REVIEW ARTICLE

Applications of Nanofibres in Textile Industry

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ABSTRACT

The term nano is derived from the Greek word nanos meaning dwarf and is a unit prefix representing a factor of 10− 9 which means "one billionth". Nanotechnology is a common name used for different set of techniques and methods to create numerous structures of nanometer sizes i.e. at the level of individual particles. Nanofibres have appeared as exciting one-dimensional nano materials and are capable to form networks of highly porous mesh with remarkable interconnectivity between their pores, which makes them an attractive choice for a number of commercial and innovative applications. Infact, the significant impact of nanofibre technology can be traced from the wide range of fundamental materials that can be used for synthesis of nanofibres. These include natural polymers, synthetic polymers, carbon-based, semiconducting and composite materials. One of the most widespread applications of nano fibres is in the field of textiles which include protective, smart, sportswear, electronic textiles, etc. These fibres have various applications in other areas also such as cosmetics; wound dressing, biomedical, filtration, drug delivery, sound absorptive materials etc. The future success of nanofibres in textile applications lies in areas where new principles will be combined into durable, multifunctional textile systems without compromising the inherent properties of textile including processability, flexibility etc.

Keywords: *Nanofibres, polymers, properties, techniques, textile applications*

INTRODUCTION

Nanotechnology is the science which is associated with the development of numerous novel products at nano levels. It is one of the fast emerging scientific disciplines due to its huge potential in creating materials that have advanced applications [1]. This technology has greatly impacted many different science and engineering disciplines, such as electronics, materials science, and polymer engineering. The use of nanotechnology in the textile industry has increased due to its unique and valuable properties. One of the major successes of nanotechnology has been nanofibres [11].

Nanofibre is the generic term that describes nano-objects with two external dimensions in the nanoscale with diameter less than 100 nm. One of the most prominent features of nanofibres is their exceptionally high surface area-to-volume ratio and high porosity with very small pore size [48]. Going along with the development of advanced science and technology, great changes have been taking place in fibres in recent years, and probably further improving the textiles. Rather than traditional fibres, the smart ones, which are developed with multi-functionality, are highly promising field due to their interactability with external environment [30]. The global nanofibre market was valued at US$ 409.14 million in 2019 and is expected to reach US$ 3,309.58 million by 2018; it is projected to grow at a CAGR of around 31.2% during 2020 to 2027. The real testament to the significance of nanofibres can be observed from the many building blocks or fundamental materials that can be used for the synthesis of nanofibres to the range of applications in which they have been demonstrated to have significant impact [34]. Till date, nanofibres have been prepared from an assortment of materials and

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polymers such as polyvinyl alcohol, gelatin, collagen, chitosan, carboxymethylcelulose *etc.* [53].

Nanofibres can be fabricated using a number of different methods using physical, chemical, thermal, and electrostatic production techniques such as electro-spinnig, template based synthesis, self-assembly, drawing, phase separation *etc.* [44]. Among all the techniques, electro-spinning has been most widely adopted for converting different types of polymers into nanofibres and may be the only process that has the potential for mass production [26]. Electro-spinning is different from other nanofibre production processes due to its ability of forming several fibre assemblies. This certainly improves the performance of materials made from nanofibres and allows application specific modifications [4]. Some noval techniques are now being introduced used for the production of nanofibres on a large scale such as CO_2 laser supersonic drawing, solution blow spinning, plasma-induced synthesis and centrifugal jet spinning [31].

Special properties of nanofibres make them suitable for a number of applications from medical to consumer products and industrial to high-tech applications for aerospace, capacitors, transistors, drug delivery systems, battery separators, energy storage, fuel cells, and information technology. They have a wide range of application in textiles such as protective, smart, medical, sports, industrial and electronic textiles [37]. Therefore, this paper reviews the different polymers and techniques used for the fabrication of nanofibres, outlines some of the unique properties of nanofibres. Finally, include the numerous applications of nanofibres in textile sector and some other areas related to it.

Polymers Used For The Production of Nanofibres

Numerous polymers, both natural and synthetic, have effectively been converted into nanofibres. They are different with respect to chemical nature, mechanical property, biocompatibility and bioresorbability.

Collagen is the main structural protein in the extracellular matrix and a biocompatible and bioresorbable natural polymer found extensively in the connective tissue of animals. Collagen occurs naturally in the form of fibre; in structure, few types of collagen have been electro-spun into nanofibres and are capable to serve as a substitute for the extracellular matrix in tissue repair or regeneration and wound care applications [29].

Gelatin is a denatured collagen and another widely used material for electro-spun nanofibre mats for medical applications due to its biocompatibility, bioresorbability and low cost [41]. Gelatin nanofibres, generally electrospun from the gelatin solution in organic solvents (e.g., HFP, trifluoroethanol), acids (e.g., formic acid, acetic acid), or water, should be cross-linked so that they can be stable enough in an aqueous environment [32].

Chitin is the second most abundant natural polysaccharide, next to cellulose and can be derived from crab and shrimp shells. It is also used for the nanofibre production in various biomedical applications [52].

Chitosan is an N-deacetylated derivative of chitin, a natural polysaccharide that has been widely used in biomedical applications because of its biocompatibility, bioresorbability and antibacterial functions. Modified chitosan or chitosan derivatives have also been used in the production of biomedical nanofibres [5].

Other natural polymers that can be used for the production of nanofibres include hyaluronic acid, polyN-acetylglucosamine, alginate-based materials, fibrinogen, elastin, poly(3-hydroxybutyrate-co-3-hydroxyvalerate), wheat gluten and zein (a protein derived from corn) [25].

Polyvinyl alcohol (PVA) is a non-biodegradable synthetic polymer used conventionally in wound dressings. PVA nanofibres can be attained using electrospinning from PVA/water solutions [57]. Heat treatment is a chemical-free alternative method for the cross-linking of PVA, by which the cross-links are formed between two hydroxyl groups by losing an H_2O at a high temperature. Heat treatment also improves the crystallinity of the electrospun PVA nanofibres [8]. *Polylactide (PLA)* is another type of synthetic polymers generally used in biomedicine. PLA is hydrophobic and is thus used in combination with other polymers, which provides an advantage to use numerous materials in biomedical applications [32]. Therefore natural polymers, such as silk fibroin, chitosan and gelatin can be blended with PLA to form hybrid or composite nanofibrous structures, and PLA can be used as a block in copolymers such as poly(ethylene glycol) and poly(lactic-co-glycolic acid) (PLGA) in the fabrication of nanofibres [16].

Polyglycolic acid (PGA) is a biodegradable and bioresorbable polyester commonly used in biomedical applications. It was first introduced as a material for bioresorbable sutures in the 1970s. PGA has good mechanical strength and a predictable bioresorbability, which is a required property for implants [19]. As a result, it is also suitable for other end uses in which initial strength and fast degradation are necessary, such as scaffolds for tissue repair and regenerations. Till date, PGA is frequently used in combination with other polymers, such as PLA, in the form of copolymers or blends to provide needed properties for biomedical applications [22, 40].

Polycaprolactone (PCL) is bioresorbable polyester often used in biomedical applications, including wound care and scaffolding for tissue repair and regeneration. PCL is hydrophobic and highly crystalline, thus able to provide prolonged mechanical stability with a low rate of degradation [48]. Performance of PCL is generally improved with the use of natural polymers e.g., gelatin and collagen via blending or coating to enhance its biocompatibility in biomedical applications [27].

Polyethylene glycol (PEG) is also known as polyethylene oxide (PEO), is a hydrophilic polyether. PEG is a material with relatively low molecular weight (e.g., several thousand), while PEO is a material with high molecular weight (e.g., over tens or hundreds of thousands). PEO is water soluble and therefore can be electrospun into nanofibres from its water solution [53]. However, water solubility makes the material unstable in a biological environment. Therefore, it is generally used in combination with other natural (e.g., collagen, chitosan) or synthetic polymers (e.g., PLA) in blends or copolymers [11].

Other synthetic polymers that have been utilized in the development of nanofibrous structures include the non-biodegradable polyurethane and biodegradable polydioxanone [35]. The advantages and disadvantages of using natural and synthetic polymers for nanofibre fabrication is given in Table 1.

Table 1. Advantages and disadvantages of natural and synthetic polymers

Natural Polymer	Synthetic Polymer
Advantages • Biocompatible and Biodegradable • Less non-toxic with minimum side effects • Capable of incorporating with drugs • Do not involve the use of harsh chemicals during processing and it is easily chemically modifiable • Able to promote cell adhesion and proliferation • Possess known cell-binding sites that support cell attachment	**Advantages** • Higher reproducibility and adequate supply • Better conjugation properties • Good mechanical and chemical strength • More flexibility in the design and development of new products • Controllable degradability by manipulating the crystallinity, molecular weight, and copolymer ratio
Disadvantages • Poor stiffness and mechanical strength due to lack of control over the pore size and mechanical properties of the product • High speed of degradation and uncontrolled rate of hydration • Limited ability to tailor for specific properties leads batch to bath variation • Slow rate of production and limited supply • Microbial and heavy metal contamination • Complicated extraction procedure	**Disadvantages** • Lack of intrinsic biocompatibility and bioactivity • Difficulty in 3-D fabrication • Uncontrollable shrinkage • Questionable cell polymer interactions • Possible local toxicity resulting from acidic degradation products • Difficult task of minimizing cytotoxicity in products

Unique Properties of Nanofibres

Morphology of nanofibres: Nanofibres have gained much research concern due to their morphological characteristics. These fibres have large surface area to volume ratio, small pore sizes and ability to produce in three dimensional forms [14]. By modifying the process parameters, these characteristics can be adapted to meet specific applications and needs. The huge surface area available on a nanofibre makes it very appropriate for noval technologies which require smaller environments for chemical reactions to take place and increasing the surface area can speed up a chemical reaction [1].

Physical properties of nanofibres: Nanofibres aquire some remarkable properties which improves the functionality of products which include small diameter of fibre, low basis weight, filtration properties, feasibility to incorporate active chemistry, layer thinness and high permeability. Nanofibres are characterized by high axial strength beside extreme flexibility [2]. Sawhney *et al.,* highlighted that materials made of nanofibres are characterized by outstanding biophysical properties, because such products have very good cooling properties, they quickly absorb and release sweat and stabilize the increase in body temperature. Another important property of nanofibres is their high resistance [47], This very significant property has been used in the fat-burning underwear. Brown *et al.,* reported that a little percent of nanofibres on the meltblown fabrics surface prominently decreases water contact angle and enhances liquid retention. Therefore, this fabric found innovative applications in technical areas such as textile, filtration, environment and biomedicine

[9]. Electrospun nanofibres could be used to collect pollutants via physical blocking or chemical adsorption as they have a large specific surface area. Thus, they can provide a solution to protect environment [43].

Production Techniques of Nanofibres

There are a number of techniques that are used for the fabrication of nanofibres such as electro-spinning, template based synthesis, self-assembly, drawing, phase separation *etc.* Among all the production techniques, electro-spinning is one of the most established and commonly used technique.

Electro-spinning

It is the process of developing fibrous structures in nanometer range (diameter 40 to 2000 nm) by subjecting a fluid jet to a high electric field. The instruments required for electro-spinning include: a high voltage supplier, a capillary tube with a pipette or needle with a small diameter, and a metal collecting screen. One electrode is placed into the polymer solution and the other electrode is attached to the collector. An electric field is applied to the end of the capillary tube that consists of the polymer solution held by its surface tension and forms a charge on the liquid surface. As the intensity of the electric field increases, the hemispherical surface of the fluid at the tip of the capillary tube elongates to form a conical shape known as the Taylor cone [11, 42]. A critical value is achieved upon further increasing the electric field in which the repulsive electrostatic force overcomes the surface tension and the charged jet of fluid is ejected from the tip of the Taylor cone. The discharged polymer solution jet is unstable and as a result elongates, letting the jet to become very long and thin. Charged polymer fibres solidify with solvent evaporation and randomly-oriented nanofibres are collected on the collector. Parameters such as jet stream movement and polymer concentration are important to control for producing nanofibres with uniform diameters and morphologies [45].

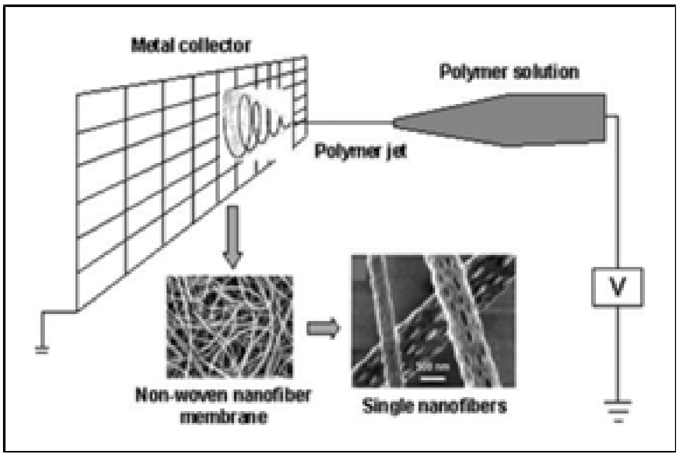

Figure 1. Schematic diagram for the electrospinning process

Joshi stated that electrospinning can also be used to produce nanofibres from polymer nanocomposites, incorporating nanoclays, CNTs and other nanoparticles that add a new dimension to nanofibres. These nanocomposite fibres when deposited over textile materials can be further used to produce fabrics, antistatic, electromagnetic shielding, high performance separation, reinforcing and electrical materials [28]. Kim *et al.* reported that mesoporous alumina nanofibres produced by electrospinning technique can be effectively applied for the removal of dye pollutant from aqueous solutions [34].

Template based synthesis

It is another frequently used method mostly to produce inorganic nanofibres e.g. carbon nanotubes and nanofibres or conductive polyaniline (PANI), polypyrrole (PPy) *etc.* Template synthesis includes the use of a template or mold to develop a preferred material or structure [18]. For the instance of nanofibre creation by Feng *et al,* the template refers to a metal oxide membrane having nano-scale diameter thickness pores. By the use of water pressure together with the porous membrane control causes extrusion of the polymer which on contact with a solidifying solution, produces nanofibres whose diameters are determined by the pores. The template based synthesis uses a nanoporous membrane template composed of cylindrical pores of uniform diameter to make fibrils (solid nanofibre) and tubules (hollow nanofibre). The uniform pores permit to control the dimensions of the fibres hence, nanofibres with very small diameters can be developed through this technique. However, a drawback of this technique is that it cannot produce continuous nanofibres at one time [15].

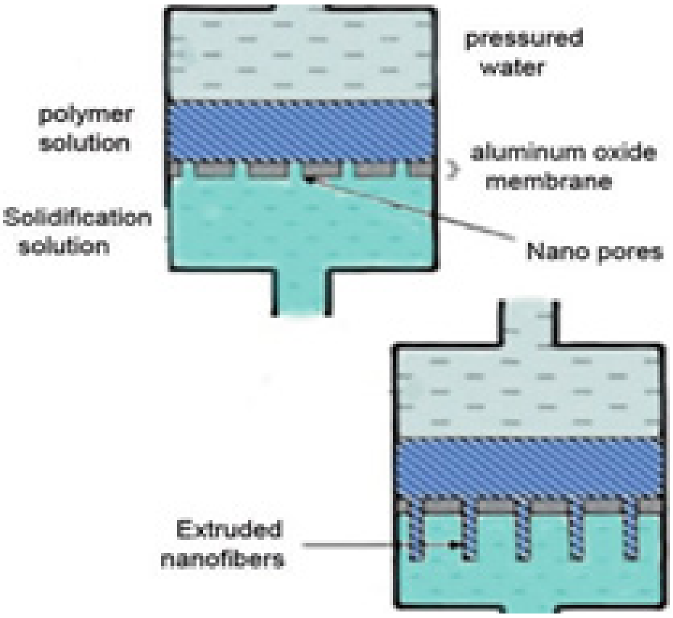

Figure 2. Schematic diagram for the Template based synthesis

Self-assembly

Self-assembly is one of the most commonly used techniques appropriate for the development of ordered nanostructures from small building blocks and used to produce peptide nanofibres and amphiphiles. The process was inspired by the natural folding process of amino acid residues to form proteins with exceptional three-dimensional structures [34]. The self-assembly method of peptide nanofibres includes many driving forces such as hydrophobic interactions, electrostatic forces, hydrogen bonding and Van der Waals forces and is influenced by external conditions such as ionic strength and pH. Recently, this process of self-assembly has been frequently used for nanofibres, which cannot be produced by other methods for the nanofibres fabrication, such as electrospinning [57].

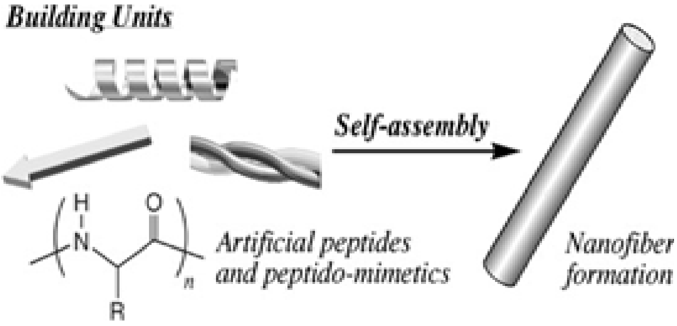

Figure 3. Schematic diagram for the Self-assembly

Drawing

The drawing method can be described as dry spinning at a molecular level and this technique can only be used for viscoelastic materials that are capable of experiencing a high degree of deformations, but remaining suitably solid to take up the applied stress during pulling. A typical drawing process needs a SiO$_2$ surface, a micropipette and a micromanipulator to produce nanofibres [27]. A micropipette with a few micrometer diameters is dipped into the droplet near the contact line through a micromanipulator. The micropipette is then removed from the liquor to pull a nanofibre. The pulled nanofibre is dumped on the surface by touching it with the micropipette end and the drawing of nanofibre is then repeated on each droplet. This method develops nanofibres one by one on a laboratory-scale which prevents it from being used at industrial level [33].

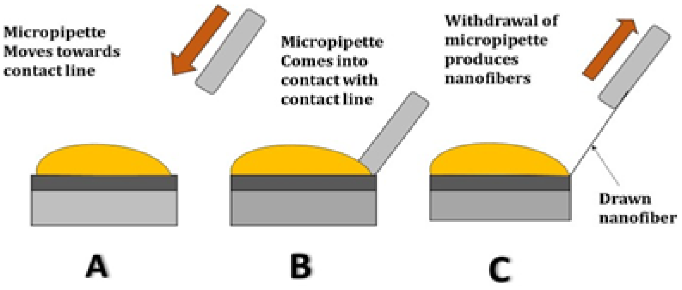

Figure 4. Schematic diagram for the Drawing Technique

Ondarcuhu and Joachim [38] found that the drawing process makes long single nanofibres strands one at a time. The pulling process is accompanied by solidification that transforms the dissolved spinning material into a solid fibre. The limitation of this method is that it can only be applied to viscoelastic materials.

Thermal-induced phase separation

It separates a homogenous polymer solution into a multi-phase system through thermodynamic changes. This process includes polymer dissolution in a solvent at a high temperature followed by a liquid-liquid or solid-liquid phase separation induced by lowering the solution temperature. Thermal-induced phase separation technique is commonly used to generate scaffolds for tissue regeneration gel with water, and freezing and freeze-drying under vacuum. It has capability of a wide variety of geometry and dimensions involve pits, islands, fibres, and irregular pore structures [51].

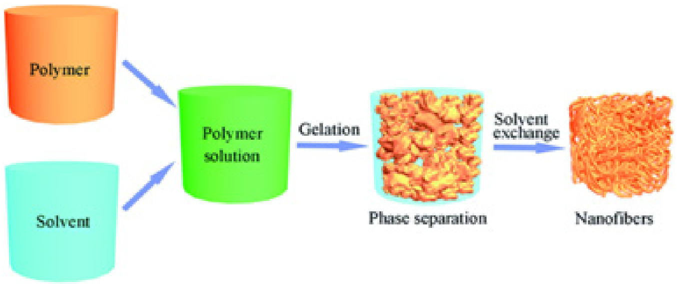

Figure 5. Schematic diagram for the Thermal-induced phase separation

Ghalia and Dahman highlighted that phase separation is primarily based on a thermodynamic process that is used for developing interwoven, nanofibrous scaffolds in tissue engineering. While the thermally induced phase separation (TIPS) method is most frequently used for phase separation [16].

New Techniques for Nanofibre Production

While most nanofibres are produced using electro-spinning, this technique includes several drawbacks such as requirement of high electric field necessities, solutions with superior dielectric properties, low production rate, high production cost and many other safety correlated topics, therefore electro-spinning is not appropriate for mass production of certain materials [31]. Subsequently, recent years have seen the increasing development of new strategies in preparing nanofibres on a large scale and highly throughput manner which are:

CO$_2$ laser supersonic drawing

This method produces long nanofibres on the basis of single continuous process without the use of chemical solvents. Using a CO_2 laser, original fibres with diameter between 100 and 200 um are melted and then passed via a supersonic airflow to attain the supersonic drawing of nanofibres based on the force of the air. Usually, this strategy is possible to be applied for a variety of thermoplastic polymers involving polylactic acid (PLA), polyethylene terephthalate (PET), and polyglycolic acid (PGA) [17]. A study conducted by Hasegawa and Milkuni demonstrated, for the first time, the synthesis of nyon-66 nanofibreswith high melting point near the equilibrium melting point using the CO_2 laser supersonic drawing. Using this simple process, the preparation of polymeric nanofibres with extended chains and increased mechanical properties could be attained[19].

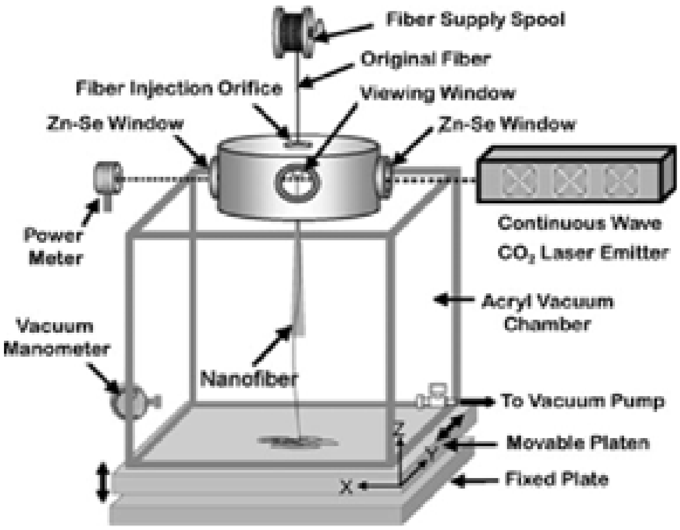

Figure 6. Schematic diagram for the CO_2 laser supersonic drawing

Solution blow spinning

This method has been developed to overcome the various limitations of conventional electro-spinning process, like the difficulty in in-situ synthesis of nanofibres and the need for high electrical potential and conducting targets. Solution blow spinning requires only a simple commercial airbrush, concentrated polymer solution, and a compressed gas source, the technique may potentially be used for in-situ deposition of nanofibre mats and scaffolds for comfortable coverage of non-conducting targets as well as various tissue engineering and surgical applications [22].

Behrens *et al.* carried out in situ deposition of conformal PLGA nanofibre mats or meshes on any material using only a painting brush and high pressure CO_2 gas. In this process, polymer nanofibres were synthesized from 10% PLGA solutions in acetone with different viscosities corresponding to low and high molecular weights under CO_2 flow [7].

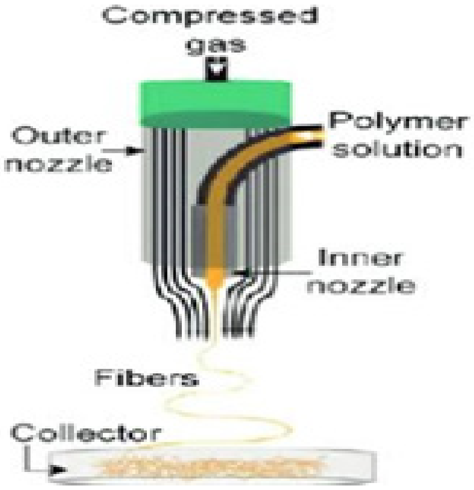

Figure 7. Schematic diagram for the Solution blow spinning

Plasma-induced synthesis

In plasma- induced synthesis technique, nanofibres are produced on the basis of five different steps i.e. rapid and energetic bombardment of radicles onto the electrode surface , atomic vapor deposition, expansion in plasma, condensation of solution medium, in situ reaction of oxygen and growth of nanofibres. Plasma is usually generated from the discharge between a pair of metal electrodes in solution by a pulse direct current. An example of the nanofibre production using the plasma-induced method is the synthesis of CuO nanofibres with diameter between 15 and 25 nm in water [24].

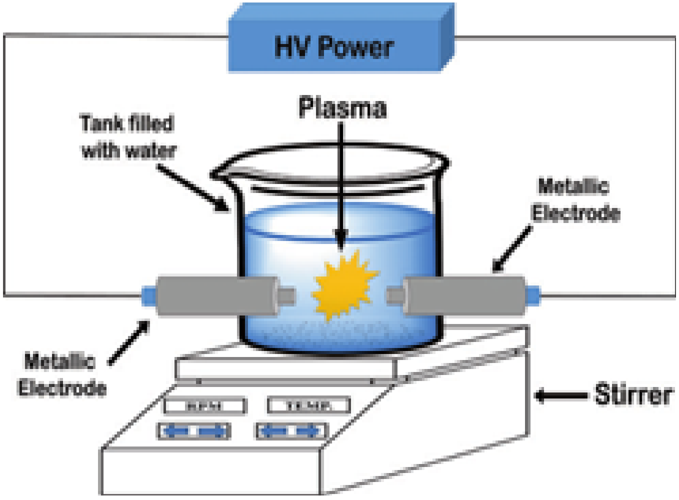

Figure 8. Schematic diagram for the plasma-induced synthesis

Centrifugal jet spinning

The versatile centrifugal jet spinning has been developed for the preparation of nanofibres in a highly effective, low cost, and higher-throughput fashion. In principle, the thinning of solution filament into nanofibres using centrifugal jet spinning is attained with the controlled manipulation of centrifugal force, viscoelasticity, and mass transfer characteristics of the spinning solutions. The elasticity and evaporation rate of spinning solution and solvent have an effect on eventual diameter of the as-produced nanofibre [44]. One of the most prominent advantages of the centrifugal jet spinning method is its exceptional throughput. Explicitly, its efficiency is predicted to be approximately 500 times greater than that of conventional electrospinning [41].

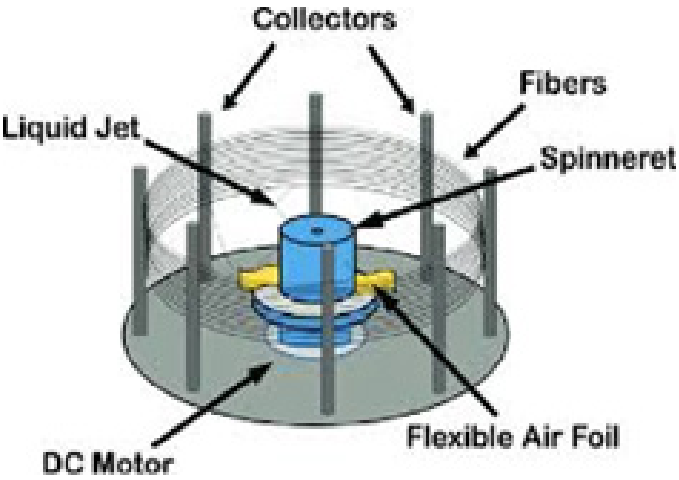

Figure 9. Schematic diagram for the centrifugal jet spinning

Applications of Nanofibres in Textiles

Protective Textiles

Protective textiles are often necessary for specific work environment and include battlefield, hospital or other occupational environment where there is a possibility of exposure to different chemicals, nano-particles or other pathogens. Electrospun fibres due to its large surface area and ease of functionalizing make it an important material for the production of protective clothing which can be light-weight while presenting a wide variety of functionality [5, 32]. Faccini *et al.,* investigated the ability of electrospun polyamide 6 (PA6) in blocking nanoparticles for use as protective textile. A study was conducted in which the electrospun fibres were adhered to a viscose nonwoven textile using hot-melt lamination through a thermoplastic adhesive powder. For the thinnest membrane coating (coating duration of 5 mins), less than 50% of 200 nm nanoparticle penetrate through the membrane. At 60 minutes of coating, less than 1% of the nanoparticles from 20 nm to 200 nm were able to penetrate through the membrane [13].

Smart Textiles

‘Smart’ or ‘Functional’ materials generally form part of a ‘Smart System’ that has the ability to sense its environment and if truly smart it responds to that external stimulus through an active control mechanism. A shirt can be produced in which the electrically-conducting nanofibres let cell phone functionality to be built in with the absence of metallic wires or optical fibres [35].

Programmable fabric

The basic idea behind this is to manufacture a material made up of small cellular units with nanofibres that attach to each other with screws. Computers would direct the cells to adjust their relative spacing with the screws. The programmable material concept is not only limited to fabrics but has numerous potential applications. One example is a space suit that allows nearly as much freedom of movement as one’s own skin [3].

Self-repairing fabrics

Fabrics made up of nanofibres could be self-repairing: sensors would detect discontinuities in the material through loss of signal and send robotic “crews” to repair the damage. Self-shaping fabrics is capable of returning to their original shape around a tear until repairs are affected [29].

Porous fabric

Micro pumps and flexible micro tubes together with nanofibres could transport coolant or a heated medium to required parts of textiles. Water might be a useful molecule to select for, to keep one side of a fabric dry or another side wet. On the wet side, the water could be transported away to an evaporator, or stored [30]. Chinta stated that in the near future, smart textiles that can monitor variables like the condition of drivercan be made. The increased use of textiles in the car contributes to the reduction of the car weight and hence fuel consumption and CO_2 emissions will also get decreased [10].

Sportswear textile

Sportswear textile with nanofibre membrane inside is developed on the basis of modern nanofibre technology in which the core of the membrane contains fibres of 1000×thinner diameter as compared to human hair. This extremely dense “sieve” having more than 2.5 billion pores per square centimeter works much more proficiently with vapor removal and provides good water resistance [4, 36]. Some of the most essential properties of nanofibres based sportswear and shoes are: water-proof, UV protection, antibacterial, self-cleaning, electrical conductivity and comfort [8]. Bagherzadeh *et al.,* compared the nanofiber mats based multi-layer fabric with a well-known commercial protective multi-layered fabric, Gortex and concluded that the use of nanofiber membranes, instead of coating material not only exhibited high windproof properties and adequate water repellent properties, but also enhanced water vapor permeability behavior [6].

Electronic Textiles

Textiles with electronic properties manufactured from nanofibres for protecting athletes in high-risk sports like mountaineering and monitoring the biological and physiological body changes and vital body signs have been one of the recent research concerns. The athletes' physical health during sport activities can be detected by wearing electronic smart sportswear. Interactive electronic textiles have been developed to observe blood pressure, time, distance, calorie and movement in active sportswear [26].

Undergarments

The 'UltraSkin' underwear collection from The Living Wear Co. is a lineup of products for men that will provide them a natural way to stay comfortable and dry all day. The undergarment lineup includes boxers, briefs, and undershirts that are all crafted from Lyocell nanofibre that is 100% natural. The renewable and nontoxic material is reported to have an absorption level that is 20-times better than traditional cotton or polyester [23].

Filtration

Numerous nano-fibre based filters have been developed for various uses such as consumer, defense, automotive, apparel applications etc. Nanofibre mats demonstrated to be proficient in filtering airborne particles, tiny liquid droplets within liquid-liquid immiscible systems and ultrafiltration for oil/water emulsion separation [14]. Electrospun nanofibres could be used to collect metal ions from a solution tank due to their huge specific surface area, high porosity and controllable surface functionality [55]. Suja *et al*. evaluated the utilization of electrospun nanofibre filtration membranes, spun by electrospinning process, for water disinfection. Result showed that removal of *Staphylococcus aureus* and *Escherichia coli* bacteria from the waste water is possible using these membranes [21, 48].

Medical and Bio-medical

Electrospun polymer nanofibres are very biocompatible due to their porous thin film structure. They are widely used in the devices which are to be implanted in the human body; these may be referred to as soft tissue prostheses application. Nanofibre technology is used in many human body transplantations like blood vessels, heart, vascular, breast *etc.* [39].

Wound Dressing

Polymer nanofibres can also be used for the treatment of wounds or burns of a human skin, as well as designed for haemostatic devices because of some unique characteristics. With the help of electric field, fine fibres of biodegradable polymers can be directly sprayed/spun onto the injured location of skin to form a fibrous mat dressing, which can let wounds heal [49]. Ignatova reported that electrospinning of poly-vinyl-pyrrolidone iodine complex and poly(ethylene oxide)/poly-vinyl-pyrrolidone iodine complex as prospective route to antimicrobial wound dressing materials [25].

Drug delivery

Electrospinning has been established as a plain technique for producing polymeric nanoscale fibers. The huge surface area to volume ratio of manufactured fibres can enhance attributes of drug loading and cell attachment. Different types of drugs such as antibiotics, anticancer, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) have been utilized by electrospun fibers [37].

Composites

Nanofibres are capable for finding many applications in nanocomposites. Nanofibres have better mechanical properties as compared to microfibres of the same material, thus nanocomposites will have superior structural properties. Electrospun nanofibres of polybenzimidazole (PBI) can be used as reinforcement in epoxy and rubber matrix [56]. Rojas *et al.,* incorporated cellulose whiskers in electrospun polystyrene–based micro and nanofibres. The manufactured nanocomposite fibres and respective nonwovens were used in high-performance applications due to their extremely porous structure and high surface areas [46].

Sound absorptive materials

Traditional sound absorption materials include paper, cotton, cork, foams, fibres, membranes, perforated panels and so on. These traditional acoustical fibrous materials have good noise reduction abilities in the high frequency range, but exhibit little sound absorption properties in the low and medium frequency range. The nanofibrous materials are favorable alternatives in the noise reduction field as they are able to absorb sound in low and medium frequency range [20]. Xianga prepared PAN nanofibrous membranes by electrospinning and evaluated the sound absorption behavior of the nanofibrous membranes and their composites with traditional acoustical materials. The results demonstrated that the nanofibrous membrane has a promising acoustical damping performance [54].

CONCLUSION

Textile industry has already been impacted by nanotechnology. Nanotechnology products are very popular in the textile sector, both in the field of fibre production and modification. Nanofibres can be produced from various natural and synthetic polymers, each having their respective advantages and disadvantages. Different traditional and noval methods can be used for nanofibres fabrication. Due to their small diameter and large surface area, nanofibres have a wide range of application in textile sector like in protective textile, smart textile, electronic textile, sportswear *etc.* They have also shown a great promise in filtration, wound dressing, cosmetics, composites, tissue engineering, drug delivery etc. Applying nanofibres will positively affect the functional properties of clothing. Such clothing is characterized by great lightness, softness and delicacy. Products made of nanofibres are characterized by excellent physical, chemical, thermal, electronic and biological properties. Research involving nanofibres to improve performances or to create unprecedented functions of textile materials is flourishing. There is no doubt that in the next few years, nanotechnology will penetrate into every area of textile industry.

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