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Review-Paramatreic investigation of electrospun nanofiber

[a]Sachin Chavan [b] Nand Jee Kanu

[a b] *Research Scholar Bharati Vidyapeeth University College of Engineering, Pune-Satara Road ,Pune410043,India*

Email-sschavan@bvucoep.edu.in,sachin_72887@rediffmail.com,Contact-9271635407

Abstract- Nanotechnology has brought revolutionary change the field of advances materials and their properties. The electrospinning process offers a potential enabling breakthrough to remove the barriers by dramatically reducing fiber diameters, resulting in vast improvements in fiber mechanical properties. To start with this process we should be familiar with the parameter with are contributing to get optimum diameter. For the new research here we have reviewed data for various parameters such as viscosity, molecular weight, ionic salt, voltage, distance between spinneret and collector, flow rate and concentration.

***Keywords**:Nanotechnology*,electrospining,process parameters and diameter

1.Introduction

Drawing, Template Synthesis, Phase Separation and Self assembly are the methods useful for developing 1-D nano structures but these methods have limitations of scalability. In contrast, Electrospinning is a simple and versatile process to generate uniform diameter fibers in random, as well as aligned fashion from wide variety of polymer, ceramic or composite solutions in cost effective manner. Low cost, scalability for mass manufacture, several areas of applications, wide variety of materials are the parameters that make electrospinning very popular process among research community associated with One Dimensional (1-D) nanostructures. Thus, the electrospinning process seems to be the only method which can be further developed for mass production of one-by-one continuous nanofibers from various polymers[17].

There are fundamental four components associated with the electrospinning process viz. spinneret, voltage supply, and collector and dispensing pump as seen in the schematic of Figure 1. There are basically three parts 1) A high voltage supplier, 2) A capillary tube with a pipette or needle of small diameter, and 3) Metal collecting screen. One electrode is placed into the polymer solution/melt and the other attached to the metal collector. The electric field produces surface tension on the polymer, which induces a charge on the surface of the polymer. Further with increasing the electric field, a critical value is attained at which the repulsive electrostatic force overcomes the surface tension and the charged jet of the fluid is ejected in form of polymer nanofibers. Also, for the quality and variety of nanofibers produced by electrospinning, certainly cost associated is very-very low. Figure 1.a is schematic for aligned and Figure 1.b for random fibers.

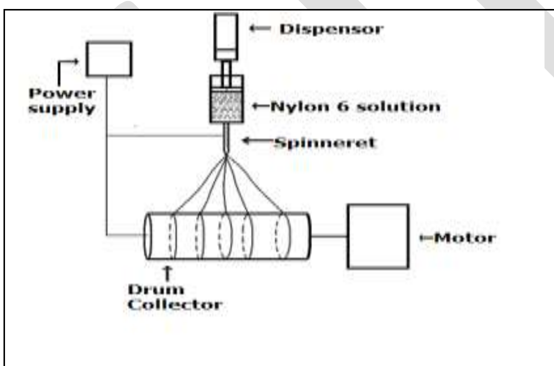


Fig 1.a)Schematic of Electrospinning Setup for Aligned Fiber Deposition[19]

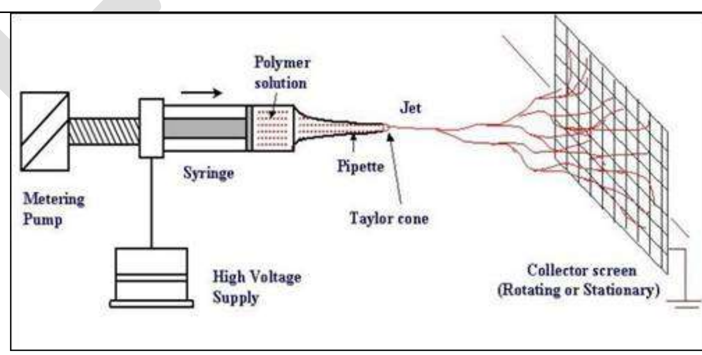


Fig 1.b) Schematic of Electrospinning Setup for Random Fiber Deposition[19]

To get uniform fibers and minimum diameter depends on main three controlling parameters i.e solution, process and ambient parameters as shown in the table 1.1

Table 1.1. Electrospinning Parameters and Fiber Characteristics [18]

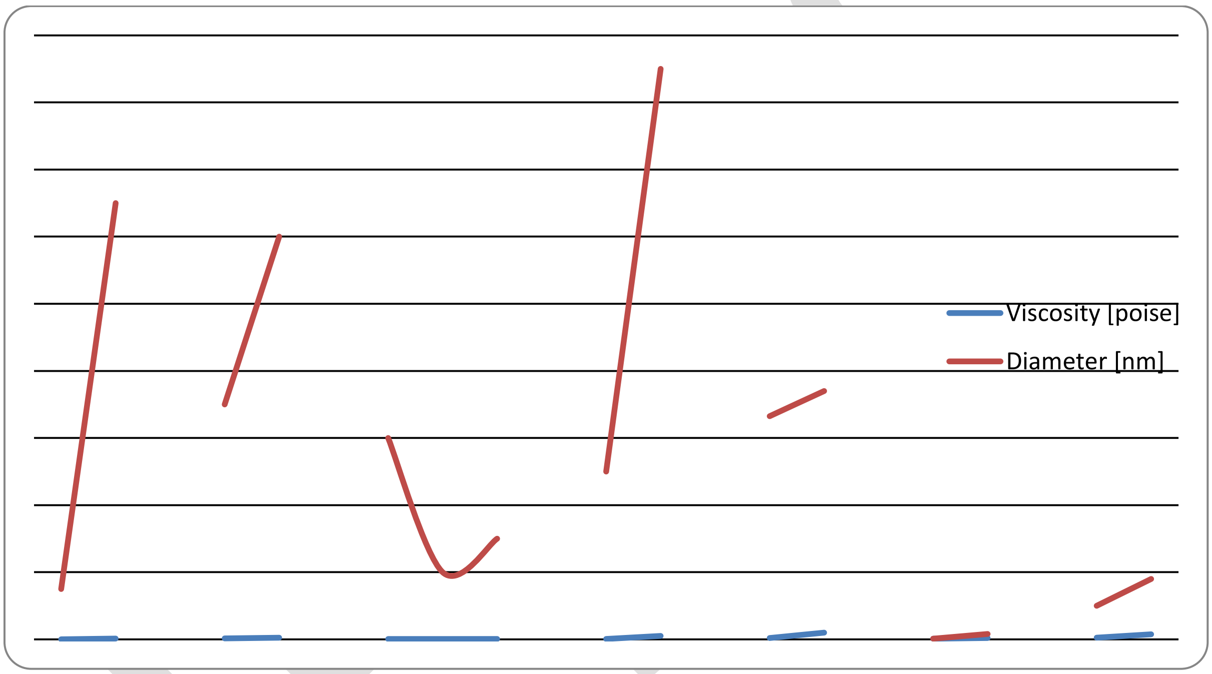
Controllable Parameters	Fiber Characteristics
A) Solution Parameters: Viscosity, Concentration Conductivity, Surface tension, Elasticity, Molecular weight	A) Structure: Diameter, Solid, hollow, ribbon, Surface roughness, with beads or pores
B) Process Parameters: Rate of dispensing, Potential difference, Distance between spinneret and grounded collector	B) Alignment: Random Non-woven, Aligned or Unidirectional
C) Ambient Conditions: Temperature, Humidity, Velocity of Air	C) Properties: Modulus, Shear strength, Glass transition temperature, Surface to weight ratio, Refractive Index etc.

Review of Solution parameters –Viscosity,Concentration ,Molecular weight and Process Parameters: Rate of dispensing, Potential difference, Distance between spinneret and grounded collector is done as follow

1.1. Effect of viscosity [independent parameter]:

SOLUTIONS	RESULTS	REFERENCES
Aluminium Borate nanofibers. Solution: Polyvinyl Alcohol [PVA] &Aluminium Acetate stabilized with Boric Acid.	1. Beads formed at low viscosity. 2. To obtain smooth fibers viscosity is increased. 3. For spinnability, viscosity must be neither very high nor very low. 4. Viscosity does not change with time [indicating stability of solution]. 5. Viscosity increases with increasing concentration of solute. 6. Thin fibers formed at 6% concentration of solute, whereas large diameter fibers formed at 10% concentration of solute. 7. Low spinnabiliity at 6% concentration of solute whereas high spinnability at 10% concentration of solute.	1
Nylon 6 [15%-25%]; Solvent: Formic Acid [96.7%]	1. If viscosity increases then diameter increases. 2. If concentration increases then viscosity increases. 3. More concentration and more viscosity and lowering surface tension favor the uniform fibers. 4. If viscosity is increased along with surface tension then diameter increases.	2
Polyurethene Polymer Solution [in various concentration of salt]; Solvent: Dimethylformamide	1. If viscosity increases then length of jet increases. 2. If concentration of salts increases then viscosity first increases and then decreases. Here fiber diameter decreases but after adding more salts fiber diameter increases.	5
Nylon 6,6, PA 6,6; Solvent: Formic Acid. Nylon 4,6, PA 4,6; Solvent: Formic Acid. Polyurethanes PU; Solvent: Dimethylformamide Polycarbonate PC;	1. At viscosity above 20 poises, electospinning was prohibited. 2. At viscosity less than 1 poise droplets formed. 3. Polymer concentration is proportional to solution viscosity. 4. Large diameters fibers being observed at higher viscosity.	6

Solvent: Dimethylformamide		
Tetra Ethyl Orthosilicate [TEOS] nanofiber using electrospinning.	1. At higher viscosity lower beads formed and vice versa. 2. Diameter increases as viscosity increases and vice versa. 3. If viscosity increases then there is good surface quality. 4. If viscosity increases than porosity increases.	7
Curcumin [1%], Geletin [1.5%]; Solvent: Formic Acid [96.7%]	1. The paper indirectly suggests that with increase in viscosity, polymeric concentration increases & hence fiber diameter increases. 2. Viscosity plays major role in determining fibers diameters/jet radius.	10
Polyacrylates Solution PA	1. The paper shows that with increase in viscosity fiber diameter increases.	11



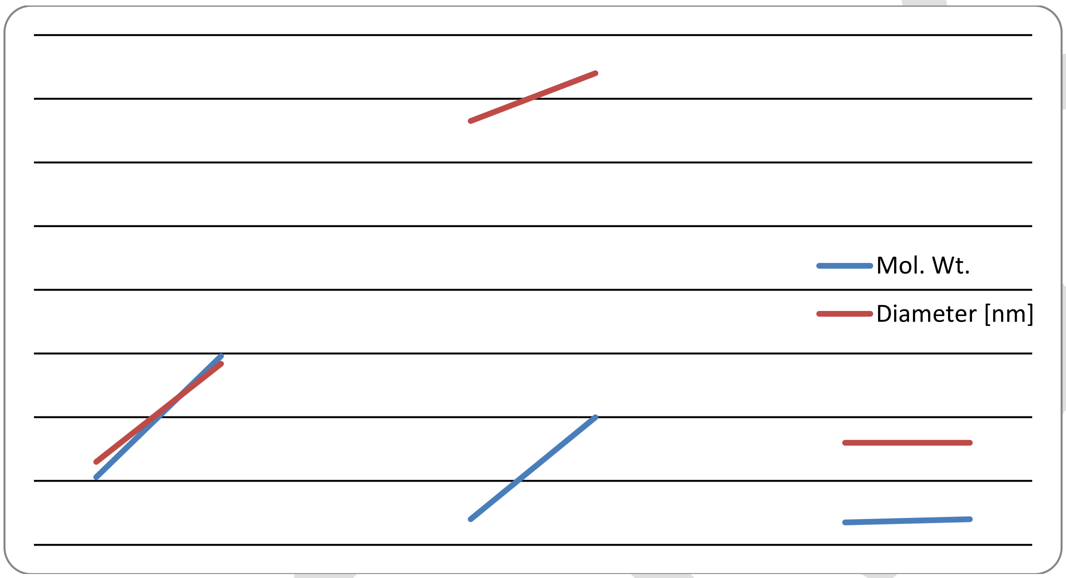
Inference

- As viscosity increases beads are reduced.
- Higher the viscosity higher the diameter.
- For spinnability, viscosity must be neither very high nor very low.

1.3. Effect of Molecular Weight (Solution parameter)

SOLUTIONS	RESULTS	REFERENCES
<u>Biopolymers:</u> Chitosan; Solvent: AcOH, TFA Chitin; Solvent: HFIP	The paper reveals the mystery on molecular weight as, with increase in molecular weight, fiber diameter increases.	3
Tetra Ethyl Orthosilicate [TEOS] nanofiber using electrospinning.	1. At higher molecular weight there are less beads formation. 2. Good surface quality at higher molecular	7

	weight. 3. Diameter increases with increasing molecular weight.	
PMMA [Polymethyl Methacrylate]; Solvents: Toluene, Dichloromethane, Tetrahydrofuran,1,1,1,3,3,3-Hexafluoro-2 Propanol [HFIP], Acetone, Chloroform, 2,2,2-Trifluoroethanol [TFE]	The paper states that the different morphologies of nanofibers were not due to solvents abilities to dissolve solute [PMMA] but rather due to other properties such as boiling points, molecular weight and molecular structure of the solvent.	8
Polyacrylates Solution PA	1. Fiber diameter is constant at high and low molecular weight. 2. The elecrospunnanofiber diameter depend mainly on the polymer and its molecular weight	11

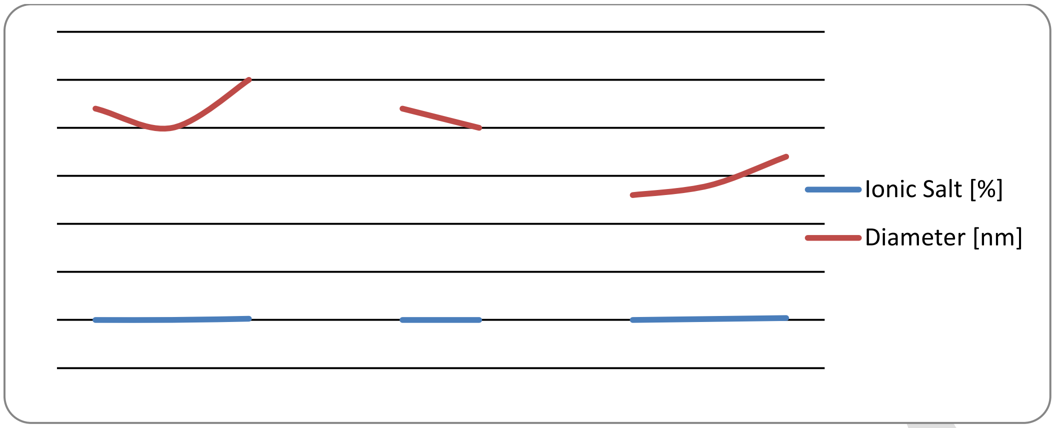


Inference

- At higher molecular weight there are less beads formation.
- Diameter increases with increasing molecular weight.

1.3. Effect of Ionic Salt (Solution Parameter)

Polyurethene Polymer Solution [in various concentration of salt]; Solvent: Dimethylformamide	1. Fiber diameter decreases with salt but after adding more salt fiber diameter increases. 2. Fiber diameter decreases with conductivity. 3. Jet length of polymer solution on drum is decreased with increasing conductivity. 4. Length of jet decreases with increasing the percentage of salt in the polymer solution. 5. With increase in concentration of salt conductivity increases and surface tension increases.	5
Tetra Ethyl Orthosilicate [TEOS] nanofiber using electrospinning.	1. Addition of ionic salt reduces beads. 2. Addition of ionic salt gives uniform diameter and reducing diameter of nanofibers. 3. Addition of salt increases surface quality, and reduced diameter has more enhanced mechanical properties.	7
Polyacrylates Solution PA	The paper suggests that with increase in amount of ionic salt fiber diameter increases.	11



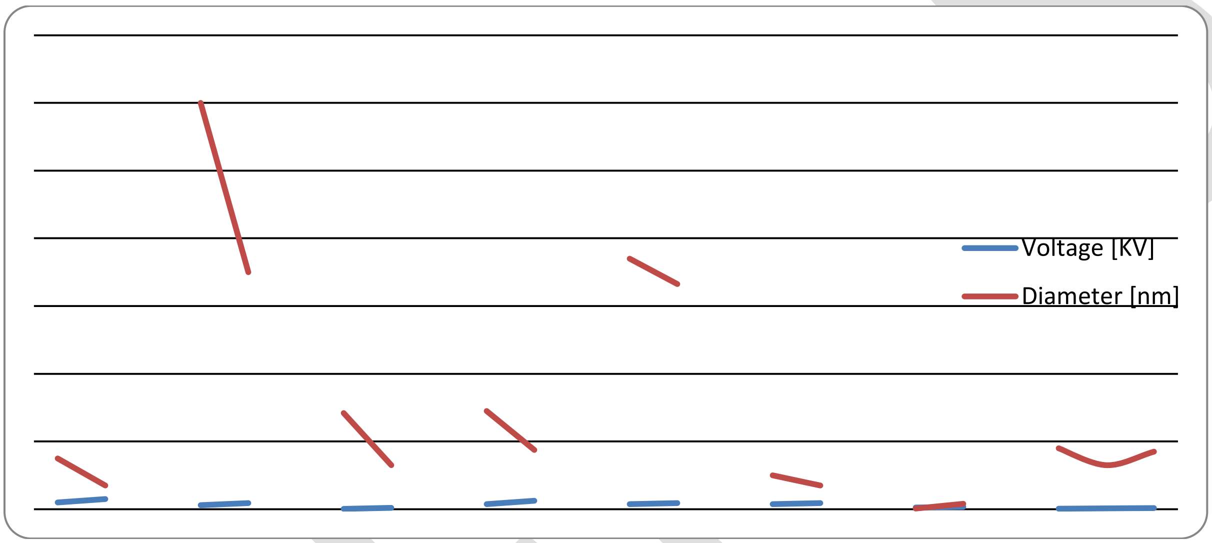
Inference

- Addition of ionic salt reduces beads.
- Addition of ionic salt gives uniform diameter and reducing diameter of nanofibers.

1.4. Effect of Voltage ([Process parameter)

SOLUTIONS	RESULTS	REFERENCES
Aluminium Borate nanofibers. Solution: Polyvinyl Alcohol [PVA] &Aluminium Acetate stabilized with Boric Acid.	High voltage i.e. greater stretching of solution due to greater columbic forces and thus reducing the fiber diameter.	1
Nylon 6 [15%-25%]; Solvent: Formic Acid [96.7%]	1. More voltage results in thin diameter. 2. Increase in voltage favours fiber diameter.	2
Biopolymers: Chitosan; Solvent: AcOH, TFA Chitin; Solvent: HFIP	1. The electrospinning process is initiated at a point at which the electrostatic force in a solution overcomes the surface tension of the solution. 2. Increasing voltage results in higher stretching and thus finer fibers as well as higher extrusion of polymer from the needle that could cause thicker fiber formation. 3. The effect of decreasing distance is almost same as that of increasing voltage.	3
Solution of PCL [Mn=80000] & the Solvent N,N-Dimethylformamide [DMF] & Methylene Chloride [MC].	1. Whipping is the main reason for the decreasing the fiber diameter, as the voltage increase, diameter decreases.	4
Nylon 6,6, PA 6,6; Solvent: Formic Acid. Nylon 4,6, PA 4,6; Solvent: Formic Acid. Polyurethanes PU; Solvent: Dimethylformamide Polycarbonate PC; Solvent: Dimethylformamide	1. Smooth fiber at low voltage. 2. Rough fiber at high voltage. 3. Higher applied electric voltage ejects more fluid in a jet. 4. Higher fiber diameter at more electric voltage.	6
Tetra Ethyl Orthosilicate [TEOS] nanofiber using electrospinning.	1. If electric field increases then beads formation increases. 2. Diameter increases when electric field	7

	increases. 3. Lower electric field results in good surface quality.	
Tetra Ethyl Orthosilicate [TEOS] nanofibers; Solution: Gel process is adapted to get the required TEOS solution.	1. Less diameter at high voltage. 2. TEOS fiber with minimum diameter are produced with two extreme values of voltage and distance between spinneret and ground collector.	9
Curcumin [1%], Geletin [1.5%]; Solvent: Formic Acid [96.7%]	1. More electric potential/electric potential base is responsible for increase in fiber diameter. 2. Electric field has moderate effect on jet radius.	10
Polyacrylates Solution PA	With increase in voltage, fiber diameter first increases, then decreases and again increases.	11



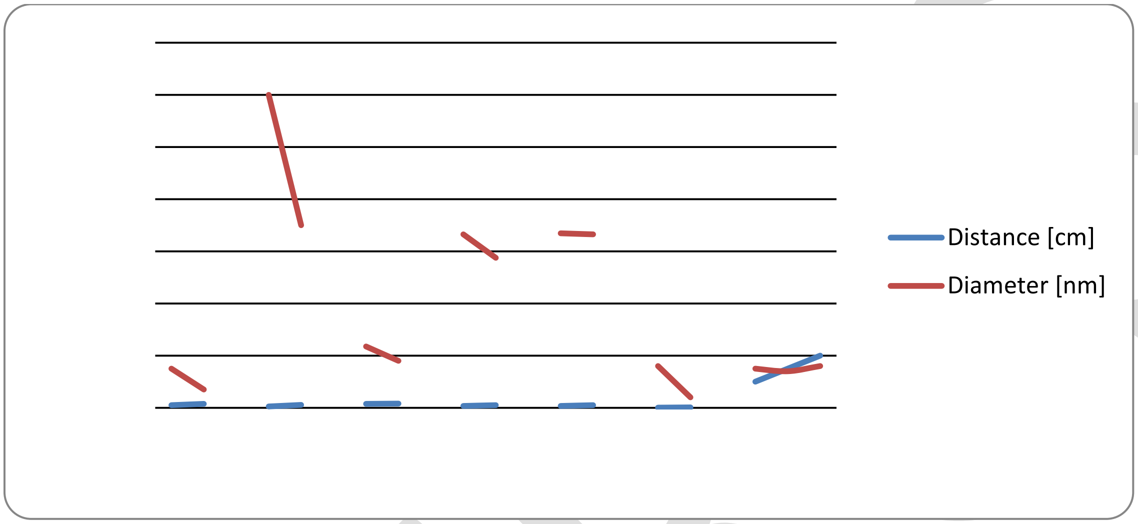
Inference

- Higher the voltage lower is the diameter.

1.5. Effect of Distance (Process Parameter)

SOLUTIONS	RESULTS	REFERENCES
Aluminium Borate nanofibers. Solution: Polyvinyl Alcohol [PVA] &Aluminium Acetate stabilized with Boric Acid.	Distance between tip and drum must be more for thin fibers.	1
Solvent: Formic Acid [96.7%]	More distance is responsible for thin nano fibers.	2
Biopolymers: Chitosan; Solvent: AcOH, TFA Chitin; Solvent: HFIP	1. Distance has direct influence on jet flight and electric field strength. 2. Decrease in distance shortens flight times and solvent evaporation time and increases the electric field strength which results in more bead formation.	3
Solution of PCL [Mn=80000] & the Solvent N,N-Dimethylformamide [DMF] & Methylene Chloride [MC].	With increase in voltage, and then increase in flow rate and keeping distance constant i.e. 15 cm for same experiment time, it has been observed that ultimately fiber diameter increases.	4
Tetra Ethyl Orthosilicate [TEOS]	With increase in distance there is increase in	7

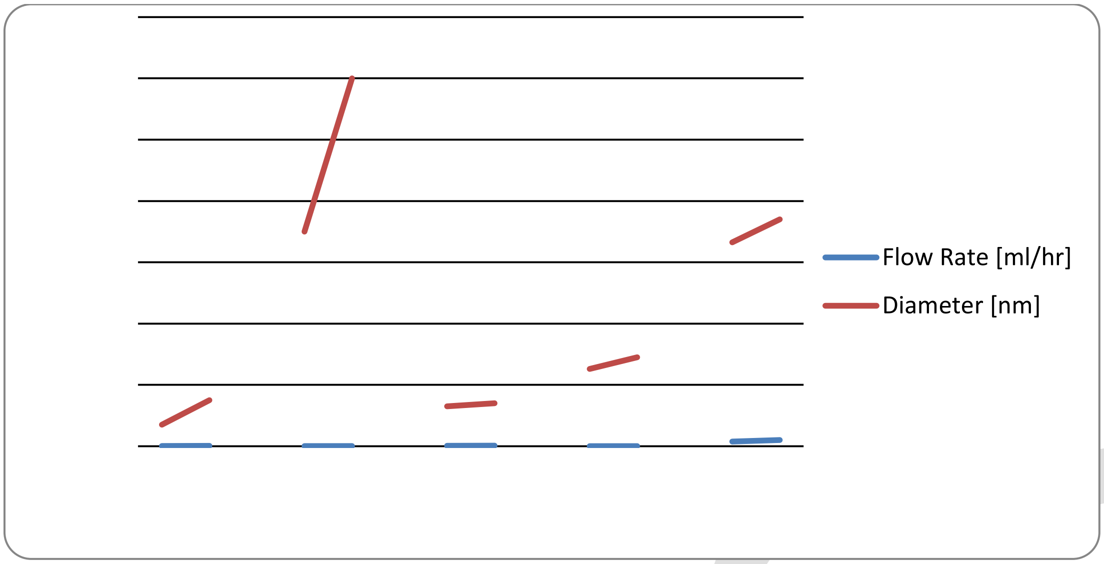
nanofiber using electrospinning.	diameter.	
Tetra Ethyl Orthosilicate [TEOS] nanofibers; Solution: Gel process is adapted to get the required TEOS solution.	1. With increase in distance diameter reduces. 2. TEOS fibers with minimum diameter are produced with 02 extreme values and distance between spinneret and ground collector.	9
Curcumin [1%], Geletin [1.5%]; Solvent: Formic Acid [96.7%]	1. With increase in distance, jet radius decreases. 2. With increase in collector distance, radius of fiber decreases.	10
Polyacrylates Solution PA	With distance fiber diameter increases first, then decreases and finally increases.	11



Inference
As distance increases diameter reduces.

1.6. Effect of Flow Rate(Process Parameter)

SOLUTIONS	RESULTS	REFERENCES
Aluminium Borate nanofibers. Solution: Polyvinyl Alcohol [PVA] &Aluminium Acetate stabilized with Boric Acid.	When feed rate increases then diameter increases.	1
Solvent: Formic Acid [96.7%]	More flow rate means more diameters.	2
Biopolymers: Chitosan; Solvent: AcOH, TFA Chitin; Solvent: HFIP	1. Increase in flow rate increases fiber diameter and bead size. 2. Smaller diameter of tip reduces clogging as well as the no. of beads which leads to less exposure of the solution to the atmosphere.	3
Solution of PCL [Mn=80000] & the Solvent N,N-Dimethylformamide [DMF] & Methylene Chloride [MC].	1. With increase in voltage, and increase in flow rate and keeping distance constant i.e. 15 cm, then height of Taylor-Cone [pixel points] decreases and thus fiber diameter decreases.	4
Tetra Ethyl Orthosilicate [TEOS] nanofiber using electrospinning.	1. As feed rate increases then beads increases. 2. Larger diameter forms at higher feed rate. 3. As feed rate increases surface quality decreases.	7

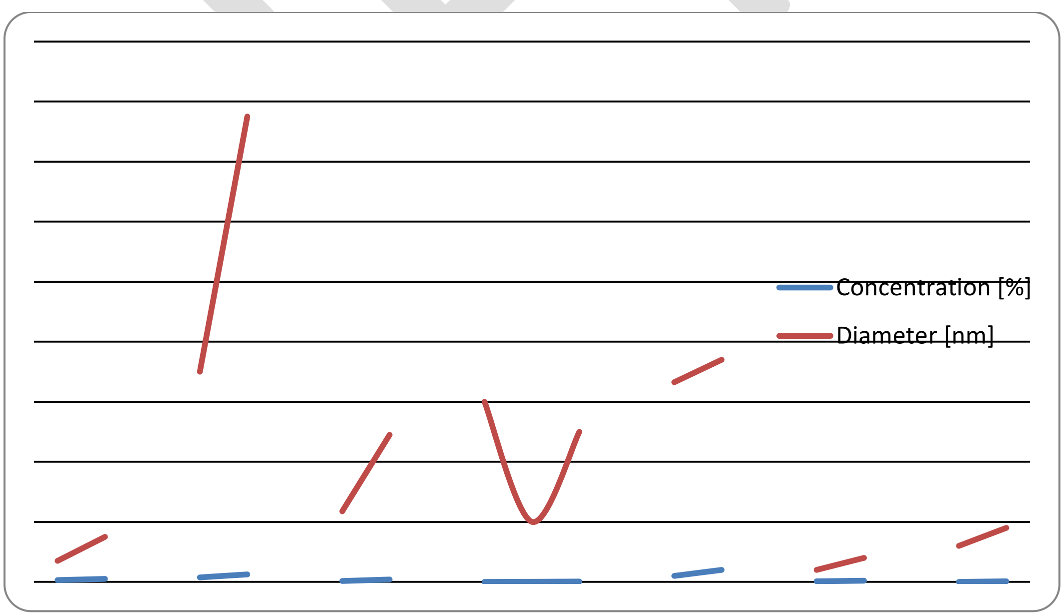


Inference
As flow rate increases diameter increases.
As flow rate increases beads increases.

1.7. Effect of Concentration (Solution parameters)

SOLUTIONS	RESULTS	REFRENCES
Aluminium Borate nanofibers. Solution: Polyvinyl Alcohol [PVA] &Aluminium Acetate stabilized with Boric Acid.	1. At 6% concentration of solute, thin fibers form at low viscosity whereas at 10% concentration of solute, large diameter of fibers form at high viscosity. 2. Finally increase in concentration, increases viscosity until smooth fibers obtained. 3. For spinnability, concentration must be neither very high nor very low. 4. At 6%, low spinnability and at 10%, high spinnability.	1
Solvent: Formic Acid [96.7%]	1. Concentration increases then viscosity increases. 2. Furthermore concentration and more viscosity and lowering surface tension favours the uniform fibers. 3. Beads disappear when concentration increases.	2
Biopolymers: Chitosan; Solvent: AcOH, TFA Chitin; Solvent: HFIP	1. Determines the resistance of polymer solution against stretching and fiber forming in electrospinning technique. 2. Decreasing the concentration increase the diameter of electrospun fibers.	3
Polyurethene Polymer Solution [in various concentration of salt]; Solvent: Dimethylformamide	1. With increase in concentration of salts, fiber diameter is decreased and after adding more salts, fiber diameter is increased. 2. Length of jet decreases with increasing the	5

	percentage concentration of salt in the polymer solution. 3. With increase in concentration of salts, viscosity increases and so length of jet increases [by using polyvinyl alcohol].	
Nylon 6,6, PA 6,6; Solvent: Formic Acid. Nylon 4,6, PA 4,6; Solvent: Formic Acid. Polyurethanes PU; Solvent: Dimethylformamide Polycarbonate PC; Solvent: Dimethylformamide	1. Higher polymeric concentration means large diameter. 2. Fiber diameter depends primarily on jet size as well as on polymer content in the jet.	6
Tetra Ethyl Orthosilicate [TEOS] nanofiber using electrospinning.	1. Higher concentration results in less beads formation. 2. Diameter as per power law relationship with exponent of about 0.5 and 0.3. 3. Good surface quality can be obtained at higher concentration.	7
Curcumin [1%], Geletin [1.5%]; Solvent: Formic Acid [96.7%]	1. With increase in polymer concentration/polymer concentration base, fiber diameter increases. 2. Polymer concentration has moderate effect on jet radius.	10
Polyacrylates Solution PA	1. With increase in salt content [which leads to increase in viscosity finally], and ultimately fiber diameter increases. 2. The fiber diameter of the electrospun web depend mainly on the polymer and its molecular weight.	11



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- Concentration increases then diameter increases
- Concentration increases then viscosity increases.
- Beads disappear when concentration increases.

Conclusion.

1. Electrospinning is one of the best methods for spinning the polymer nanofibers .
2. Higher the viscosity higher the diameter.
3. For spinnability, viscosity must be neither very high nor very low.
4. Diameter increases with increasing molecular weight.
5. Addition of ionic salt gives uniform diameter and reducing diameter of nanofibers.
6. Higher the voltage lower is the diameter.
7. As distance increases diameter reduces.
8. As flow rate increases diameter increases.
9. Concentration increases then diameter increases
10. Concentration increases then viscosity increases.

REFERENCES:

1.Mehtap Ozdemir, ErdalCelik, UmitCocen, Effect of Viscosity on the Production of Alumina Borate Nanofibers Via Electrospinning, Original Scientific Article, VDK 6203:66,017,ISSN 1580-2949, MTAEC9, 47(6)735(2013).

2. Mohammad Chowdhary and George Stylios, Effect of Experimental Parameters on the Morphology of Electrospun Nylon 6 fibers, International Journal of Basic & Applied Sciences IJBAS-IJENS VOL: 10 NO: 06.

3. MasoumehValizadeh, SeyedAbdolkarimHosseiniRavandiAndSeeramRamakrishna, Recent Advances in Electrospinning of some selected Biopolymers, Journal of Textiles and Polymers, Vol-1, No.2, June 2013.

4. Yuanyuan Liu, Changjuan Jing, Dali Liu, Qingxi Hu, Research on high quality NanofiberElectrospinning Manufacturing System: Detecting Method of Taylor-Cone And Fiber Diameter control strategy, PrzegladElektrotechniczny (Electrical Review), ISSN 0033-2097, R88 NR96/2012.

5. FatmaYEVER, BaturalpYELEINKAYA, OldrichJIRSAK, New Measurement Methods for studying of Mechanism of roller Electrospinning , Nanocon 2013, 16.-18.10.2013, Brno, Czech Republic, Eu.

6. Zheng-Ming Huang, Y-Z. Zheng, M.Kotaji, S.Ramakrishna, A Review on Polymer Nanofibers by Electrospinning and their applications in Nanocomposites, Elsevier, Composite Science & Technology 63(2003)2223-2253.

7. Dr.S.M.Shendokar, Mr.S.S.Chavan, Mr.P.V.Londhe, Assesment of ElectrospunNanofiber properties in Two Phase Composites, Nancon 2010.

8. Yong-Fang Qian, Yan Su, Xiao-Qiang Li, Hong-Sheng Wavg And Chuang-Long He, Electrospinning of Polymethyl Methacrylate Nanofibers in different Solvents, Iranian Polymer Journal 19(2), 2010, 123-129.

9. Sachin S. Chavan, Mukesh K. Sinha, P.V.Londhe, Synthesis & Characterization of Composite Nanofibers with VARTM and Electropinning Process, Applied Scence Innovations Pvt. Ltd., India, Carbon-Sci. Tech 5/3(2013)289-295.

10. C.J. Thompson,G.G.Chase, A.L.YarinYarin, D.H.Renekar, Effects of Parameters on Nanofiber diameter determined from Electrospinning Model, Elsevier, Science Direct, Polymer 48(2007)6913-6922.

11. Ruotsalainen.T., Turker J., Heikkila. P., Ruokolainen J., Nykanan A., Laitinen T., Torkkeli M; Serimaa R, Ten Brinke G, Harlin A, Ikkala O., Towards Internal Structuring: ElectrospunNanofibers by Self-Assembly of Polymeric Comb-Shaped Supramolecules, Advanced Materials, 17(8)2005, 1048-1052.

12. Ristolainen N. Heikkila P., Harlin A., Seppala J., Polyvinyl Alcohol & Polyamide-66 Nanocomposites Prepared By Electrospinning, Macromolecular Materials & Engineering, 291(2)2006,114-122.

13. Heikkila P., Sipila A., Peltola M., Taipale A., Harlin A., ElectrospunPA Coating on Textile Surfaces, Textile Research Journal, 77(11)2007, 864-870.

14. Heikkila P., Uusimaki J., Soderlund L., Kettunen L. Harlin A., Exploitation of Electric Field in Controlling of Nanofiber Spinning Process, Polymer Engineering & Science, 47(12)2007, 2065-2074.

15. Heikkila P., Taipale A., LehtimakiM.Harlin A., Electrospinning of Polyamides with different Chain Composites for Filtration Application, Polymer Engineering & Science, 48(6)2008, 1168-1176.

16. Heikkila P., Harlin A., Parametric Study Of Electrospinning Of Polyamide-6, European Polymer Journal, accepted 23 June 2006, Doi: 10.1016/j.eurpolym.2008.06.03R.

17. Zheng-Ming HuangY.-Z. Zhang, M. Kotaki, S. Ramakrishna "A review on polymer nanofibers by electrospinning and their pplications in nanocomposites" Composites Science and Technology 63 (2003) 2223–2253

18. Doshi J., Reneker D.H, "Electrospinning process and applications of electrospun fibers," *Journal of Electrostatics*, Vol. 35, (1995), Pg. 151-160

19.Bergshoef MM, Vancso GJ. Transparent nanocomposites with ultrathin, electrospun Nylon-4,6 fiber reinforcement. Adv Material Science 1999;11(16):1362–5