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Effect of Processing Parameters on Morphology of Electrospun Fibers

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ABSTRACT: On the basis of electrostatic repulsive force electrospinning technique fabricates fibers of diameter from nano to micro size range. The technique attracted much attention due to its nanoscale output. Nano or micro fibers are used in making of biomedicine and drug delivery. Electrospinning is easy and less expensive method. Electrospinning comes with some parameters related to instrumental, solution based and ambient. The optimization in parameters of electrospinning provides effective and efficient fabrication of fibers. The change in these parameters helps to control morphology, size, porosity, surface area and topography of parameters. Electrospinning technique provide wide range of material selection and flexibility in parameters control, due to such property technique having widespread applications in drug and gene delivery, wound dressing and tissue engineering.

KEYWORDS: Electrospinning, Drug delivery, Parameters, Morphology, Optimization.

I. INTRODUCTION

Electrospinning technology fabricate ultrafine fibers from polymer solution. The technology is based on the electrostatic force where high voltage is applied on polymer solution which makes fibers of micro to nanometer scale.[1] Fibers are prepared from various methods such as phase separation, self-assembly, template synthesis and mechanical drawing. Electrospinning is a conventional technique, it requires simple tools, easy to operate and cost effective than the other methods.[2] the electrospinning system used in different fields such as filtration, cosmetic mask, military protecting clothing, wound dressing[3], drug delivery,[4] enzyme immobilization[5] and tissue engineering.[4] The electrospinning technique provide alterations in parameters which are capable of control morphology, porosity and topography and density of fibers.[7]

In 1882 Rayleigh introduces the principle of electrospinning. Formhals patented electrospinning as for fabrication of small diameter fiber in 1934.[7] In the second patent of formhals they improved the drawbacks from earlier apparatus.[8] Researches on electrospinning process investigated the effect of various parameters on fiber's morphology and properties. Investigation on impact of parameters helps to control the morphology of fibers and making them applicable for various applications.[6] Electrospun fibers exhibit high surface area to volume ratio.[9] They are used as anode in lithium ion batteries[10]conducting and magnetic materials in micro or nano devices.[11] Due to the surface property of Electrospun fibers are used in the high performance air filters.[12] The different fields of applications need desired structures of fibers. The optimization in the parameters of electrospinning help to control the fibers structure and properties.

II. PROCESS

Basic setup of electrospinning contains three major parts, syringe pump with needle, high voltage supply and a collector. Syringe pump is filled with polymer solution and having needle at end. One end of high voltage is connected to the syringe and other to the collector.Various types of collectors are used to obtain different structures of fibers [14]

Process is starts with filling of polymer solution in syringe pump which control the rate of dispense. Needle is placed at a distance in centimeters from collector for proper solvent evaporation from fiber. The high voltage is applied in the setup. As the force applied on the syringe to push the solution, droplet get formed. At application of high voltage, solution overcomes the surface tension and conical shaped geometrical shape forms called as 'Tylor cone'. The electrostatic force make the continuous fiber jets runs toward the collector. When the fibers get ejected solvent evaporates and dry polymeric fibers are deposited on the collector.[1]

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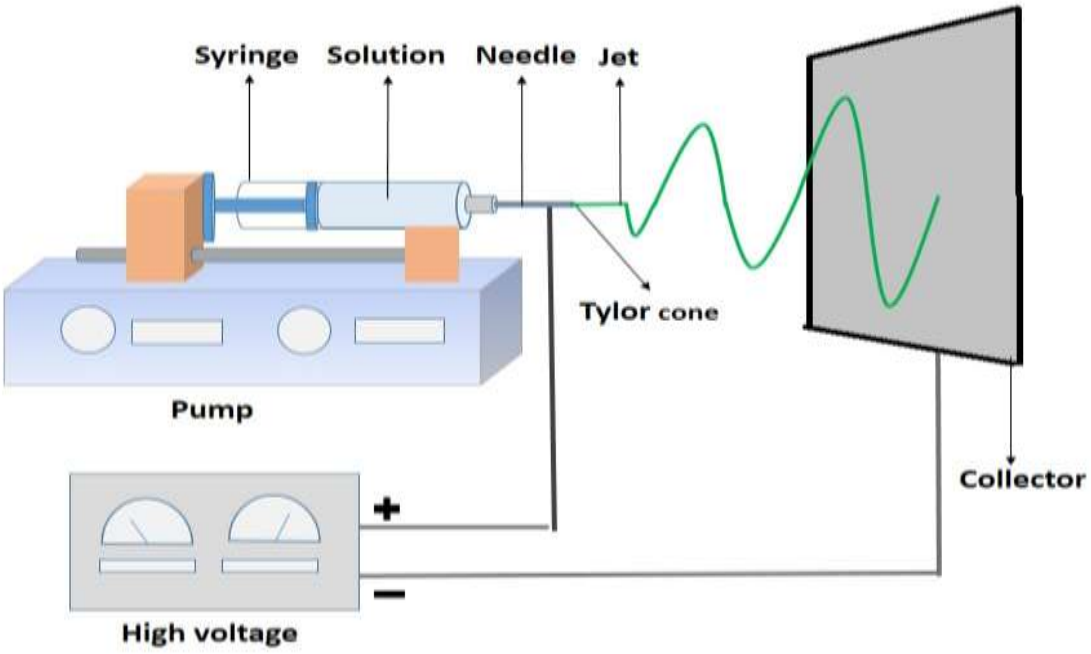

Figure 1 : Electrospinning setup

III. INSTRUMENTAL PARAMETERS

1) Voltage

The voltage applied to polymer solution produces electrostatic repulsive force. The force is required in certain value at which polymer solution overcome its surface tension and resulting in fiber formation. Fiber formation is depend on applied high voltage. Change in voltage directly effect on orientation of the molecular chain and affect crystal nature of fiber. Two types of voltage are used in electrospinning, direct current (DC) and alternating current (AC). Magnitude of voltage influence morphology and structure of the fiber.[15] application of AC current forms multiple jets on surface of liquid and DC current forms only one jet.[16] the appropriate value of voltage is depend on type of polymer solution used for electrospinning.[6] increase in the applied voltage decreases diameter of polymer. Further increase in thevoltage more the polymer ejection and fibers produces of large diameter with bead defects.[17]

2) Flow rate

Flow rate of the Electrospun solution influence the shape of polymer. Amount of spinnable solution is determined by solution flow rate.[15] With higher flow rate of solution production rate of electrospinning can be increased but at uncontrolled process effect on morphology of fibers.[18] Minimum flow rate help to accelerate the material transfer rate. A proper flow rate maintain the stability of Tylor cone at nozzle during electrospinning process. At constant voltage increase in the flow rate increases the diameter of prepared fiber.[15] at high flow rate insufficient drying of fiber jets leads to bead defect and flat or ribbon like fibers are observed.[19]De Schoenmaker et al. explains there is a limit of increase in fiber diameter. They reported increase in flow rate from 2 to 4.5 ml/h increases diameter of fiber, when flow rate increase beyond 4.5ml/h the diameter of fiber decreases. Fiber jets are ejected at applied voltage, when the flow rate exceeds the rate then imbalanced mass leads to formation of unstable jets and beaded fibers.[18]

3) Distance

Distance between the nozzle and collector effect on size and morphology of Electrospun fiber. The distance isrequired for evaporation of solvent and deposition of fiber on collector.[15] A particular distance is required to prevent defects of beaded, merged and flattened fibers. The distance

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is depend on electrospinning solution and experimental conditions. As the distance between nozzle and collector increases, thin and uniform fibers get formed. The fiber deposition area also increases with increase in distance.[18] Too far distance between nozzle and collector reduces the strength of electric field and velocity of jets, such state obtains fibers of large diameter. Too close distance makes fibers with beads defects. [15]In the conventional method of electrospinning 10 to 20 cm distance is a effective spinning distance.[19]

4) Receiving device

Different type of receiving devices are used to obtain random fibers, pattern fibers, ordered fibers and three-dimensional fibers. Metal collector obtain smooth fibers. Grounded solid collector (Fig.2D) with aluminum foil as collector obtain randomly oriented fibers. To obtain fibers with different patterns, guide wire collectors (Fig.2E) are used. When rotating devices are used as receiving device, more aligned fibers get obtained than stationary target. There are three different types of rotating devices; rotating mandrel (Fig.2A), rotating disk (Fig.2B) and rotating wire drum (Fig.2C) and. Coagulation of water and ethanol can be used for collection of three-dimensional fibers. Fibers get solidified in liquid bath (Fig.2F) and collected by rollers.[15] Fibers can be arranged by adjusting the rotation speed of collector.Conductive frame collector obtain better alignment than non conductive frames.[20]

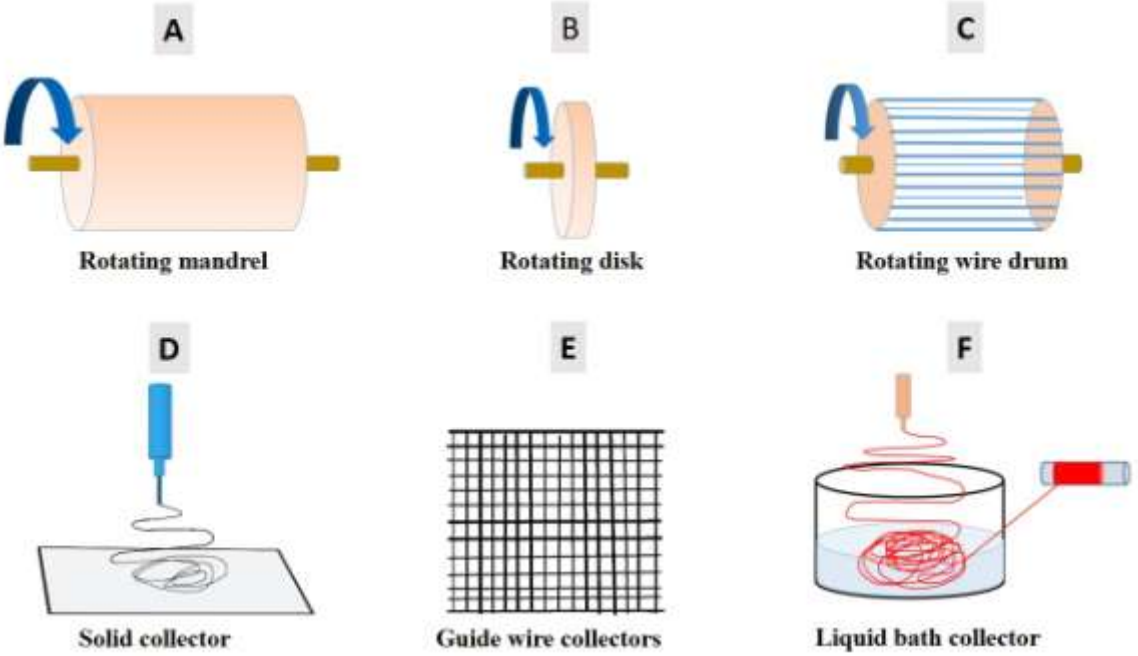

Figure 2 : Electrospinning receiving devices (A) Rotating mandrel, (B) Rotating disk, (C) Rotating wire drum, (D) Solid collector, (E) Guide wire collector, (F) Liquid bath collector.

IV. PROPERTIES OF POLYMER SOLUTION

1) Polymer concentration

Electrospinnability of polymer solution is depend on the concentration of polymer. Molecular weight of polymer directly affect rheological and electrical properties of polymer. If same polymer of different molecular weight is used for electrospinning then fibers of different diameter will produces.[21] The use of high voltage on lower polymeric concentration makes charged jets does not produces continuous fibers, the discrete droplets ejects from capillary. In the electrospinning solution increased polymer concentration increases chain entanglement and viscosity of solution.Electrospinnability of solution is depend on viscosity and surface tension of solution which is due to the concentration of polymer in solution. As the polymer concentration increases in solution, diameter of fiber also increases. When concentration increases above the

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certain limit the flow of solution disturb due to high viscosity of solution.[6]

2) Viscosity

Ability of solution to forms fibers is depend on the viscosity of electrospinning solution. viscosity, molecular weight and concentration of polymer combine determines the morphology of fibers.[19]In the electrospinning solution polymer of greater molecular mass and longer molecular length properly entangle molecular chain in solution and achieve viscosity. To prepare such solution the molecular mass of polymer is determined and then concentration of polymer is considered. If the concentration of polymer is increases then viscosity of solution is also increases. Morphology of fibers can be controlled by adjusting the viscosity of electrospinning solution to a certain limit.[21] solution of lower viscosity forms droplet without complete drying during electrospinning, it unable to form continuous fibers. For higher viscous solution high electric strength is required. The use of two solvents in preparation of solution for electrospinning achieve better fiber production due combine effect od solvent.[19]

3) Surface tension

The force applied in the plane of surface per unit length called as surface tension.[21] electrospinning solution made of mixture of polymer and solvent. Surface tension of solution is the attractive force between molecules of electrospinning solution. The surface tension is depend on composition of constituents.[19] To produce smooth and continuous fibers the applied electrostatic repulsive force on polymer solution is need to be in greater than its surface tension. Uniform fibers get forms when increase in the concentration of solution, it reduces the surface tension to the certain value. At constant concentration, smooth and continuous fibers are prepared by change in the solvent composition or addition of surfactant which helps to adjust the surface tension of solution.[15] In electrospinning solution multi-solvent system optimize the surface tension and viscosity parameters.[19]

4) Conductivity

Conductivity is defined as the electrification ability of polymer solution.[15] conductivity affect the electrospinning of polymer solution and morphology of fibers. Increase in the charge-carrying capacity rises the conductivity. Solutions of higher in conductivity and lower conductivity experiences respective tensile force in electric field. As the conductivity of solution increases, the diameter of Electrospun fiber decreases.[19] The polylectrolytic nature of natural polymer makes poor fibers than the synthetic fibers.[21] semi-conductive and insulating liquids with sufficient amount of voltage produces stable jet of fiber. The conductivity of solution can be adjusted by addition of salt. Sodium phosphate, potassium phosphate, lithium chloride and ammonium chloride are used to change the conductivity of solution.

V. ENVIRONMENTAL PARAMETERS

1) Temperature

In the electrospinning process the temperature affect the molecule of solution, conductivity, viscosity and evaporation rate of jets. As the temperature increases to the boiling point of the solvent used, increased evaporation of solvent molecule makes pores in Electrospun fiber.[21] Increase in the temperature improves the conductivity and reduces the viscosity of solution used in electrospinning. Temperature in the process of electrospinning improves the properties of solvent and impact on fibers prepared. Improved conductivity, viscosity and evaporation rate controls the fiber by decreasing size of diameter.[15]

2) Humidity

Humidity of environment impact on fiber size and porous nature of fibers prepared by electrospinning. Humidity and temperature are related to each other. Humidity decreases as the temperature increases. Decreased humidity help in evaporation rate of solvent during process. In higher humidity fibers with thick diameter get produced due to effect on volatility of solvent in the electrospinning process. Fibers of porous structure produced when hydrophobic polymers with organic solvent are used. Number and size of pores changes with change in the humidity in environment.[22]

3) Air pressure

Electrospinning process mostly done in the atmospheric pressure. Using of air pressure during process affect rate of evaporation. The change in air pressure affect diameter and deposition of fiber. Morphology of fibers can be optimized by using pressure. If the pressure goes to unstable then ejected fiber also get unstable and affect deposition of fibers. Unstable fiber

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deposition leads to affect the consistency of Electrospun fibers.[23]

Table no. 1 : Parameters and their effect on fibers structure

Sr. no.	parameters	Electrospun fibers morphology	
		Lower value	**Higher value**
1.	Voltage	Fibers of minimum diameter at high voltage	At too high value of voltage, beading occurs
2.	Flow rate	Fibers with smaller diameter	Fibers does not dry before reaching to collector
3.	Distance	Minimum distance required for drying the fibers	Beading in fibers
4.	Polymer concentration/ Viscosity	Beads and junctions in fibers	Fiber diameter increases
5.	Surface tension	Diameter of fiber decreases	Diameter of fiber increases
6.	Conductivity	Affect electrospinning	Uniform bead free fibers
7.	Temperature	diameter size increases	Viscosity decreases and Smaller fibers forms
8.	Humidity	At optimum level thin fibers obtained	Thick fibers obtained

VI. CONCLUSION

This study reviewed all parameters which control the morphology of Electrospun fibers. Parameters are associated with the basic components of electrospinning setup. The instrumental parameters and solution properties are interrelated with each other. Viscosity of the Electrospun solution and applied voltage are should be at critical value to obtain continuous fibers. The distance between needles to collector need to at particular where solvent get evaporates and dry fibers get deposit but it also work on intensity of applied voltage. Concentration of polymer is make impact on viscosity and surface tension of liquid for electrospinning. The change in these parameters affect the size and porosity of fiber. Electrospun fibers are used in various fields where they need different structures of fibers. All these parameters allow to control the morphology of Electrospun fibers by controlling these parameters.

REFERENCES

[1]. Huang Y., Xie Z. Electrospinning of Polymeric Nanofibers for Drug Delivery Applications. Journal of Controlled Release. 2014; 185:12-21.
[2]. Rahmani M., Bidgoli S. A., Rezayat S. M., Electrospun Polymeric Nanofibers for Transdermal Drug Delivery. Nanomed Journal. 2017; 4(2):61-70.
[3]. Schiffman J., Rieger K., Birch N. Designing Electrospun Nanofiber Mats to Promote

Wound Healing – A Review. Journal of Materials Chemistry B. 2013; 1:4531-4541.
[4]. Bahrami S., Kananii A. Review on Electrospun Nanofibers Scaffold and Biomedical Applications. Trends Biomater. 2010; 24(2):93-115.
[5]. Khan N. Applications of Electrospun Nanofibers in the Biomedical Field. Studies by Undergraduate Researchers at Guelph. 2012; 5(2):64-73.
[6]. Pillay V., Dott C., Choonara Y. A Review of the Effect of Processing Variables on The Fabrication Of Electrospun Nanofibers For Drug Delivery Applications. Journal of Nanomaterials. 2013:1-23.
[7]. He J., Liu Y., Xu L. Apparatus for Preparing Electrospun Nanofibers: A Comparative Review. Materials Science and Technology; 2010; 26(11):1275-1287.
[8]. Formhals A. Process and Apparatus for Preparing Artificial Threads. Us Patent 1-975-504, 1934.
[9]. Sharifi F., Sopriyarachchi A. Altural H. Fiber Based Approaches As Medicinal Delivery Systems. Mechanical Engineering Publications; 2016:1-66.
[10]. Yao W., Yang J., Wang J. Synthesis and Electrochemical Performance of Carbon Nanofiber-Cobalt Oxide Composites. Electrochimica Acta. 2008; 53(24):7326-7330.
[11]. Macdiarmid G.,Jones W., Norris I. Electrostatically-Generated Nanofibers Of Electronic Polymers. Synthetic Metals. 2001; 119(1-3):27–30.
[12]. Park S., Kim C., Choi Y., Yang S. Preparations of Pitch-Based Cf/Acf Webs By Electrospinning. Carbon. 2003; 41(13):2655–2657.
[13]. Cleeton C., Keirouz A., Chen X. Electrospun Nanofibers for Drug Delivery and Biosensing. Acs Biomaterials Science And Engineering. 2019; 10:1-81.
[14]. Schiffman J., Schauer C. A Review-Electrospinning of Biopolymer Nanofibers and Their Applocations. Polymer Reviews. 2008; 48(2):317-352.
[15]. Zhang P., Yao Q., Sun Y. Electrospun Fibers and Their Application In Drug Controlled Release, Biological Dressings, Tissue Repair, And Enzyme Immobilization. Rcs Advances. 2019; 9:25712–25729.
[16]. Domokos A., Vass P., Szabo E. Scale Up Of Electrospinning Technology: Applications in Pharmacerutical Industry. Nanomedicine and Nanobiotechnology. 2019; 12:1-24.
[17]. Yongtao Y., Yuncheng X., Bing W. Recent Development in Electrospun Polymer Fiber and Their Composites with Shape Memory Property: A Review. Pigment & Resin Technology. 2018; 47(1):47-54.
[18]. Salehhudin H., Mohamad E., Afifi A. Multiple-Jet Electrospinning Methods for Nanofibre Processing: A Review. Taylor & Francis in Materials and Manufacturing Processes. 2017; 10:1-70.
[19]. Bhattarai R., Bachu R., Boddu S. Biomedical Applications of Electrospun Nanofibers: Drug and Nanoparticle Delivery. Pharmaceutics. 2019; 11(5):1-30.
[20]. Quynh P., Sharma U., Ph.D., Mikos A. Electrospinning of Polymeric Nanofibers for Tissue Engineering Applications: A Review. Tissue Engineering. 2006; 12(5): 1197-1211.
[21]. Thenmozhi S., Dharmaraj N., Kadirvelu K. Electrospun Nanofibers: New Generation Materials for Advanced Applications. Materials Science and Engineering. 2017; 217:36-48.
[22]. Medeiros E., Mattoso L., Gregorski K. Electrospun Nanofibers of poly (Vinyl Alcohol) Reinforced with Cellulose Nanofibrilis. J Journal of Materials and Bioenergy. 2008; 2(1-12):231–242.
[23]. Prajuli D., Koomsap P., Parkhi A. Experimental Investigation On Process Parameters Of Near-Field Deposition Of Electrospinning Based Rapid Prototyping. Virtual and Physical Prototyping. 2016; 11(3):193-207.