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A Review Article: Electro-Spinning Thin Film Nano-Spun Fibers

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Abstract: Electrospinning is an electron – hydrodynamic process which is gainful and flexible method. Electrospinning forms fibers in 100 NM ranges. Electrospinning mainly composed of 3 main components. High voltage, Spinners and Target collector plate. It is versatile and viable technique for ultra-thin fibers generation. Electrospinning is mainly because there is an increase in surface area compare to volume as particle get smaller. Nanotechnology accomplished most attraction by researcher a nanomaterial exhibit novel and significantly improve properties in terms of physical, chemical, biological, mechanical properties produced of electro spun nanofiber and they can be modified accordingly. Nanotechnology is a budding technology that has been identified as a vital scientific and commercial venture with global economic benefits.

I. INTRODUCTION

Electrospinning is the branch of technology that deals with dimensional and tolerances of less than 100 Nano meter, especially manipulation of individual atoms and molecules. Electrospinning has been the most widely used technique in the late 20th (1990) and early 21st (2000) century[8]. It is a modern and efficient method having structural and function advantages. Electrospinning technique is mostly used for creating polymers fibers of 100nm ranges. Electro spun fibers have great potential as vehicle used for drug release, bimolecular sensors, Nanen capsulation of bioactive molecules and ultra-filtration media. Thin fiber is produced in this technique. Two are used in this technique, one is connected to polymer solution niddle and second to collector. A syringe siphon was utilized for constant flow. Electrospinning has gathered significant interest because of its ability to fabricate nanostructure with the unique properties such as high surface area and inter/intra fibrous porosity. Important characteristics of membrane is uniform pore size. It has wide application in industries such as filtration, composite material, medical, membrane, food coating, etc. Recently, several approaches how been developed to ensure high production rate of nanofiber. Electrospinning is known as scientist imdisciplinary research approach, is now ready to move towards a practice based inter disciplinary approach in a variety of field. In this review we will gives its basic ideas about process, principle, mechanism, and application in food and other industries[7].

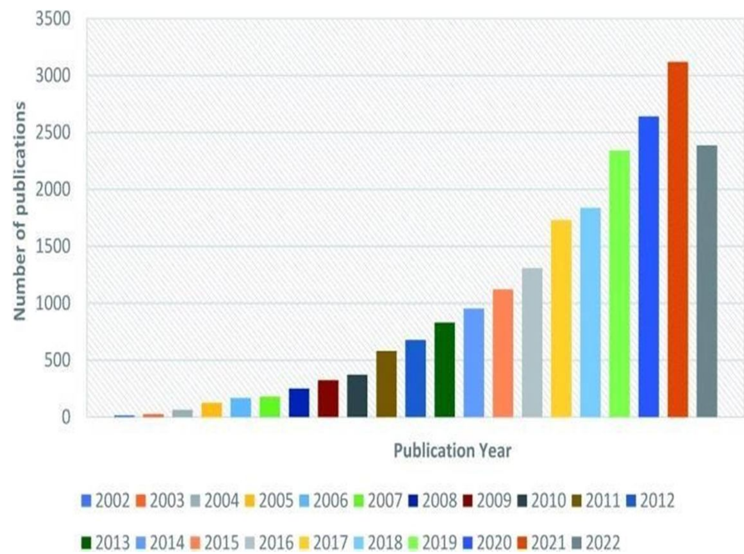

Fig:7.1 Graphical representation of publication per year from 2002 to 2022 obtained from Scopus database 'Electrospun Nanofiber'

II. PRINCIPLE

Electrostatic force can be utilized in electrospinning to frame a fine fiber from polymer solution.

Component of electrospinning instruments are used to induce a excess electric charge within the liquid polymer. Fiber's strand is useful for collecting the grounded collector. Fluid polymer is siphoned from the spinneret at a consistent volume steam utilizing a syringe siphon[2]. When the electric field is followed out to liquid or polymer solution, an electrostatic charge accumulates on the tip of this droplet. Electrostatic repulsive force is produced when this charge work again the surface tension of droplets. Due to the electrostatic repulsive force the droplet gets deformed and get converted into elongated cone shaped. This is known as Taylor cone[3].When the surface strain of liquid droplet deals to the charged polymer at that time jet get ejected out from the capillary spinneret. This jet has complex route and it is subjected to instability induced by stability charge is called whipping instability [3] . Whipping instability leads to jet elongation and quick evaporation of solvent and solid thin fibers is deposited to the collector.

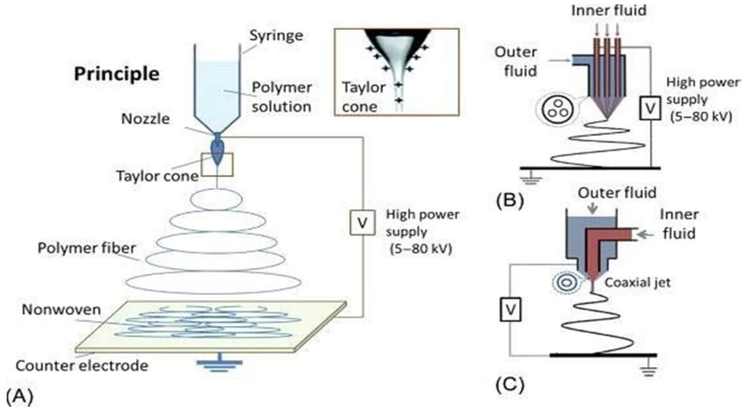

Fig:7.2 Basic principle of Electrospinning.

III. ADVANTAGES OF ELECTROSPINING

1) The substance which are thermo-labile can formulated by E-spun.
2) High surface area-volume ratio of nanofiber.
3) Less wastage, and more production.
4) Widely used to form nanofiber.
5) Ease to fiber functionalization.
6) Relatively low start -up cost.
7) Ease of material combination.
8) Varieties of Nano fibrous structure have been constructed.
9) Ease of fiber deposition on polymeric film.
10) Mass production capability demonstrated[2].

IV. DISADVANTAGES OF ELECTROSPINING

1) Dose uniformity is difficult to maintain.
2) Process depends on many variables.
3) Only those active pharmaceutical ingredients having small dose can be incorporated.
4) Problematic to obtain 3D structure as well as sufficient size of pores needed for biomedical applications.

V. APPLICATION Of ELECTRO SPUN NANO FIBERS

Applications of nanofibers become wider due to some characteristics that can be used in large specific surface area (Dong et al., 2009).

VI. ELECTRO SPUN NANO FIBERS IN FILTRATION PURPOSE

Filtration is most widely used process in house as well as industries for removing solid waste from air or liquids. Nano fibers provide advantageous filtration property due to high surface area to volume ratio, high porosity and large interconnected pores. Filtration is used in wide range for water purification also.

VII. ELECTRO -SPUN NANO FIBERS IN BIOMEDICAL ENGINEERING

1) *Tissue Engineering Scaffolds*

Scaffolds for tissue engineering are support structures designed to facilitate cellular growth and proliferation upon implantation into patient. They are used in tissue engineering application such as blood vessels , skin , bones, muscles for providing support for cells to regenerate extracellular matrix. [12]

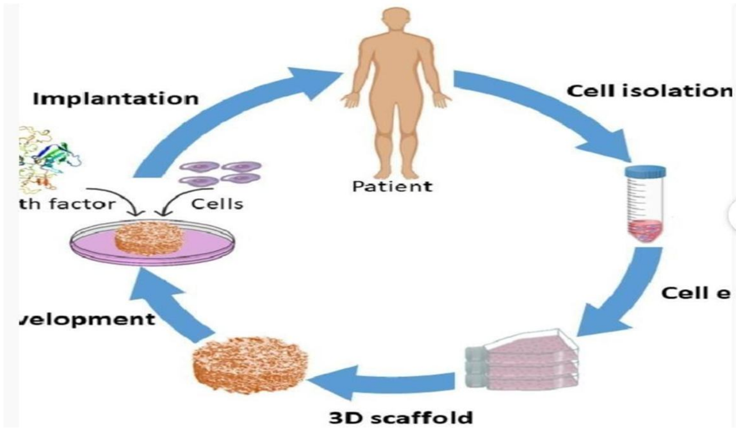

Fig:7.3 3D scaffold

2) *Blood vessels*

First artificial blood vessels based on collagen scaffolds is fabricated at 1986.yearly, the interest on vascular tissue engineering is ongoing increasing. The main reason for using electro-spun nanofiber for the replacement of blood vessels is the size which is ranging from 200nm to 2um, shape distribution is almost similar to collagen fibrin. Major component of the extracellular matrix are collagen which provides tensile stiffness for friction against rupture [12].

3) *Blood*

Natural bone is composed of two materials: inorganic (hydroxyapatite crystals) and organic (type 1 collagen matrix) material. Researchers suggest that the pore size of the nanofiber membrane must be in between 200 and 400um to allow the cell proliferation and infiltration. There should be growth of non- mineralized osteoid tissue and prevention of neovascularization. Poly and hydroxyapatite are mostly used as scaffolds material for bone repair due to its biocompatibility, non-toxicity and non-inflammation property [12].

4) *Muscles*

Collagen Nano fiber were used first for culturing smooth muscle cell. Cell growth was increased and well integrated into the Nano fiber network after seeding of 7 days. smooth muscle cell also get adhered and proliferated, when other polymer Nano fiber mats for blended with collagen. Collagen in incorporation results in improve fiber elasticity, tensile strength, and cell adhesion. Baker et al. Reported that, an increased fiber wettability can be achieved when the polystyrene Nano fibers were treated argon plasma which results in better cell attachments by two folds. The nanofiber alignment can promote skeletal muscles cell morpholo genesis. Dong et al. Investigated that smooth muscles cell culture on polymer nanofiber like polyglycolic acid (PGA) , poly (lactic coglycolic acid) and Poly (L- lactide-co-€-coprolactone) causes degradation of the nanofiber, especially for PGA [12].

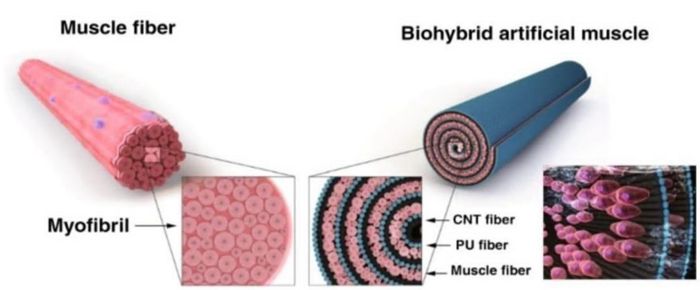

Fig: 7.4 Schematic illustration of biohybrid artificial muscles.

5) Electro-spun nanofiber in wound dressing

In electro-spinning, scaffold generated are more homogeneous than conventional skin substitutes, but when observed structurally it is heterogeneous, obtained by freeze drying. Scaffold provide with support for the new healthy tissue growth in an injured area. They protect us from infection and dehydration due to Nano spore size and large surface which allow fluid absorption and oxygen permeating. Some polymer like carboxyethyl, chitosan, collagen, silk fibroid, etc. Are suggested for wound dressing [12].

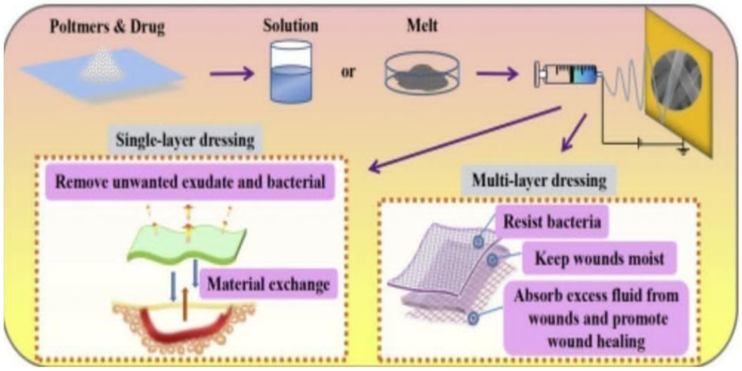

Fig:7.5 Wound Dressing

6) Electro-Spun Nanofiber As Drug Delivery Carrier

Electro-spun nanofiber is used extensively in delivery of numbers of drugs including antibiotic, anticancer drugs, proteins and DNA due to high surface area and short diffusion passage length. During drug delivery, electro-spun nanofiber, enclose the medicinal agent to maintain integrity and bioactivity of drug molecules and at wound treatment. They help to reduce the systemic absorption of the drug and reduce the side effect from drugs by locally inoculation of medicines. Also, by varying some parameters like mesh size and fiber diameter drug release can be controlled to be used in disease like Aids and cancer [12].

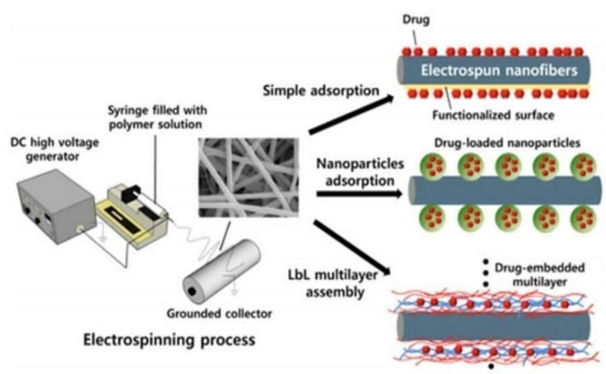

Fig:7.6 Drug Delivery Carrier

7) Air filtration

Nanofibers mats are most widely being used in an air filtration now-a-days. Due to less dimension, nanofiber mats provide better efficiency in filtration. The nanofiber used is 800 times smaller than the conventional filtration media. Nanofibers membrane is a potential solution for indoor air filtration [12].

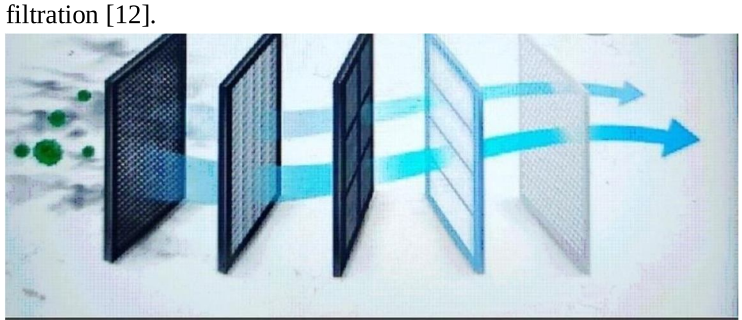

Fig:7.7 Nanofiber technology (air filtrator)

8) Vehicle cabin filtration

Vehicle cabin filters are important in mining work. It is a matter of great concern that these places must be kept contamination free. Nanofiber composite filter exhibited higher percentage (92%) of both sub-micron and repairable (>1um) dust removal while standard cellulose filter removes 68% and 86% respectively [12].

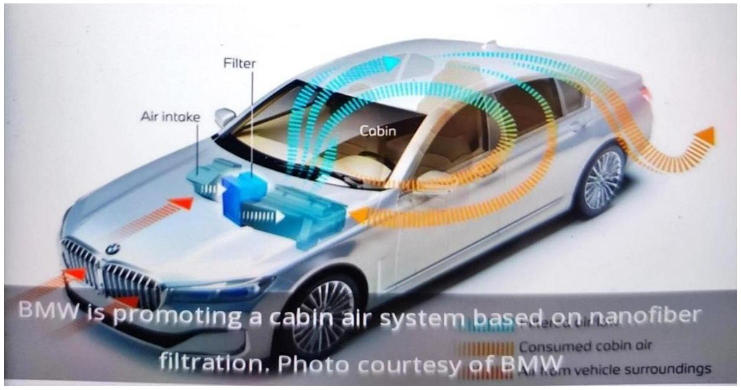

Fig:7.8 Vehicle cabin filtration

9) Liquid filtration

Nano fibrous membrane being highly permeable due to their high porosity and interconnected pores offer better water filtration at low energy costs. Membrane processes like microfiltration (MF) and ultrafiltration (UF) are very common to achieve higher removal of micron sized and other suspended solid particles from water. These MF and UF can be prepared by phase inversion method. Electro Spun Nano fiber membrane can be used as energy saving membranes as they exhibit several time higher water fluxes. Nanofiber membrane is made up of poly-sulfone and leads to removal of micron sized particle [12].

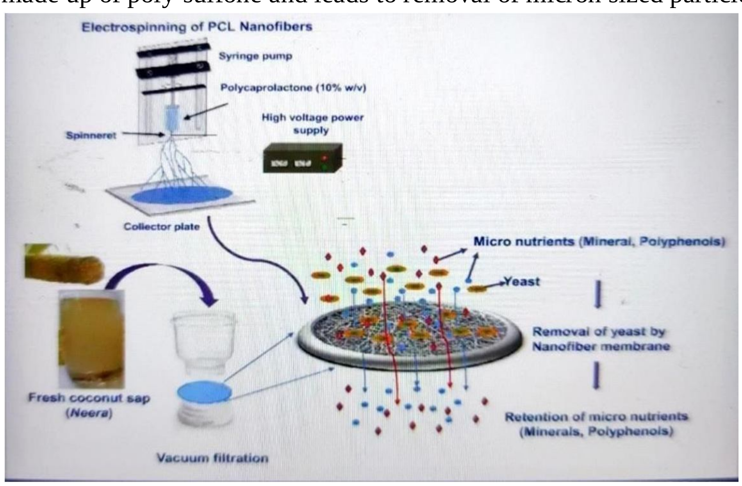

Fig:7.9 Liquid filtration

10) Electro-Spun Nanofiber In Cosmetics

Electro-spun nanofiber membrane has various cosmetics application such as facial masks, perfumes, deodorants. Skin cleansing have been utilized as a cosmetic skin care mask with or without adding any API. This skin mass contains high surface area. By emulsion electro-spinning ®- (+)-limonene a highly volatile fragrance is encapsulated in PVA fibrous matrix used in cosmetics due to presence of high fragrance loading capacity. Medicated soaps and antiaging products are suitable cosmetics application [12].

11) Electro-Spun Nanofiber In Metal Ion Adsorption

Extracted heavy metals has become a serious pollutant in water resources that is a serious threat to human health due to industrialization. Adsorption and filtration are the methods used for removal of the contaminants. They possess high surface to volume ratio and large surface area, high gas permeability and small interfibrous pore size. addition of amino, carboxyl, phosphoric, imidazoline and amidoxime improve adsorption capacity of electro-spun nanofiber [12].

VIII. ELECTROSPINING PARAMETERS

In the Electrospinning Parameters involves three types of parameters molecular parameter, process parameters ambient parameter. Therefore, all soluble fusible polymer can be used for Electrospinning (e.g. Natural polymer, synthetic polymer or blend both). This wide range of polymer it's involve protein, nucleic acids and polysaccharides [8].

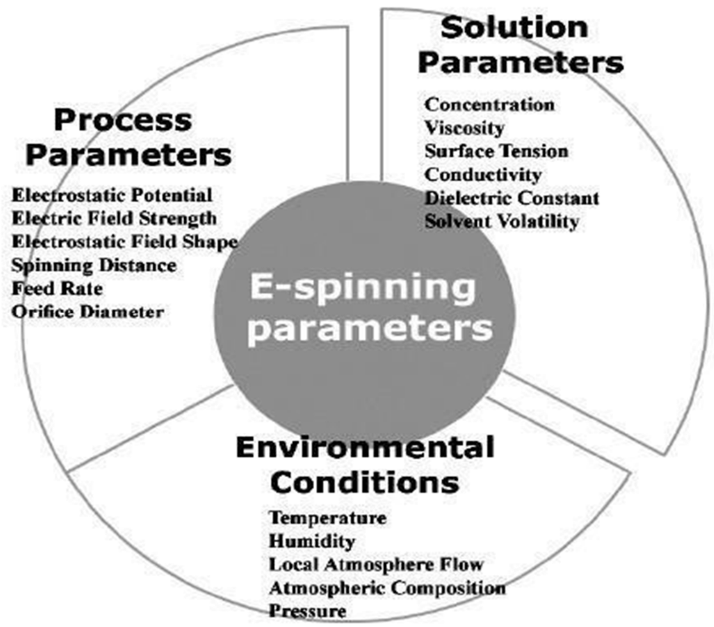

Fig:7.10 E-spinning parameters

IX. ELECTROSPINNING SETUP

A typical electrospinning setup consists of three components, a high voltage supplier, a capillary tube with a needle and a collecting screen. According to Taylor, 6kv voltage is applied for initiation of Electrospinning process.

However, grounded target is introduced nearer to spinneret, is responsible to run the electrospinning process at a lower applied voltage. Clip spinneret, tube-less spinneret, co-axial spinneret and heating are widely used [12].

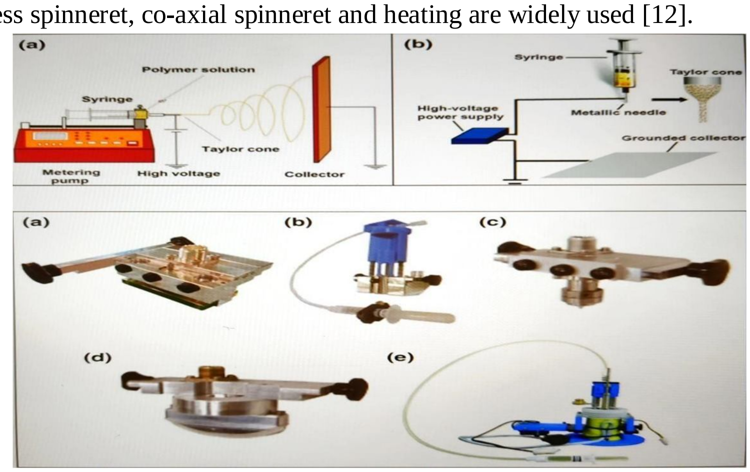

Fig:7.11 Schematic diagram of an electrospinning apparatus

X. THE MAIN FACTORS AFFECTING ELECTROSPINING

1) Effect Of Applied Voltage

In 2012, Laudenslager and Sigmund state that, "it is a known fact that the flow of current from a High-voltage power supply into a solution via a metallic needle will cause a spherical droplet to Deform into a Taylor cone and form ultrafine nanofibers at a critical voltage" (25).

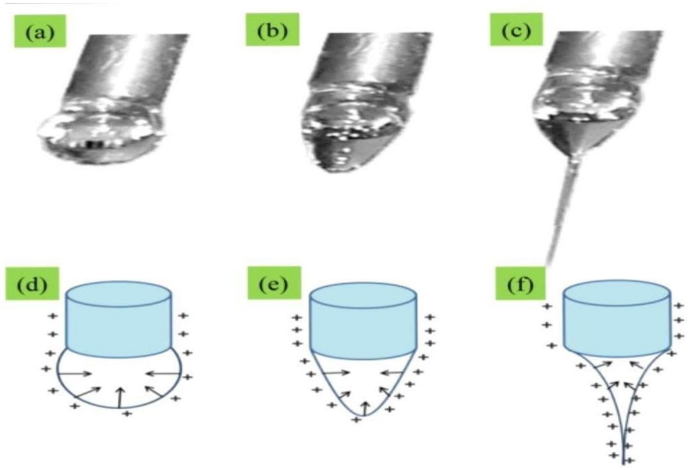

Fig: 7.12 Effect of applied voltage

a) In 2008, Sill and Von Rectum, “This critical value of applied voltage varies from polymer to polymer. The formation of smaller-diameter nanofibers with an increase in the applied voltage is attributed to the Stretching of the polymer solution in correlation with the charge repulsion within the polymer Jet” (Sill and von Recum, 2008).
b) In 1971, Baumgarten, “the diameter of the nanofibers was also reported to increase with an Increase in the applied voltage. This increase in the diameter was attributed to an increase in the Jet length with the applied voltage” [8].

2) *Effect Of Solution Flow Rate*
a) In 2002 Rogalski et al., State that, “The flow of the polymeric solution through the metallic needle tip determines the morphology of the electro-spun nanofibers. Uniform bead less electro-spun nanofibers could be prepared via a critical flow rate for a polymeric solution. This critical value varies with the polymer system. Increasing the flow rate above the critical value could lead to the formation of beads. For example, in the case of polystyrene, when the flow rate was increased to 0.10 mL/min, bead formation was observed. However, when the flow rate was reduced to 0.07 mL/min, bead-free nanofibers were formed. Increasing the flow rate beyond a critical value not only leads to an increase in the pore size and fiber diameter but also bead formation”
b) In 2002, Megelski et al., And In 1935, Zeleny, state that , “Because increases and decreases in the flow rate affect the nanofiber formation and diameter, a minimum flow rate is preferred to maintain a balance between the leaving polymeric solution and the replacement of that solution with a new one during jet formation” [8].

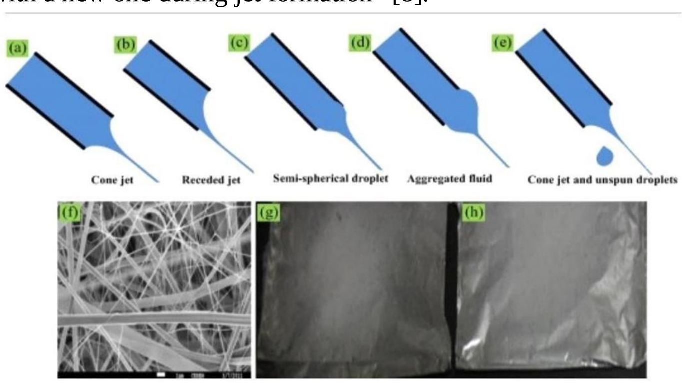

Fig: 7.13 Effect of solution flow rate

3) *Effect Of Humidity And Temperature*
a) In 2015, Huan et al., In 2013, Pelipenko et al., State that, “Besides the electrospinning and solution parameters, recently it has been reported that environmental (ambient) factors such as relative humidity and temperature also affect the diameter and morphology of the nanofibers”

b) In 2013, Bae et al., State that, "Humidity causes changes in the diameter of the nanofibers by controlling the solidification process of the charged jet. This phenomenon is, however, dependent on the chemical nature of the polymer. Pelipenko et al., studied the change in nanofibers diameter with change in humidity using PVA, PEO, and their blend solution PVA/hyaluronic acid (HA), PEO/(chitosan (CS)). They observed that the diameter of the nanofibers decreased from 667 nm to 161 nm (PVA) and 252 nm to 75 nm (PEO) with an increase in humidity from 4% to 60%. For the blend the decrease was even more; for example, humidity decreased from 4% to 50%, and the diameter of the nanofibers for PVA/HA decreased from 231 nm to 46 nm and for PEO/CS from 231 nm to 46 nm. Further increase in humidity led to bead fiber for individual polymers and almost no electrospinning for the blends (Pelipenko et al., 2013). A similar decrease in the nanofibers diameter of PEO with an increase in humidity is also reported by Park and Lee (2010). Humidity also plays an important role in the creation of porous nanofibers when a binary solvent system is used. Bae et al. used PMMA and a binary solvent system (dichloromethane (DCM): dimethylformamide (DMF) in an 8:2 ratio to produce highly porous nanofibers. The creation of the pores was attributed to the different evaporation rates of the two solvents. The more volatile solvent (DCM) starts to evaporate faster than the less volatile solvent (DMF) (while the fibers are flying toward the collector. This difference in rates of evaporation of the two solvents causes a cooling effect, a phenomenon similar to perspiration. This cooling effect results in the condensation of water vapor into water droplets (as also observed during cloudy conditions or in fog). The water droplets settle on the fibers. As water is miscible with DMF, hence the two mix well with each other on the inner and outer surfaces of the fibers. The complete evaporation of the solvents and the water droplets from the fibers results in the formation of porous PMMA electro-spun fibers "

c) In 2009, De Vrieze et al., state that, "Temperature causes two opposing effects to change the average diameter of the nanofibers: (i) it increases the rate of evaporation of the solvent and (ii) it decreases the viscosity of the solution. The increase in the evaporation of the solvent and the decrease in the viscosity of the solution work by two opposite mechanisms, however, both lead to a decrease in the mean fiber diameter. A similar observation was reported by Vrieze et al. using cellulose acetate (CA) and poly(vinylpyrrolidone) (PVP)" [8].

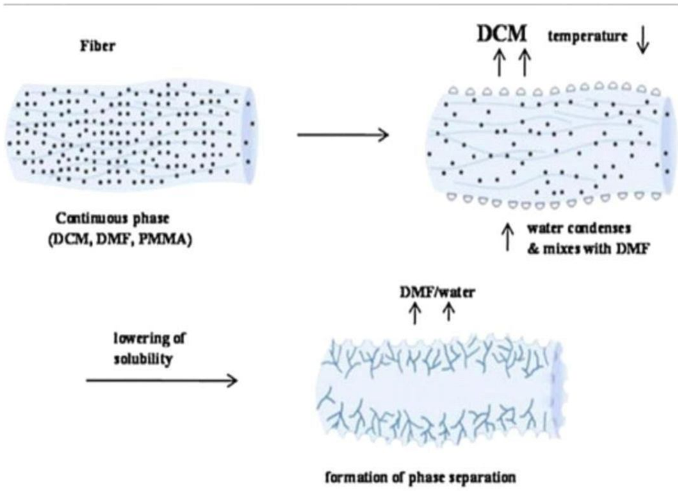

Fig:7.14 Effect of humidity and temperature

4) Role Of Solvent In Electrospinning

a) In 2007, Lannutti et al., And In 2008 Sill and von Rectum state that, "The selection of the solvent is one of the key factors for the formation of smooth and beadless electrospun nanofiber. Usually, two things need to be kept in mind before selecting the solvent. First, the preferred solvents for the electrospinning process have completely soluble polymers. Second, the solvent should have a moderate boiling point. Its boiling point gives an idea about the volatility of a solvent. Generally, volatile solvents are fancied as their high evaporation rates encourage the easy evaporation of the solvent from the nanofibers during their flight from the needle tip to the collector. However, highly volatile solvents are mostly avoided because their low boiling points and high evaporation rates cause the drying of the jet at the needle tip. This drying will block the needle tip and hence will hinder the electrospinning process. Similarly, less volatile solvents are also avoided because their high boiling points prevent their drying during the nanofiber jet flight. The deposition of solvent-containing nanofibers on the collector will cause the formation of beaded nanofibers" *b)* In 2011, Kanani and Bahrami state that, “Numerous research groups have studied the effects of the solvent and solvent system on the morphology of nanofibers”

c) In 1999, Fong et al., state that,” concluded that similar to the applied voltage, the solvent also affects the polymer system” [8].

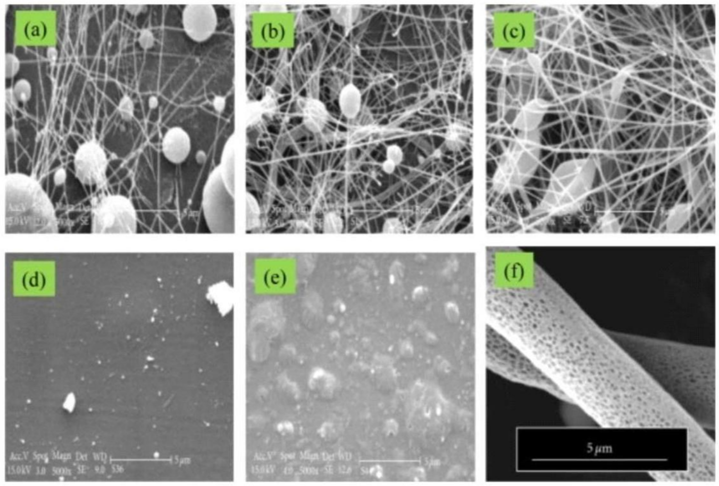

Fig: 7.15 Role of solvent in Electrospinning

5) Effects Of Polymer Concentration And Solution Viscosity

d) In 2013, Haider et al., 2013, Pillay et al., State that, “The electrospinning process relies on the phenomenon of the uniaxial stretching of a charged jet. The stretching of the charged jet is significantly affected by changing the concentration of the polymeric solution. For example, when the concentration of the polymeric solution is low, the applied electric field and surface tension cause the entangled polymer chains to break into fragments before reaching the collector”

e) In 2013 Haider et al., State that, “These fragments cause the formation of beads or beaded nanofibers. Increasing the concentration of the polymeric solution will lead to an increase in the viscosity, which then increases the chain entanglement among the polymer chains. These chain entanglements overcome the surface tension and ultimately result in uniform beadles’ electro-spun nanofibers. Furthermore, increasing the concentration beyond a critical value (the concentration at which beadles uniform nanofibers are formed) hampers the flow of the solution through the needle tip (the polymer solution dries at the tip of the metallic needle and blocks it), which ultimately results in defective or beaded nanofibers’’[8].

XI. RUDIMENT OF ELECTROSPINING

The application of high voltage to produce changed jet by generating mutual repulsive force to overcome surface tension in the charged polymer liquid and attenuation of the charged jet for thinning is done mainly by the bending instability associated with the Electrospinning jet and this all are based on Electrospinning procedure the spinneret and collector and a surface charged builds up on the surface of the solution when a applied voltage

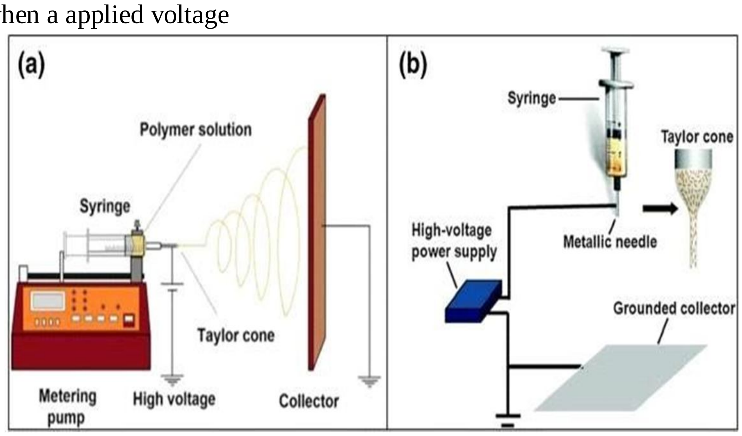

Fig:7.16 Role of solvent in Electrospinning

XII. GENESIS AND DEVELOPMENT OF ELECTROSPINING

In the early twentieth century the first-time realistic attempt on Electrospinning was detected. In 1900, 1902, 1903, the John Francis Cooley the first to archive patent on Electrospinning, and three failed patents. In 1902 W.J Morton described the method of preparing fibers which can be used in textile or other purpose and parented it. Antonin formhals invented the procedure of fabricating textile yarns from cellulose acetate by using 57 KV applied voltage, acetone and mono methyl ether as solvent in 1934. In the after some years a series of patent has been failed by formuhals. Charles L. Norton invented the electric current and air steams assisted melt-spinning process of fabricating fibers from viscous solution in 1936. Vonnegut and new Bauer invented the method of preparing diameter of 0.1 mm uniform droplets by electrical disintegration of liquid in 1952 [10].

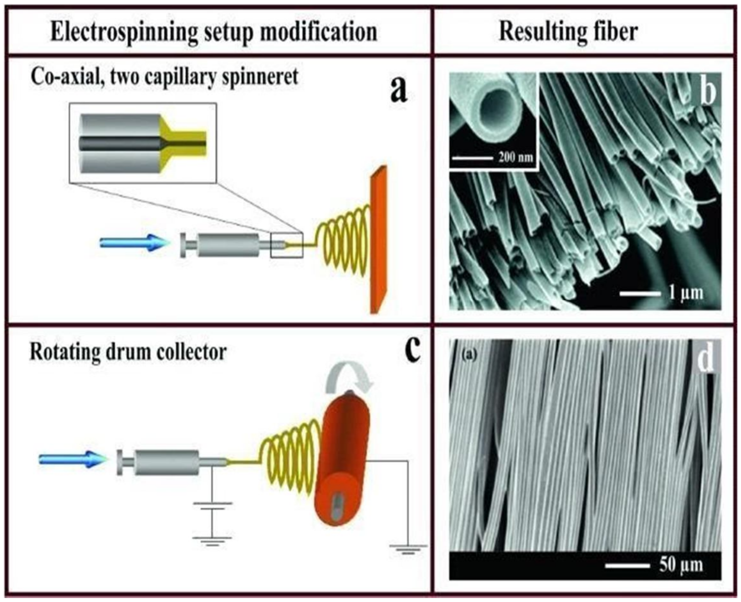

Fig:7.17 Genesis and development of Electrospinning

XIII. CHARACTERISATION OF ELECTRO SPUN NANO FIBERS

1) Geometrical Characterization

Geometrical characterization is to characterize the geo-metric properties of nanofibers such as fiber diameter, diameter distribution, fiber orientation and fiber morphology. Scanning electron microscopy (SEM), fiele mission scanning electron microscopy (FESEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM) [25] are used to characterize these geometric properties. Fiber morphology has been observed using SEM by many researchers. Again, the sample must be in a dry state for SEM compared with another method, TEM, where dry state of sample is not required. TEM can be used to determine fiber diameter up to < 300 nm. AFM being an accurate measurement of nanofiber diameter require sa rather precise procedure that includes tip convulation.

However, AFM is the best measurement to observe surface morphology and exact description of the fiber surface. AFM can also be used to characterize the rough-ness of the fiber [25].

2) Chemical Characterization

Chemical characterization of a material gives information about its composition. Chemical composition of electrospun fibers can be determined by Fourier transform infra-red (FTIR) and nuclear magnetic resonance (NMR) techniques [26]. These methods can determine both the structure and intermolecular interaction of two polymers when they are blended together for nanofiber fabrication. In case of a collagen and PEO blend, the NMR spectrum showed a new phase structure which was caused by the hydrogen bond formation between the ether

oxygen of PEO and the protons of the amino and hydroxyl groups in collagen. The confrigation of the macromolecules in a nanofiber can be characterized by optical birefringence [27], wide angle X-ray diffraction (WAXD), small angle X-ray scattering (SAXC) and differential scanning calorimeter (DSC). Surface chemical properties of nanofibers can be evaluated by XPS, water contact angle analysis of the nanofiber membrane surface and ATR-FTIR analyses. Researchers have used Raman Spectroscopy and Fourier Transform Infrared Spectroscopy for the changes that may be taking place at the molecular level.

3) Physical Characterization

Generally Physical characterization means the determination of all the physical properties of a material such as stability, melting point, water uptake etc. It's possible to measure thermal properties such as the melting point, the crystallization point and the glass transition with a differential scanning calorimeter (DSC). The thermal stability of a compound is checked with a thermos gravimetric analyzer (TGA) which measures the mass loss during a heating ramp rate. Dynamic moisture vapor permeation cell (DMPC) is used to measure air and vapor transport properties of Nano fibrous mat. Both moisture vapor transport and the air permeability of continuous films, fabrics, coated textiles and open foams can be measured by this device.

4) Mechanical characterization

Mechanical characterization of Nano fibrous nonwoven membranes can be done using conventional mechanical testing techniques[28]. Mechanical characterization is achieved by applying loads to specimens prepared from the electro-spun ultra-fine non-woven fiber mats. Various approaches have been applied towards mechanical characterization of nanofiber and nanowires by employing nanoindentation, bending tests, resonance frequency measurements, and micro scale tension tests. Young's modulus, tensile strength, and the strain at break can be determined by performing tensile tests with single polymer fibers. According to Tanetal a commercial Nano tensile testing system (Nano Bio nix System, MTS, TN, USA) is being used to conduct the tensile test for the evaluation of mechanical properties of single ultrafine polymeric fibers of polycaprolactone.

In aietal. have also carried out tensile tests of single electro-spun poly (l-lactic acid) nanofiber collected from a rotating disc at different collection speed. Atomic resolution can be obtained with very slight contact by measuring the defection of the cantilever due to the repulsion of contacting atomic shells of the tip and the sample. AFM Phase Imaging being an extension of tapping mode allows detection of variations in composition and hardness.

The bending moduli and shear moduli of the electro-spun collagen fiber have been determined by AFM by performing micromechanical bending tests with native and glutaraldehyde cross-linked single electro-spun fibers. Researchers have used resonant contact AFM approaches for measuring the elastic modulus of the nanofiber. In this testing method, nanofiber must be attached to a cantilever tip [29].

XIV. CHALLENGES FOR THE DIFFERENT APPLICATION OF NANO FIBERS

Electro-spun nanofibers showed great potential in air and liquid filtration application. However, in air filtration is successful utilization of electro-spun fibers were the only reported for particles ranges from (100 to 1000) nm. Therefore, further modification of the electro-spun fiber surface may have been needed to capture particles less than the 100 nm.

Besides, engineered approaches are needed to prepare dimensionally stable electro-spun fibrous scaffolds so that they can be employed in capturing volatile organic solvents [19]. Moreover, having poor mechanical properties restrict their application in large scale industrial applications especially in liquid filtration. Low mechanical stiffness of the membranes can lead to filter split. Therefore extensive research is still needed for sorting the ways to improve mechanical stiffness of the nano fiber membranes which will also lead to the longer service life of the membrane Biomedical application is another exciting use of electro-spun nanofiber membranes.

However, the electrospinning method tend to produce very dense fibers on a solid collector having smaller inter fiber pores which is a much smaller than the cell size. Therefore, the very little to no cell infiltration was observed by the researchers in the electro-spun nanofiber scaffolds, as the cells tend to stay in the surface of the electro-spun fiber and grow two dimensionally which needs to be overcome for true mimicking of the natural extra cellular matrix. Having a larger pore structure can help to overcome the poor infiltration of the electro-spun fiber. Therefore, synthesizing nanofiber scaffolds with controllable pore size is a very promising area to be the explored further[16]. Furthermore, two-dimensional nature of the electro-spun scaffolds also need to be the modified as three-dimensional structure of scaffolds are necessary for the cell-permeability.

Therefore, more research needs to be done to synthesize 3-D scaffolds to have beneficiary effect in tissue engineering and drug delivery applications Use of the electro-spun fibers in wearable e-textiles as well as in solar energy conversion and electronic circuits are the relatively new approaches. However, the primary challenge that still the need to be overcome is the controlled alignment of the fibers.

Besides, non-conductive polymers need to be added to the conductive polymers to increase their electro-spin ability which eventually reducing the electrical conductivity of the resultant electro-spun fibers. Therefore, the smarter engineered ways need to be developed to increase the electrical conductivity of the polymer matrix to apply in real life [19].

XV. CONCLUSION

Electrospinning is a simple technique to make fibers. It is Diodes, FET's, Sensors. Some of these devices are multifunctional. All of the work presented was done by high school students and undergraduates. It is used as a promising continuous fiber fabrication method in the electrospinning procedure for as many as 80 years. Electrospun nanofibers can be used in wide range of application like filtration, biomedical engineering, textiles, electrical engineering and renewable energy. The parameters used like concentration, molecular weight, viscosity, voltage, surface tension, flow rate, syringe to collector distance etc.

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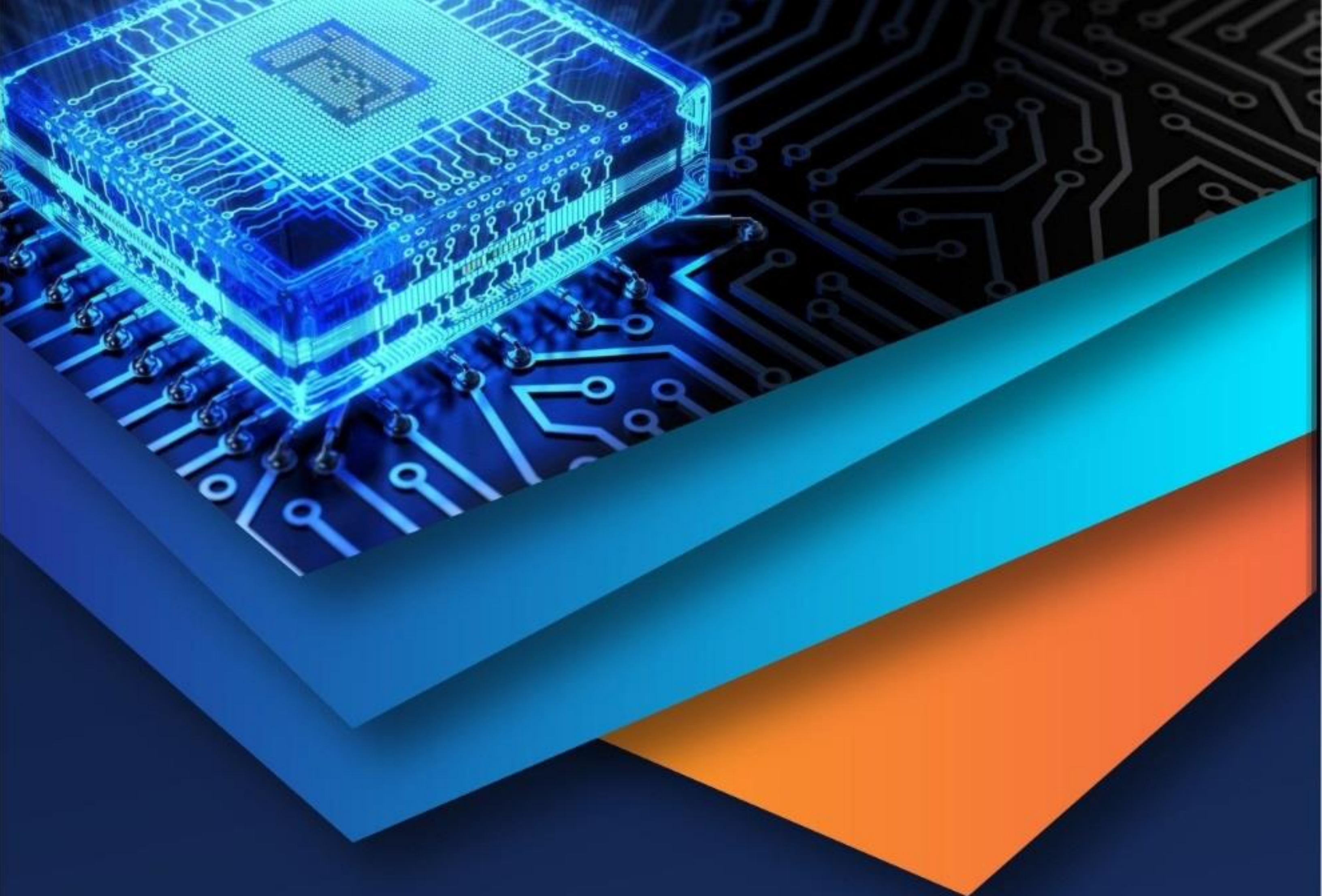

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