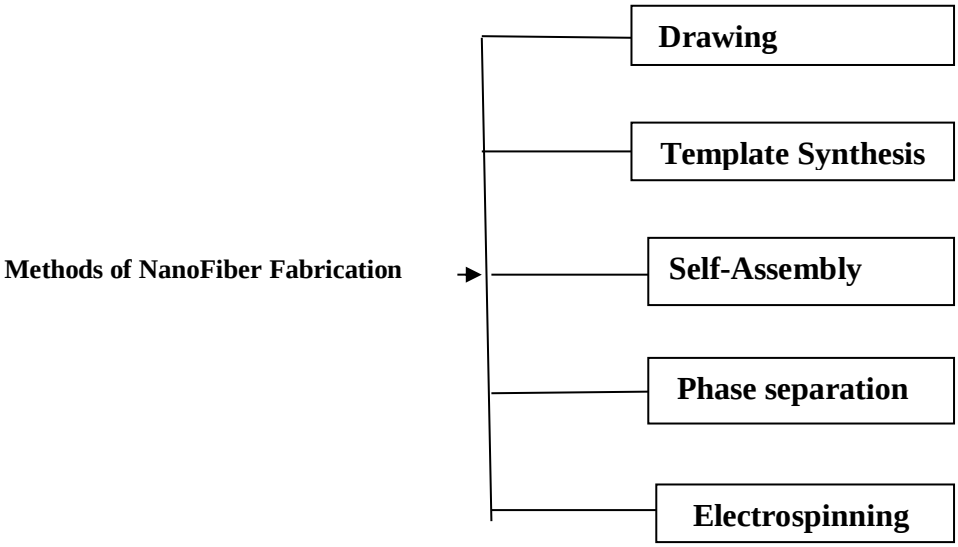

Fig.3. Block diagram representing different methods of nanofiber fabrication.

Among these all, electrospinning is the basic, minimal effort, and high profitable procedure is simple for business use. It doesn't need high temperature for creating fine fibers [2], [3]**.**

A. Electrospinning Technique

Electrospinning is a moderately straightforward unique fiber-framing process; furthermore, it offers a special strategy to create nanofibers from polymer melts in an extensive range around 100nm [4], [5]. Electrospinning depends on electrostatic powers acquired by applying an electrical field by methods of a DC voltage source between the tip of a nozzle (where polymer solution is filled) and collector [4], [6]. The resulting applied electric field elevates the liquid to defeat the droplet's surface pressure at the spinneret's tip, and the droplet shapes a Taylor cone. The polymer solution's consistency obstructs independent droplets' development, permitting a solitary fiber to be drawn from the solution [7]. At that point, the jet contracts in width to frame fibers of micro and nano-scales that dry and get gathered on the counter. The electrospinning cycle has four phases: jet initiation, rectilinear jet, bending instability, fiber sedimentation, and the collection, as in Fig.4. During the first phase, strong Coulomb forces overwhelm the creation of the Taylor cone. In the second phase, the viscoelastic powers and surface strains unite for any jet disturbance [8].

Nonetheless, the viscosity can presently don't balance out the disturbance, and whipping happens, known as the

bending instability phase, where the reduction in fiber diameter generally occurs. Now the jet begins whipping in a round movement, with each sequential round bigger than the past one. At long last, the whipping jet arrives at the collector, and the finally formed fibers get stored on its surface [6]. With the modern upturns of concern in electrostatic fiber spinning due to its profitable suited applications, we require a detailed understanding of the parameters affecting the electrospinning process & the yield [5]. Therefore in this paper, we've made an effort to seek information regarding the effects of parameters like concentration of polymer solution, the voltage applied, temperature & humidity on the size and surface morphology of our final product, i.e., fabricated nanofibers [2].

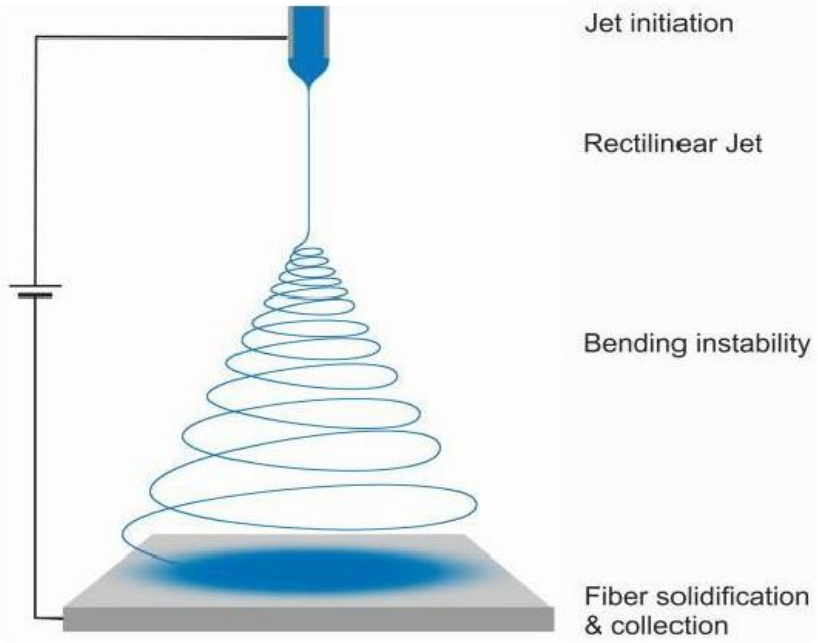

Fig.4. A simplified diagrammatical representation of different steps of Electrospinning Process.

B. Parameters affecting the formation of nanofibers using Electrospinning Technique *[1]–[3], [5], [9]–[11]* ***are :***

a) **Material Parameters -** Solution Viscosity, Polymer concentration, Elasticity, Surface Tension.
b) **Operating Parameters** - Applied Voltage, Distance from needle to the collector.
c) **Ambient Parameters** - Temperature, Humidity**.**

II. Literature review of few parameters affecting size & morphology of resultant polymer nanofibers has been discussed here.

A. Applied Voltage

The first parameter which influences and starts the electrospinning process is the applied voltage. Thus, the electric field affects the stretching & acceleration of the jet, which in turn, affects the diameter and morphology of the resultant fibers.

More droplet-formation was seen by Zhong in 2002 due to enhanced inconstancy of the jet at high voltage. After that, Krishnappa in 2002 too told about increased droplet density at high voltage & increase in fiber thickness due to combination of droplets at higher applied voltage.

Lee in 2004 explained the reduction in the thickness of fibers with higher voltage. He said that the polymer solution stretching occurred due to the high electric field and columbic forces in the jet at a higher voltage. With this variation in nanofibers' size, the impact of voltage on the polymer's crystallinity was also noticed by Zhao in 2004. The acceleration of the polymer fibers gets incremented due to enhanced supplied voltage, which lessens the jet's flight time. As a result, fibers try to sediment before the alignment of polymer molecules. So, crystallinity, i.e., the ordered arrangement of polymer molecules, gets disturbed above a certain limit of the applied voltage.

Pawlowski, in 2005 found that the high voltage increases the electrostatic force, which helps in surmounting the surface tension of the polymer solution. This results in

more evaporation & hence we get moisture fewer fibers [10]. S-H. Tan used HM-PLLA (high Molecular Weight of Poly L-Lactic Acid) polymer dissolved in solvents like pyridine & DCM (Dichloromethane) in 2005. The polymer solutions were electro-spun with two levels (minimum & maximum) of the applied voltage. Maximum voltage caused multiple jets, which resulted in non-uniform fibers of short diameter & minimum voltage had no substantial effect on the fiber-diameter and hence on its morphology [11].

John Wiley used PEO (Polyethylene Oxide) polymer solution for his study. He noticed beaded fibers' formation at 5kV & a web-like structure of thicker fibers at (10-17.5) kV voltage due to the jet's inconstancy at a higher voltage. On increasing the voltage to 20kV, the thickness of fibers decreases & the "droplet-on-fiber" shape was observed at 25kV. This variation in fibers' behavior might be attributed to the external electric field's impact on the charges formed on the jet. Again above 25kV, he found the droplet's complete fading at the tip of the nozzle & the jet started to flow promptly from the tip of the spinneret [9].

Amir Doustgani, in 2015 did an experiment with PCL (Polycaprolactone) and nHA (nanohydroxyapatite) in solvents like chloroform/DMF at a voltage range of 10-22kV. In the voltage range of (10-19) kV, fiber diameter decreased from 489nm to 410nm because of the prolonged jet compared to flow rate with increasing voltage. At 22kV, fiber diameter again increased to 437nm because of the more polymer solution's ejection out of the tube with increasing voltage [12].

Daenicke in 2019 used Polypropylene for electrospinning. At extremely low voltages, no fibers were created. At extremely high voltages, the flow of the jet became unsteady due to rupturing of fibers. Between minimum & maximum range, the extension of fibers takes place & hence the thickness of fibers decreases [13] [14].

Nand Jee Kanu in 2020 used a solution having 1.5% gelatin, 1% curcumin in 10mL of 98% concentrated Formic Acid & obtained 254nm thick fibers at 15kV and 181nm thick fibers at 10kV [15]. Fuat Topuz too performed an experiment with CD (Cyclodextrin) fibers using water & N, N-dimethyl formamide (DMF) as solvents. He worked at a voltage range of (7.5-22) kV and got droplet-free fibers at all ranges. At 12.5kV, approximately 690nm thick fibers and at 20kV, approximately 980nm thick fibers were obtained. The increment in fibers' diameter might be due to enhanced mass flow as we increase the applied voltage, i.e., electric field. Besides 20kV, unalike fibers were obtained. The most symmetrical fibers were obtained at 17.5kV [16]. After this, Deepika Sharma used two biopolymers: PLA (Polylactic Acid) & PCL, to study the effect of applied voltage on the morphology of obtained fibers. She found that droplet-formation was lessened on incrementing voltage up to 20kV. This was due to more sedimentation of fibers due to more flow of liquid into the jet. On further increasing voltage, the electrostatic force to expel the charged jet increases, which results in low fiber-sedimentation & hence the droplet-formation increases as shown in Fig.5. [17].

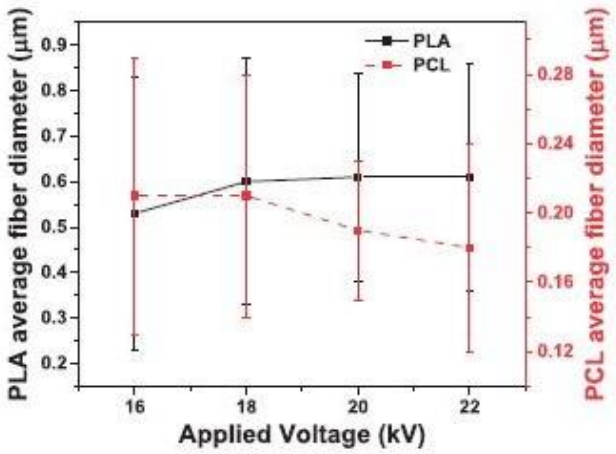

Fig.5. Diagram representing the variation of diameter of PLA & PCL fibers with the supply of applied voltage.

B. Polymer Concentration

Generally, the increment in polymer concentration (under the same conditions of voltage supplied, temperature, collector to nozzle distance, flow rate, etc.) enhances the resultant fibers' thickness [10]. A higher concentration of polymer not just brought about a bigger breadth of ZnO-nano fibers yet, in addition, lead to more extensive distribution of nanofibers distance across because of non-uniform discharge of liquid stream [18].

C. Temperature

Mostly it is seen that the increment in temperature of polymer solution creates fibers of less diameter due to an increase in evaporation rate & decrease in viscosity. But the neighboring temperature does not affect the size and the morphology of the resultant fibers. Clerck used ethanol for the polymer PVP (Polyvinyl Pyrrolidine), while for the polymer CA (Cellulose Acetate), a combination of Acetone and N, N-dimethyl acetamide (DMAc) was

utilized as a dissolvable. The tests demonstrated that two significant factors were reliant on temperature and affected the normal fiber measurement. The first factor was the dissolvable dissipation rate (i.e., evaporation rate) that incremented with expanding temperature & therefore jet took more time to get solidified, continuing the jet's elongation, hence decreasing the fiber diameter. The second factor was the polymer solution's viscosity that diminished with expanding temperature because of getting the freedom to move apart, increasing the stretching rate, and decreasing fibers' diameter. At the lowest temperature (283 K), the first factor was found supreme over second due to exponential increment of solvent evaporation rate with increasing temperature & at the higher temperatures (303 K), the second factor was found supreme over first due to exponential decrease of viscosity with increasing temperature. Therefore. We got thinner fibers at both temperatures. At intermediate temperature (293 K), the fiber diameter increased due to a combination of both factors [4]. Again, the increment in intensifying temperature brought about diminished distance across size and greater consistency of ZnO-nanofibers because of PVA deterioration (Polyvinyl Alcohol). The ideal intensifying temperature and term were discovered to be 500°C and 2h correspondingly. No critical change in ZnO-nanofibers distance across and structure had been observed after 2h strengthening at 500° C [18].

D. Humidity

As we normally know that fast evaporation takes place at low humidity, which, in turn, results in the formation of fibers of greater diameter. On the other side, slow evaporation occurs at higher humidity giving fibers of low diameter. As we increase the RH (Relative Humidity) value, the freezing process gets retarded & the liquid in the jet gets much more time to flow. This phenomenon can be easily understood by the simplified diagrammatical representation of jet formation on different RH value variations in Fig.6 [3].

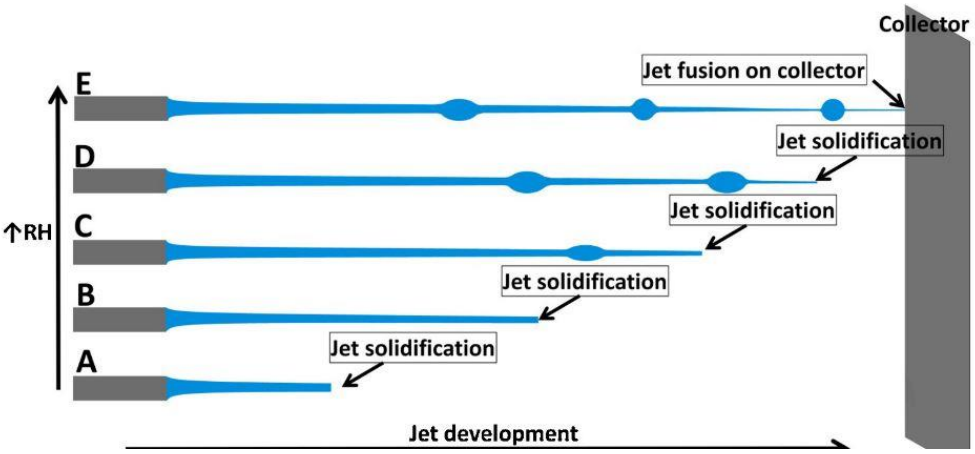

Fig.6. Conventional diagram representing the development of jet at different values of RH.

In Fig.6. A, B represents fibers of low diameter;
C, D represents bead- formation on fibers;
E represents jet fusion on the collector plate due to sedimentation.

Humidity levels increase/decrease the size of nanofibers according to the chemical bonding of the polymer. In 2007 with PEO fibers where water was used as a solvent, it was seen that higher RH values decrease the size of resultant fibers. Clerck in 2009 saw the impact of humidity on two polymers: CA (Cellulose Acetate) & PVP (Polyvinyl Pyrrolidone). Both had the opposite impact on the diameter of nano-fibers as a result of increasing humidity. PVP was dissolved in ethanol, which consumes the surroundings water easily throughout the electro spinning process. This, in turn, doesn't permit dehydration during the jet's flight, which results in a clear crystalline film created by fused fibers at a higher value of humidity (60% RH), i.e., no formation of precise nanofibers occurs. At lower RH values, the creation of fibers was partial due to partial evaporation of the solvent. It was observed that with increment in RH values (from 20% to 30% & from 30% to 45%), the polymer solutions were unable to solidify faster. Hence more stretching takes place & we get nanofibers of lower thickness. In the same manner, CA was dissolved in acetone, DMAc. Including water in it gives rise to rapid precipitation at higher RH values, which in turn stops the stretching of the jet, giving nanofibers [8], [19] of more thickness [4]. Jan Pelipenko also proved that higher humidity levels give rise to a slow evaporation rate, providing more stretching of jet and thinner nanofibers in output [3].

III. Summary

In the previous sections, a concise preface to the nanofibers, their demand in forthcoming years due to possessing advanced features, and the process of electrospinning used to fabricate nanofibers from different polymer solutions were described. Moreover, a literature review describing some of the parameters (like the applied voltage, polymer concentration, temperature, humidity) impacting nanofibers' size fabricated by electrospinning technique & using different polymer solutions was explained. It was noticed that the parameters try to increase/decrease the diameter of nanofibers according to the variation in their values & also with the variation in the polymer solution. This shows that the solvent's nature, in which the polymer is dissolved, also influences nanofibers' size. So, in the future, those solvents should be used, which help decrease the size of nanofibers & reduce the impact on the crystalline nature of the resultant nanofibers.

IV. Acknowledgments

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