

“A Review: Electrospinning and Electrospinning Nanofibre Technology, Process & Application”

Somesh S. Bhagure

Abstract: Electrospinning is a versatile and viable technique for ultra-thin fiber generation. Remarkable progress has been made with regard to the development of Electrospinning methods and the engineering of Electrospinning Nanofibre to suit or enable different applications. We aim to provide a comprehensive overview of Electrospinning, including principles, methods, materials and applications. We begin with a brief introduction to the early history of Electrospinning, followed by a discussion of its principle and its typical apparatus. Subsequently, we discuss the applications of electrospun Nanofibre, including their use as smart mattresses, filtration membranes, catalytic supports, energy harvesting / conversion / storage components, and photonic and electronic devices, as well as biomedical scaffolds. We highlight the most relevant and recent developments in the application of electrospun Nanofibre by focusing on the most representative examples.

Keywords: -Electrospinning, Nano fiber, Filtration, Textile, Fiber.

I. INTRODUCTION

Fibers are ubiquitous in nature, in the form of either continuous filaments or elongated objects. Spiders have relied on fibre webs to trap prey for more than 140 million years. The webs are made of silk fibers with diameters varying from 2 to 5 microns. Silkworms are also well known for their amazing ability to create silk filaments to build cocoons. Such and many other natural processes have served as a vital source of inspiration for the creation of man-made fibers [1–3]. Fibers have, in addition, been an integral part of human life since the beginning of time. Civilization Day Human history of fiber processing can be traced back to prehistoric times. Fragments of cotton articles dating back to 5000 BC were excavated, and silkworm cultivation for the production of silk fibers and textiles began in 2700 BC. Around 1300 the spindle was developed to produce wool and cotton fibers for the manufacturing of fabrics and garments, and in the 1880s this activity gradually expanded into the textile field. The first man-made fabrics are the Rayon, made of cotton or wood cellulose fibres. Though reported in 1891, it was not sold commercially until 1911[4]. About 50 years later, synthetic fibers were developed along with the advancement of chemistry and polymer science. Nylon was introduced by DuPont in 1938 as the first commercially viable synthetic fiber, and it immediately caught the

public's attention [5,6]. Thereafter, many different types of polyesters and other synthetic polymers were developed one after the other for the manufacture of synthetic fibers [7]. The synthetic fibers significantly reduce the public's demand for natural fibers while expanding it considerably.

Many methods for producing fibers from synthetic polymers have been developed, most notably those based on spinning wet, dry, melt, and gel [8, 9]. Wet spinning involves a spinneret submerged in a chemical bath. When a polymer solution is extruded from the spinneret into the chemical bath, the dilution effect or chemical reaction causes the polymer to precipitate out, generating fibers by solidification. A polymer solution is extruded into air through a spinneret for dry spinning, and fibers are collected from the jets as a result of solvent evaporation assisted by a stream of hot air. A polymer melt is extruded from a spinneret during melt spinning to produce fibers upon cooling. Gel spinning is used to create high mechanical resistance fibers or other special properties by spinning a polymer in the "gel" state, then drying in the air and then cooling in a liquid bath. During these spinning processes, jets are mainly formed when passing through spinnerets under external shear forces and/or mechanical drawing, and fibers are formed as a result of precipitation or drying after the jets is solidified. The jets are extended only to a small degree, leading to the creation of fibers with diameters usually within the range of 10–100 μm [8, 9], although with more mechanical drawing during the solidification process or after full cooling of the jets, the resulting fibers cannot even exceed the sub micrometer scale.

Charles V. Boys reported in 1887 that, in the presence of an external electric field, fibers could be extracted from a viscoelastic liquid [10]. He used an apparatus consisting of an insulated dish connected to an electrical supply. A viscous liquid (e.g., beeswax and collodion) was shown to be drawn through fibers as it passed to the edge of the platter. Now commonly known as Electrospinning, this technique opens the door to ultrathin fiber development with diameters down to the nanometer scale. Electrospinning typically allows for the easy development of continuous fibers with diameters ranging from tens of nanometers to many micrometers [11]. Electrospun fibers with diameters down to 1 nm, and even below, were also reported [12], in literature, electrospun fibers are also referred to as Nanofibre when their diameters are thinner than around 500 nm.

The concept of Electrospinning was conceived in an earlier study conducted by William Gilbert in 1600, in which he observed the formation of a cone-shaped water droplet in the presence of an electrical field [13]. About a century later, Stephen Gray observed the electro hydrodynamic atomization of a water droplet from which a very fine stream was generated [14]. Abbé Nollet performed the earliest one in 1747. In 1882, he theoretically estimated the maximum amount of charges a liquid droplet could carry before liquid jets would be ejected from the surface [16]. Electrospinning can be considered a variant of the electro-spraying technique [17], both relying on the use of a high voltage to eject liquid jets. The major differences between Electrospinning and electro-spraying are the viscosity and viscoelasticity of the involved liquid, and thus the jet's behavior. The jet may be held in a continuous form during Electrospinning to generate fibers instead of breaking into droplets (for particle formation) as with electro-spraying.

In 1902, John Cooley and William Morton filed two patents on Electrospinning, describing a prototype of the Electrospinning setup, respectively [18,19]. In 1934 and 1944, Anton Formhals subsequently filed a few additional patents to disclose the improvement in the equipment, moving towards the commercialization of Electrospinning for the manufacture of textile yarns [20,21]. In 1938, Electrospun Nanofibres were first implanted in the Soviet Union for the development of air filters, known as "Petryanov filters," for the capture of aerosol particles. By 1939, this work had led to the establishment of a factory in Tver for the production as gas masks of smoke filters with Nanofibre-based mats. A mechanistic understanding of Electrospinning was developed gradually during this time period. Between 1964 and 1969, Geoffrey Taylor published a series of pioneering papers showing how the spherical droplet to conical shape change of a polymer solution or melt droplet under the influence of a strong electrical field could be mathematically described and modeled [22–24]. Specifically, as the strength of the electrical field increased beyond a critical level, the spherical droplet would gradually develop into a cone. Afterwards, the development of the Electrospinning technique experienced 20 years of stagnation, as during this period it did not receive much attention from academia or industry. The lack of characterization instruments capable of reliably measuring the sizes of fibers with diameters down to the sub-micrometer range may largely contribute this stagnance. Nevertheless, during this period a variety of applications for electrospun fibers were proposed, including their potential use as wound dressing materials as described in a patent filed in 1977 [25]. In the early 1980s, Donaldson Co. Inc. started manufacturing and selling filters for air filtration in the U.S. that included electrospun fibers. To order to achieve advantages over its rivals, the company did not reveal the composition of their products however.

It wasn't until the early 1990s that several research groups began to reinvent this technique, notably those led by Darrell Reneker and Gregory Rutledge [26–32]. This was made possible by the increased accessibility of electron

microscopes capable of resolving features down to the nanometer scale. Those groups showed that many different organic polymers could be spun into Nanofibre. To explain this method, the word "electro-spinning" was popularized. Their experiments gave Electrospinning new life, and eventually this technique became the method of choice for producing long and continuous fibers with diameters down to the nanometer scale. At the beginning of this century, Electrospinning started to receive increasing attention when its capability was further expanded by switching to new materials and formulations for the fabrication of composite and ceramic nanofibers [33–35]. The ability to electrospin new materials quickly enabled new applications in catalysis, as well as energy harvesting, conversion, and storage, which were traditionally dominated by inorganic nanoparticles. In parallel, new techniques for regulating the structure and alignment of electro-spun Nanofibre were also created, opening a range of opportunities in energy-related and biomedical applications. Notably, several methods for aligning the nanofibers were developed, demonstrating the feasibility to combine different properties arising from the size, structure, composition, morphology, porosity, and assembly of nanofibers [35–38]. At the same time, coaxial Electrospinning was developed to produce continuous core–sheath and hollow nanofibers [39]. The fabrication of continuous yarns of electro-spun nanofibers was also reported [40]. Such achievements make Electrospinning a flexible and viable technology for Nanofibre-based materials development to target a wide range of applications.

A. System Electrospinning

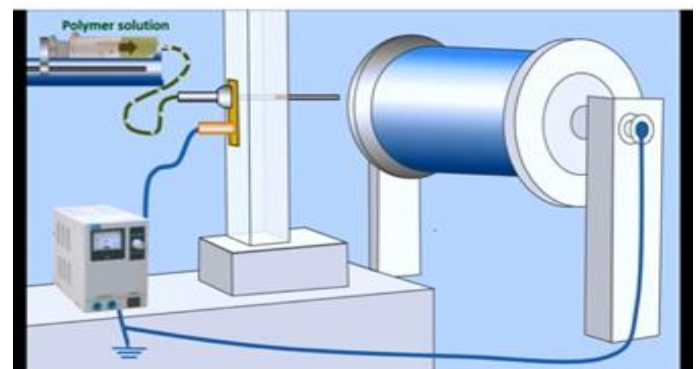


Fig 1:- basic process for Electrospinning technique.

Many teams and groups have done many theoretical researches on the Electrospinning process [41–43]. The conduct of electrostatic and magnetic emanation was explained by Sir William Gilbert at the end of the 1500s. He found that the water obtains cone and hopper shape by affecting the water droplet by electrostatic field, and a droplet extrudes from the hopper's head. This was the first electro-spraying process. Electrospinning can be seen as a form of electro-spraying. As with electro-spraying, the Electrospinning raw material is connected to a high-voltage power supply to enhance the electrostatic liquid potential. Depending on their inter-molecular interaction, high molecular degree polymers are often used as raw materials.

There is a direct relationship between the surface charge of liquid and electrostatic potential; hence, by increasing or reducing one of these, the same action can occur with another. The volume shape of the fluid is usually deduced by surface tension. By charging the fluid, the surface charge reverses the surface tension, causing the fluid to change shape, forming the structure known as the Taylor cone. The Electrospinning of fibers is influenced by many parameters and therefore the study and research in this field is difficult.

For example, by increasing 0.25 wt. per cent of ionic salts, the rate of mass transfer is reduced due to a phenomenon known as the "virtual orifice"[44]. Several of those essential parameters have been discussed in the following.

B. Sampler (Collector)

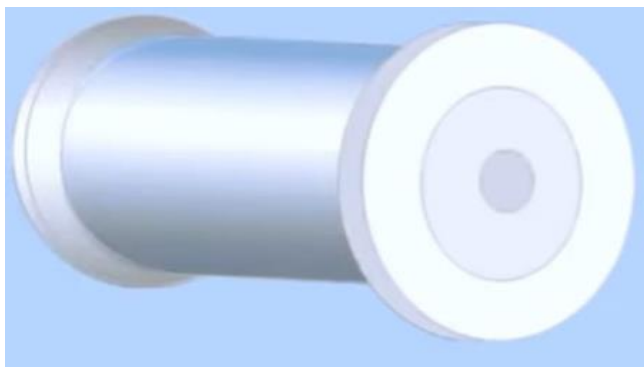


Fig 2:- Product Collector

The physical properties of electrospun fibers (such as crystal morphology and molecular orientation) are affected by collector character [45–47]. Rotating drum collector is the most commonly used collector. The fiber diameter can be controlled with this collector (due to drum speed) [48, 49]. Rotating disk is used to create balanced uniaxial fibres. The most important advantage of using disk collector rather than drum collector is that a large number of fibers are residue on the edge of the disk and the aligned fibers are collected as nano fibers [50–54]. Another form of collector uses two or more par-allel electrodes to obtain excellent alignment on each electrode based on air holes through the electrodes which cause electrostatic rebuttal between the fibers [55–57]. The fibers (isotropic / anisotropic) are affected by the speed and type of disk or drum collector. Collector speed can improve the crystal orientation of fibers due to the alignment of polymer molecular chains in the direction of the fiber axis obtained by the force of collector rotational velocity [58]. It should be noted that the use of high-speed rotational collector can create ventilator effect and solvent evaporation [59].

C. Applied voltage

The voltage applied in Electrospinning has a major duty in the ultimate characterization of fibre. The forwarding of charge in Electrospinning is due to the flow of polymer towards the collector, and the flow of polymer

mass from the nozzle has a direct effect on the current decrease or increase.

Increasing the voltage can cause spinning current to rise [60]. Increasing spinning current can lead to beaded morphology incidence and this structure can reduce the surface area. Increasing or decreasing the voltage applied can cause changes in fiber morphology and structure [61]. The study shows that the voltage increase leads to fiber length increases and fiber size decreases [62–64].

D. Distance between nozzle pickers

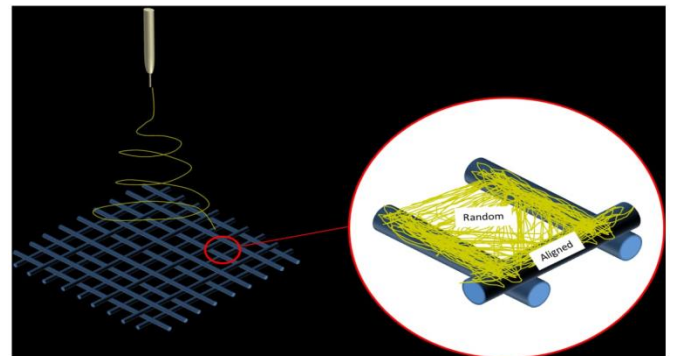


Fig 3:-Difference between nozzles to collector

The other parameter that has affected electrospun fibers' morphology, structure, physical and chemical properties is the distance between the nozzle and the collector. This has the direct effect on the final fiber properties depending on rate of evaporation, time of deposition and period of inconsistency. Studies show that we have wet electrospun fiber that has beaded structure, by decreasing the distance between nozzle and collector. The morphology of final fibers has also modified in some fibers from circular to flat form [62, 64]. At the other hand, the study shows that more distance is required to dry out the fiber for aqueous polymer dispersion [64].

E. Dispersion levels

The other effective parameters for producing fiber in terms of physical and chemical properties are the polymer flow rate. Shift in the rate of polymer flow (from the Electrospinning system syringe) causes fiber morphology to alter. The diameter of the fiber is increased by increasing the flow rate, and beaded morphology is observed [62, 65–67].

F. Electrospinning Materials

Electrospinning was used for the generation of Nanofibre from different material types. Organic polymers in the form of either solution or melt are the most commonly used materials. Small molecules can also be electrospun directly into Nanofibre if they self-assemble and generate sufficient entanglement to the chain. In combination with sol-gel chemistry a variety of composite materials were electrospun directly into Nanofibre. The as-obtained mixtures were also used for Electrospinning by introducing Nano scale components with different dimensions and/or morphologies (e.g.,

nanoparticles, Nano rods, nanowires, nanotubes, and Nano sheets) to polymer solutions.

G. Products by Electrospun

These fibers have received a lot of attention for use in many applications, based on electrospun special characters such as diameter, production process, and fiber filament.

Composite fibers, carbon nano tubes, inorganic fibers and tissue scaffolds are among the more active areas of application. Preparation of polymer dispersion of different materials in composite electrospun fibers is very simple. Thus different fibers can be produced with their own and new characteristics [68–73]. Nano-diameter inorganic fibers are not easy to produce. Table 1 compares the various methods of nano-fibre production. Usual method is to coat the electrospun matrix by chemical sinter with inorganic materials [74]. Tissue scaffolding is one of the usages of electro-spun fibers. The porosity of the nonwoven electrospun mat and its high surface area cause tissue scaffolding to develop. It has free area between fibers with length scale to cell size approximately 1–10 μm [75]. The electro-spinning of natural polymer chitosan [76] was reported in 2006 by Ohkawa et al. Schiffman et al. also showed cross-linked chitosan mats at the base of the ship using Electrospinning, which was achieved faster [77]. On the other hand, regenerated silk dispersion fibroin in formic acid was electrospun by Min et al., the fibroin of which consists of a quarter of alanine and 42 percent glycine [78]. Soffer et al. also use aqueous process to electrospun nonwoven Nanofibre made from Bombyx mori silk fibroin. Fantastic results are shown by mechanical characterization tests [79]. Many authors studied and reported collagen Electrospinning (one of the most common proteins) of 1, 1, 1, 1, 3, 3-hexafluoro-2-propanol [80–83], but Zeugolis et al. reported that most of its properties were lost to 1,1,1,1,3,3,3-hexafluoro-2-propanol or 2,2,2-trifluoroethanol during Electrospinning [84]. Li et al. reported on gelatin – elastin – PLGA electrospun composite and succeeded in producing it with a diameter of 380 nm so it could be used as a tissue [85]. Also electrospun gelatin-hydroxyapatite Nanofibre was produced for guided tissue engineering by Kim et al. [86, 87].

H. Carbon nano tubes (CNT)

Carbon nano tubes (CNT) have a number of mechanical features, such as high modulus and high tensile strength [88–91]. When the carbon nano tubes are used in composite as reinforcement, stringing them is so difficult and this is a disadvantage for CNTs. This nano-composite cannot contemplate the mechanical properties it was thought to have. Much research has therefore been carried out to synthesize CNTs into polymer nano fibers produced by the electro-spinning method [92, 93]. The Electrospinning process is expected to string the CNTs from one end of the fiber to another based on opposite polymer dispersion conductivity and sheer Electrospinning force [93]. Jiang et al. reported that great application of carbon nanotube / polyaniline in the field of electrochemical energy was achieved through Electrospinning of carbon nanotube / polyaniline based on

high current response, high conductivity and specific capacity [94]. Maitra et al. Also reported that CNT / PAN Electrospinning investigated the conductivity of fiber increases and the impression of the manufacturing method on the arrangement of carbon sheets in electro-spun nano fibers, and suggested a tempering effect of CNTs leading to increased graphification [95]. According to Mazinani et al. [96], electrical conductance measurement on electrospun nano fiber showed an electrical infiltration threshold of around 2 wt. percent multiwall CNTs. Furthermore, Rana et al. showed that electro-spinning of poly-urethane (PU) core and composites sheath with multiwall CNTs is very impressive in increasing the physical properties of nano fiber. The results also show that the product is rapidly restored in shape, in contrast to that of pure form memory PU and PU / MWNTs [97].

I. Alignment of fibres

Nano-scale fibers were almost achieved through nonwoven techniques and no longer had applications, and were limited to filtration [98, 99], implant coating film [63], tissue [100] and wound dressing [101]. Aligned micro-fibers pay particular attention to nerve-tissue engineering based on axon size and diameters and myelinated nerve fibers [102–104]. One way of acquiring aligned electrospun fibers is by sedimenting fibers on a rotating, electrically grounded edge of the wheel [105]. The sharp-ened wheel is spun at a stable angular velocity. The fiber flow is extruded in such a way that the fibers align with each other parallel to the keen edge. This method contains a proportional plain arrangement and can produce aligned fibers, but the utmost fiber diameter is limited to the small area around the rotating side [55]. Next uniaxial aligned fiber deposition target includes double magnetic pole, and electro-spinning dispersion in the area covering the magnetic poles is entrusted. This method can produce highly aligned fibers at inter-electrode distances of up to 1 mm, but the fiber efficiency is limited as the fiber alignment area is surrounded by the electrode's orthogonal edges. Typical alignment also reduces distances greater than 1 mm with the inter-electrode [106].

J. Dressing in Wound



Fig 4:-Electrospinning application in dressings

Electrospinning could create a wound-proofing platform. The studies show that the ultra-fine nano fibers can be spun directly onto the injured skin place to form a fibrous mat dressing [101, 107] using electric field. These nano fibers with pore sizes between 500 and 100 nm are suitable for bacteria protection against wounds. Many polymers, such as carboxyethyl chitosan / PVA[108], collagen / chitosan[109], silk fibroin[78], and ABA-type poly(dioxanone-co-L-lactide)-block-poly(ethylene glycol) (PPDO / PLLA-b-PEG) block copolymer[110], were electrospun and suggested for wound dressing. Hong reported that he prepared PVA / AgNO₃ electro-spinning wound dressing and used ultraviolet or heating to treat the webs[111]. As reported, Duan et al. also made poly(ϵ -caprolactone) (PCL) antibacterial Electrospinning Nanofibre with small nano particles of silver-loaded zirconium phosphate (nano AgZr) for potential use in wound dressing. The result shows that the electrospun fibers still possess antibacterial properties[112]. Kim et al. also explained an electro-spinning device that uses a guiding air blowing system and electrode to allow the production of poly(ϵ -caprolactone) nano fibers for wound dressing covers[113]. Ignatova et al. Also reported that poly-vinyl-pyrrolidone iodine complex Electrospinning and poly-ethyl-neoxide / poly-vinyl-pyrrolidone iodine complex as a prospective route to antimicrobial wound dressing material as [114]. On the other hand, Han et al.[115] investigated effects on early stage wound healing of poly(3-hydroxy butyrate-co-3-hydroxy-valerate) (PHBV) electrospun nanofiber cultivated with hair follicular cells.

K. Filtration

Produced electrospun fibers were specified with attention to their use in air filtration by measuring fiber diameter and fiber coating filtration performance[116]. Fiber filtration is one of engineering's fields of most applicability. Media fiber filters, for example, benefit from high filtration performance and a small air repellent [117,118]. Filters performance is related to fiber fineness and is one of the most important factors for filters. Electrospinning nano fibers are capable of catching oil droplets as small as 0.3 nm and this is an important property in the filtration sector. So fibers with Electrospinning are good candidates for removing unfriendly small particles. The efficiency of electrospun nano fiber filters can be enhanced based on the magnificent volume surface area that increases the cohesion of the surface[119]. In 2002 Emig et al. suggested a new method for producing a dust filter bag including a layer of nonwoven nano fiber[120]. Through a series of tests, Xiao-Hong Qin et al. Measured the fiber diameter, whole diameter, filtration yield and filtration repellent of Nanofibre texture and sub-layers. The consequences show that the diameter of Nanofibre is very fine compared to sub-layers. The hole diameter of the web of Nanofibre, on the other hand, is very small than sub-layers. Furthermore, Nanofibre' filtration performance and resistance is greater than sub-layers[121]. Many studies have reported excellent filtration efficiency for the electrospun poly-acrylic Ionitrile (PAN)[122].

L. Drug supply

Electro-spinning has been demonstrated as a plain technique for the production of nano-scale polymeric fibres. Different types of artificial and natural polymers were successful- fully electro spun into fine and small fibers. The high surface-to - volume ratio of produced fibers can increase the drug charge and the attributes of cell attachment. Electro-spun fibers have used many types of drugs, such as antibiotics, anticancer, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) [123, 124]. Using Electrospinning it is possible to prepare nanofiber based capsules including drugs to control the drug delivery system [125–129]. Mami Hamori et al. reported that methacrylic acid copolymer Electrospinning is an effective drug delivery technique for both polar and non-polar drugs [126]. Toncheva et al. compared dual spinneret Electrospinning with single spinneret Electrospinning using poly (L-lactide) as the base fibrous, and diclofenac sodium (DS) and lidocaine hydrochloride (LHC) as the drug. They observed that the dual spinneret approach permitted a resolution of the ionic action and reaction between diclofenac sodium and lidocaine hydrochloride [130].

II. CONCLUSION

Electrospinning is a simple method for producing fibers on a nano scale both in the laboratory and in industry. This technique has become one of the most acceptable methods for producing Nanofibre due to its wide application such as medicine, filtration, textile, etc. The number of research on this method and its applications has increased in the last decade and this demonstrates the importance of Electrospinning. Electrospun Nanofibre has found widespread use in a variety of applications due to their remarkable properties.

Applications from catalysis to protection of the environment, energy harvesting / conversion / storage, and biomedicine. Nonwoven mats of electrospun Nanofibre were specifically applied as advanced filters for removing pollutants from both polluted air and wastewater, due to their high porosity and large specific surface areas. Upon optimization in terms of diameter, porosity, alignment, stacking, surface functional groups, mechanical properties, and biodegradability, Nanofibre-based scaffolds were explored to enhance repair or regeneration of various tissue types, including nerve, skin, heart, blood vessel, musculoskeletal system, and tissue interfaces. Recent clinical trials on electrospun nano-fibers have begun paving the way for their ultimate implementation in regenerative medicine, particularly for use as barrier membranes to prevent post-operative adhesion between tissues.

➤ Nano fibers safety concerns-

The safety concern of Nanofibre, as a class of 1D nanomaterial's, stems not only from the production process but also from their potential harm to humans and other living species. During the production process, the safety concern relates mainly to the toxicity and environmental burden of the polymers and solvents as discussed above. Although Electrospinning has been used to process

recycled common plastics (e.g. PS, polyethylene terephthalate, polycarbonate and their mixtures) into high-value and high-performance products by eliminating the step of purifying the recycled raw materials, the use of organic solvents still makes this technology less environmentally friendly[131,132].

The diameter, length, and composition of the Nanofibre all need to be considered when assessing the impacts of electrospun Nanofibre on human beings and other living species. Electrospun Ag Nanofibre of 5–20 μm in length were reported to be lodged in mice's lungs and caused respiratory problems when intrapleurally injected into the lungs[133]. Other studies also suggested the harmful effects of relatively short inorganic Nanofibre, with diameters within or below tens of nanometers[134]. The chance of the electrospun Nanofibre reaching the lung at such a length scale is quite small. As shown in a study involving the model of rat silicosis, biodegradable and biocompatible electrospun cellulose nano-fibers (length 20 μm) inhaled into the lung could even facilitate the clearance of silica particles[137]. Nevertheless, only a very limited number of studies have been carried out to date to address the inhalation safety of electrospun Nanofibre; no conclusion can yet be drawn.

➤ Other Nanofibers Production Techniques-

In addition to Electrospinning, in recent years other techniques for generating (nano)fibers have also been developed[138]. In these new variants, the electrostatic force required in the Electrospinning process to produce Nanofibre is replaced by other forces, such as centrifugal and shear forces. For example, a nozzle-free centrifugal spinning method has been reported which could produce polymer Nanofibre with a diameter as thin as 25 nm[139]. The method involves applying drops of a polymer solution on a standard spin coater, followed by rapid rotation of the spin coater chuck. The formation of fiber is based on the instability of the spin-coated liquid film resulting from the competition between the centrifugal force and the surface curvature-induced Laplace force. A rotary jet-spinning technique was developed based on this design to further improve the production throughput[140]. In that process, in the middle of the system, polymer solution is fed into a rotating reservoir. Rotation causes a polymer solution jet to be ejected from the orifices onto the side wall of the rotating reservoir. To initiate the jetting, the centrifugal force must be greater than the capillary force exercised in the orifices by the polymer solution. Based on its inherent viscosity and centrifugal force, the jet experiences an extension. Once the jets are solidified, fibers are formed on a cylindrical collector placed around the reservoir and deposited there. This technique can be used to produce polymer Nanofibre with diameters thinner than 100 nm[141]. Variations of this technique have also been reported, including Forcespinning, [142].liquid shearing spinning, [143], magnetospinning[144], and brush spinning[145]. In addition, the integration of centrifugal spinning with solution blowing to produce polymer Nanofibre[146-147] has developed a pressurized gyration process. In a typical process, a gas stream is connected to the rotating reservoir by blowing a gas to enhance the

stretching of the jet. With a throughput of 6 kg / h, this technique can produce Nanofibre, offering mass production capability. Although these techniques can improve nanofiber production throughput, they tend to suffer from problems such as the difficulty of producing core-sheath, aligned, and/or patterned Nanofibre. Therefore, a new technique capable of producing Nanofibre with diversified properties and at a high throughput still needs to be developed.

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