Patan Adam khan. et al. / Vol 3 / Issue 1 / 2013 / 47-55.

International Journal of Pharmaceutical Research & Analysis

e-ISSN: 2249 – 7781
Print ISSN: 2249 – 779X

www.ijpra.com

NANOFIBERS - A NEW TREND IN NANO DRUG DELIVERY SYSTEMS

Patan Adam khan*, K. Sasikanth, Sreekanth Nama, P. Suresh, B. Brahmaiah

*Department of Pharmaceutics, Priyadarshini Institute of Pharmaceutical Education & Research,
Kornepadu (V), Vatticherukuru (M), Guntur-522017, Andhra Pradesh, India.

ABSTRACT

Polymer nanofibers, with diameters in the nanometer range, possess larger surface areas per unit mass and permit easier addition of surface functionalities compared with polymer microfibers. Hence, polymer nanofiber are being considered for use as filters, scaffolds for tissue engineering, protective clothing, reinforcement in composite materials and sensors. Although some of these applications are in the development stage, a few have been commercially exploited. Research on polymer nanofibers, nanofiber mats, and their applications has seen a remarkable growth over the last few years. Among all methods, electro spinning has been used to convert a large variety of polymers into nanofibers and may be the only process that has the potential for mass production. Although there are many methods of fabricating nanofibres, electro spinning is perhaps the most versatile process. Materials such as polymer, composites, ceramic and metal nanofibres have been fabricated using electro spinning directly or through post-spinning processes. However, what makes electro spinning different from other nanofibre fabrication processes is its ability to form various fibre assemblies. This will certainly enhance the performance of products made from nanofibres and allow application specific modifications. It is therefore vital for us to understand the various parameters and processes that allow us to fabricate the desired fibre assemblies. The structure, morphology, and geometry of nanofibers and the porosity and tensile properties of nanofiber mats can be investigated through conventional techniques and instruments.

Keywords: Nanofibers, Electro spinning, Electro spuns.

INTRODUCTION

Fiber is diameter in nanometer range. Nanofibers are a nanomaterial with one dimension less than 100 nm. Wide range of polymers such as polyvinyl alcohol, gelatin, collagen, chitosan and carboxymethylcelulose can be subjected to electro spinning technique to produce nanofibers. Nanofibers have large specific surface area with small pore size and these unique properties showing opportunities in management of wound care applications [1]. The benefits of the nanofibers are; development of nanofiber layers from different polymer, drugs or growth factors can be incorporated into different nanofiber layers for wound care management. Role of nanofibers in advanced wound care managements are; a) absorption of exudates, b) addition of drugs to the nanofibers and showing anti-adhesive effect. In addition, nanofibers can be used in drug delivery systems to improve control drug delivery of drugs via nanofiber [2].

Technology of nanofibers – Electro spinning technology

Electro spinning is the process using electrostatic forces to form a fine filament of the polymer solution. Electro spinning is an inexpensive method of nanofiber production by exposing a polymer solution to high voltage electric field, fiber can be formed which are 1000 times smaller in diameter than the average human hair (100nm v.100um). . When a high voltage is applied to the metal syringe needle, electrical charge builds up on the surface on the solution. The charge is attracted to an electrically grounded collector, in our case; a piece of aluminum foil as the charge jumps to the electrical ground, a thin jet of

Corresponding Author:- Patan Adam khan Email:- brahmaiahmph@gmail.com

polymer solution is pulled from the needle. After the solution leaves the syringe, the solvent evoparets and a very thin stream of polymer is completing a circuit started by the voltage power source. Finally nanofibers are collected and patterned on a grounded plate. The benefits of electro spinning technology are; a) high rate of nanofiber can be produces; b) simple set up and production costs is low[3].One of the most important quantities related with electro spinning is the fiber diameter. Since nanofibers are resulted from evaporation or solidification of polymer fluid jets, the fiber diameters will depend primarily on the jet sizes as well as on the polymer contents in the jets. It has been recognized that during the traveling of a solution jet from the pipette onto the metal collector, the primary jet may [4-6] or may not [7-12] be split into multiple jets, resulting in different fiber diameters (Fig no-1). As long as no splitting is involved, one of the most significant parameters influencing the fiber diameter is the solution viscosity. A higher viscosity results in a larger fiber diameter [13-16]. However, when a solid polymer is dissolved in a solvent, the solution viscosity is proportional to the polymer concentration. Thus, the higher the polymer concentration the larger the resulting nano fiber diameters will be. In fact, Deitzel et al. pointed out that the fiber diameter increased with increasing polymer concentration according to a power law relationship**.** Further found that the fiber diameter was proportional to the cube of the polymer concentration. Another parameter which affects the fiber diameter to a remarkable extent is the applied electrical voltage. In general, a higher applied voltage ejects more fluid in a jet, resulting in a larger fiber diameter [17].

Electro spinning setups

A basic electro spinning setup consists of three elements: an electrical generator (high voltage supply), a capillary (jet source) and a metal collector (target) (Fig. 2).

Properties of nanofibers

- large specific surface area
- high porosity
- small pore size
- diameter range (50 – 1000) nm

Material

- Polymer solutions or melts
- More than 30 polymers, including polyethylene oxide, DNA,
- Polyaramids, and polyaniline, have been electro spun.
- These fibers can be made of variety organic (nylon, polyester, acryl) or biological polymers (proteins, collagens).
- PVA, PS, PAN, but also peptide amphiphiles or cellulose.

Functionalization of nanofibers

Activation process for porous nanofibers

Nanofibers have many benefits because of their large surface area for active reaction sites. Activation processes for improving these active sites have been applied by chemical/physical activation. As a representative case of physical activation, the activation agent was embedded into the fibers and then removed by physically removing the agents. The process for PAN-based porous nanofibers physically activated by silica is presented in Fig. 3 [20]. The silica-activated carbon nanofibers are shown in Fig.3 [20]. The pores generated by physical activation are clearly observed.

Heat treatment effect for physical properties

Heat treatment has been carried out widely because it can change physical properties. The electrical enhancement of PAN-based carbon fibers was presented by [21].In Fig. 3. A stabilization treatment was carried out at 280 °C for duration of 4 h, and samples with the same stabilization process parameters were used as the starting material of the carbonization treatment. Cyclic voltammetry (CV) measurements were carried out in a potential window of 0 to 1 V with different scan rates ranging from 100 to 1000 mV/s. It is noted that the curve for electro spun PAN-based carbon fibers shows a zigzag-like behavior, which indicates the hydrogen ions in the electrolytes are not easily adsorbed on the surface pores of PAN-CFs. In contrast, after thermal treatments (especially after the carbonization process), the capacitive performance is still stable even at the scan rate of 1000 mV/s. This result reveals that the capacitive performance of PAN-based carbon fibers is improved by the carbonization process.

Modification of nanofibers

The modification of nanofibers has been applied widely to give them improved properties. The result, which shows that the removal of multi-metal ions was improved by surface modification using acid treatment, is shown in Fig. 4 [22]. They explained that the surface functional groups containing oxygen content by acid treatment played an important role for the removal of metal ions. A plasma treatment was carried out to enhance the surface energy of carbon nanofibers for good bonding to the matrix [23]. The gas-state plasma treatment was carried out by using the fluidized bed plasma reactor depicted in Fig. 4. The surface energy increased over two fold after 5 min of plasma treatment.

Nanofibers complex

The use of nanofibers as the reinforcing filler and conducting additive in polymers to improve their mechanical and electrical properties is generally encountered in polymer technology. Nanofibers, such as carbon and glass fibers, are routinely used in composites of a range of different polymers. Improvement in modulus and strength, achieved by using nanofibers in a composite, has been presented by many researchers. The improved storage modulus of epoxy resin by addition of carbon nanofibers.

Application of Nanofibers

Energy storage materials

Nanofibers have been applied as a storage media for alternative energy sources such as hydrogen and natural gases. Porous carbon nanofibers have especially been investigated widely due to their large specific surface area and high pore volume. Hydrogen and natural gases can be stored by physical adsorption, indicating that the use of these gases is easy. The superior storage capacity of porous carbon nanofibers was presented through comparison with other porous carbon materials such as graphite, carbon nanotubes, and activated carbon, as shown in Fig. 5 [24].

Composite application

One of the most important applications of traditional (micro-size) fibers, especially engineering fibers such as carbon, glass, and Kevlar fibers, is to be used as reinforcements in composite developments [25].With these reinforcements, the composite materials can provide superior structural properties such as high modulus and strength to weight ratios, which generally cannot be achieved by other engineered monolithic materials alone. Needless to say, nanofibers will also eventually find important applications in making nanocomposites. This is because nanofibers can have even better mechanical properties than micro fibers of the same materials, and hence the superior structural properties of nanocomposites can be anticipated. Moreover, nanofiber reinforced composites may possess some additional merits which cannot be shared by traditional (microfiber) composites. For instance, if there is a difference in refractive indices between fiber and matrix, the resulting composite becomes opaque or nontransparent due to light scattering. This limitation, however, can be circumvented when the fiber diameters become significantly smaller than the wavelength of visible light [26].

Other applications

In addition to composite reinforcement, other application fields based on electro spun polymer nanofibers have been steadily extended especially in recent years. One of the best representatives in this regard is shown by relevant US patents, in which most applications are in the field of filtration systems and medical prosthesis mainly grafts and vessels. Other applications which have been targeted include tissue template, electromagnetic shielding, composite delamination resistance, and liquid crystal device. More extended or perspective application areas are summarized in Fig. 7. It should be realized that most of these applications have not reached their industry level, but just at a laboratory research and development stage. However, their promising potential is believed to be attracting attentions and investments from academia, governments, and industry all over the world.

Filtration application

Filtration is necessary in many engineering fields. It was estimated that future filtration market would be up to US $700b by the year 2020 [27]. Fibrous materials used for filter media provide advantages of high filtration efficiency and low air resistance [28]. Filtration efficiency, which is closely associated with the fiber fineness, is one of the most important concerns for the filter performance. In the industry, coalescing filter media are studied to produce clean compressed air. These media are required to capture oil droplets as small as 0.3 micron. It is realized that electro spinning is rising to the challenge of providing solutions for the removal of unfriendly particles in such submicron range. Since the channels and structural elements of a filter must be matched to the scale of the particles or droplets that are to be captured in the filter, one direct way of developing high efficient and effective filter media is by using nanometer sized fibers in the filter structure [29].

Fig. 1. PLLA nanofibers with different diameters and pores [18]

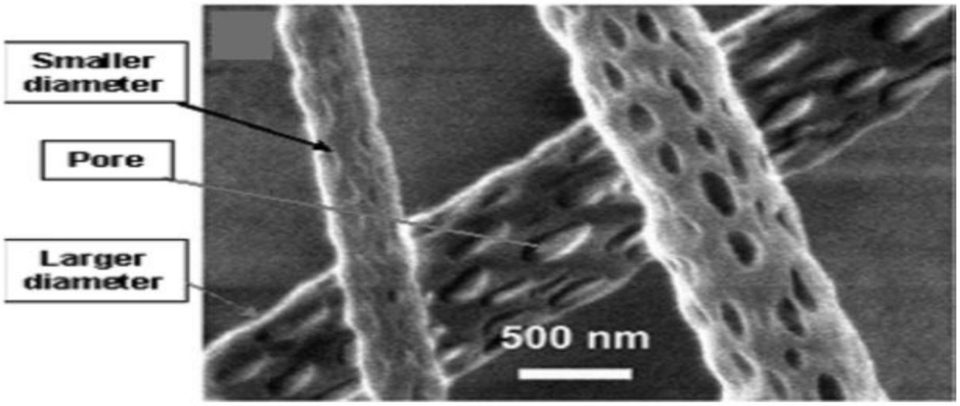

Fig. 2. Diagram of the electro spinning apparatus [19]

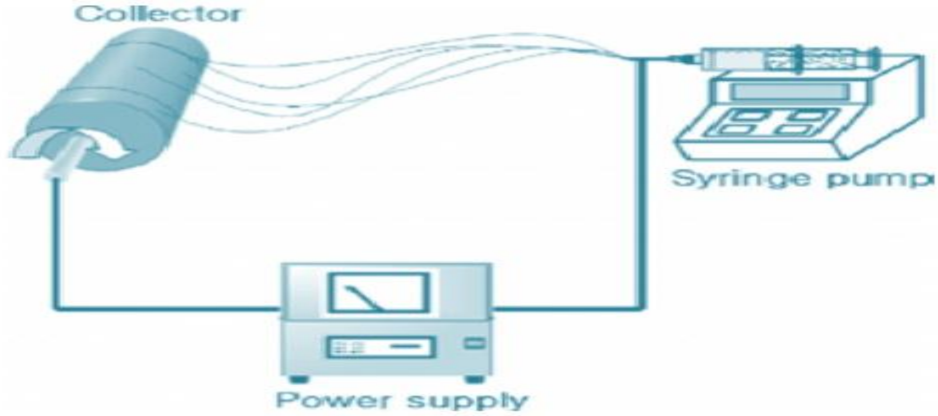

Fig. 3. The procedure of manufacturing carbon fibers and silica-activated carbon fibers

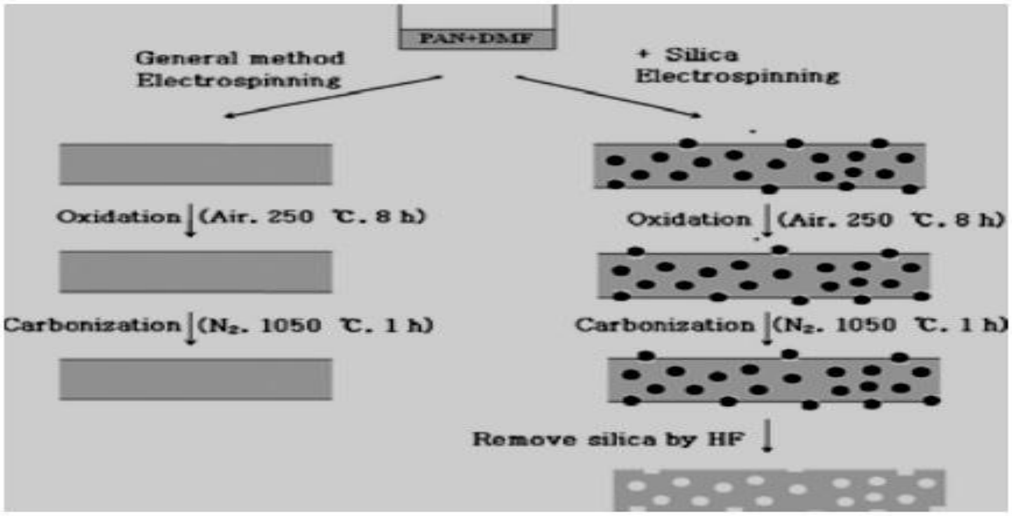

Fig. 4. Fluidized bed plasma reactor [23]

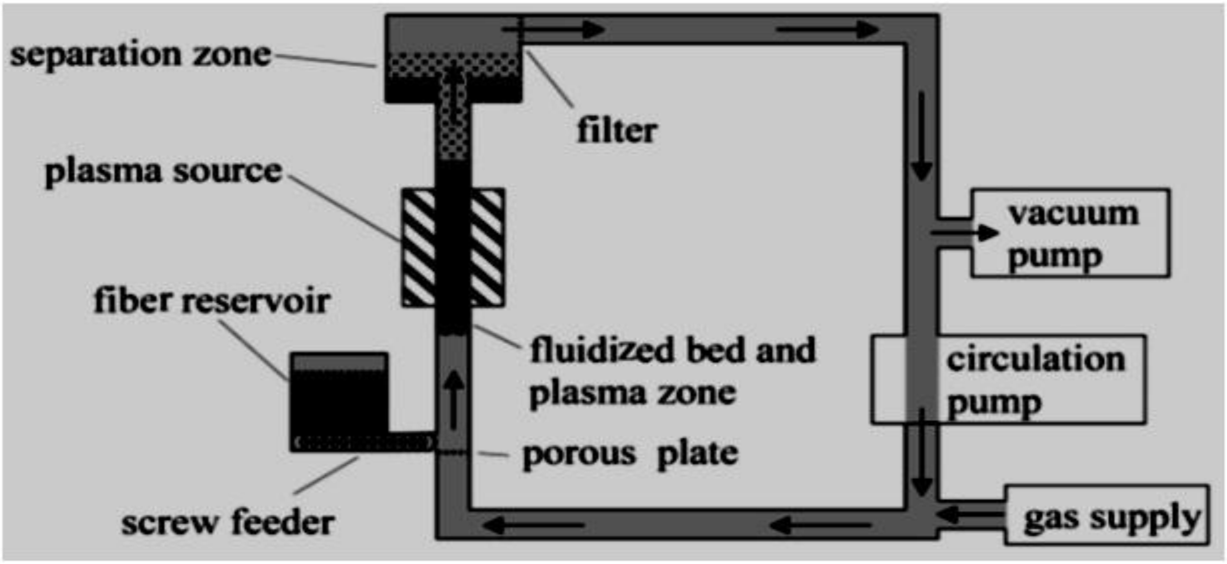

Fig.5. the mechanism of hydrogen adsorption using various carbon materials;(a): activated carbon, (b): single walled carbon nanotube, (c): graphite

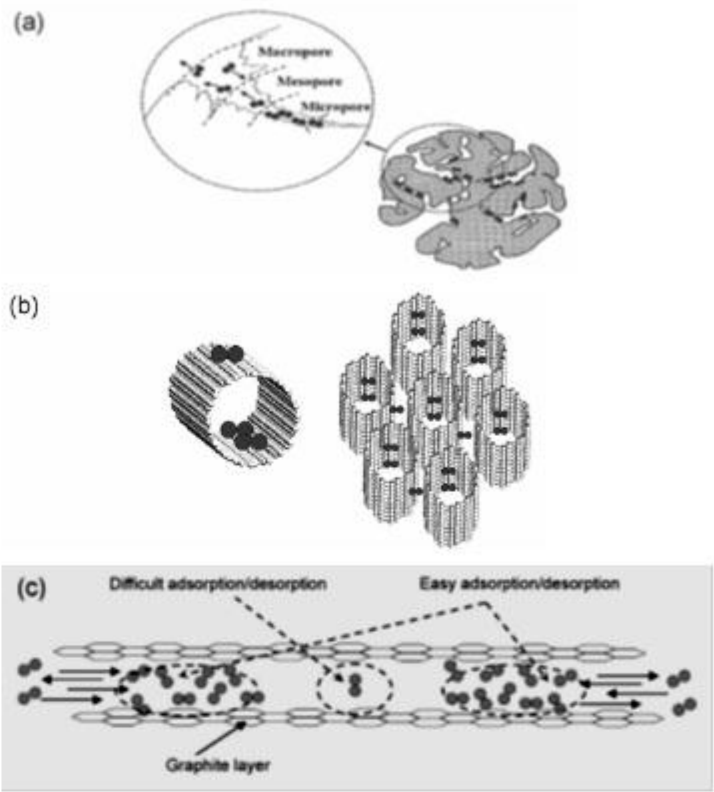

Fig. 6. Application fields targeted by US patents on electrospun nanofibers

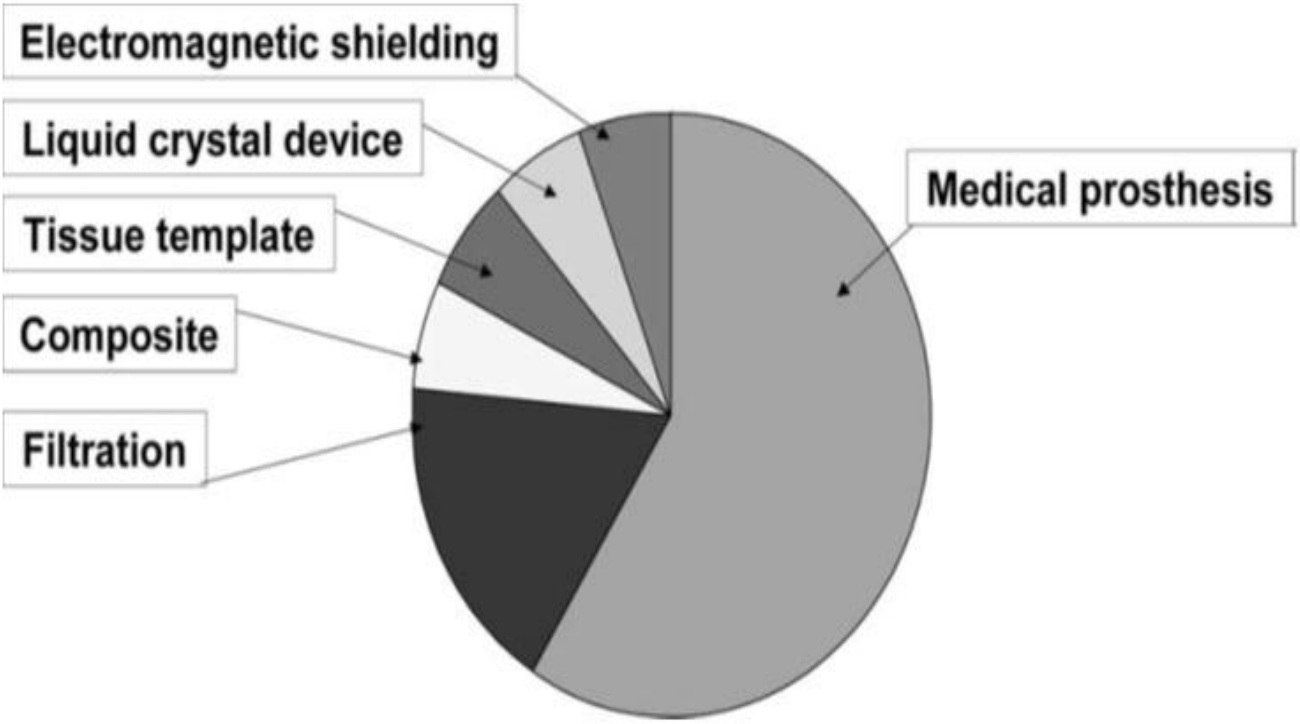

Fig.7. Potential applications of electro spun polymer nanofibers

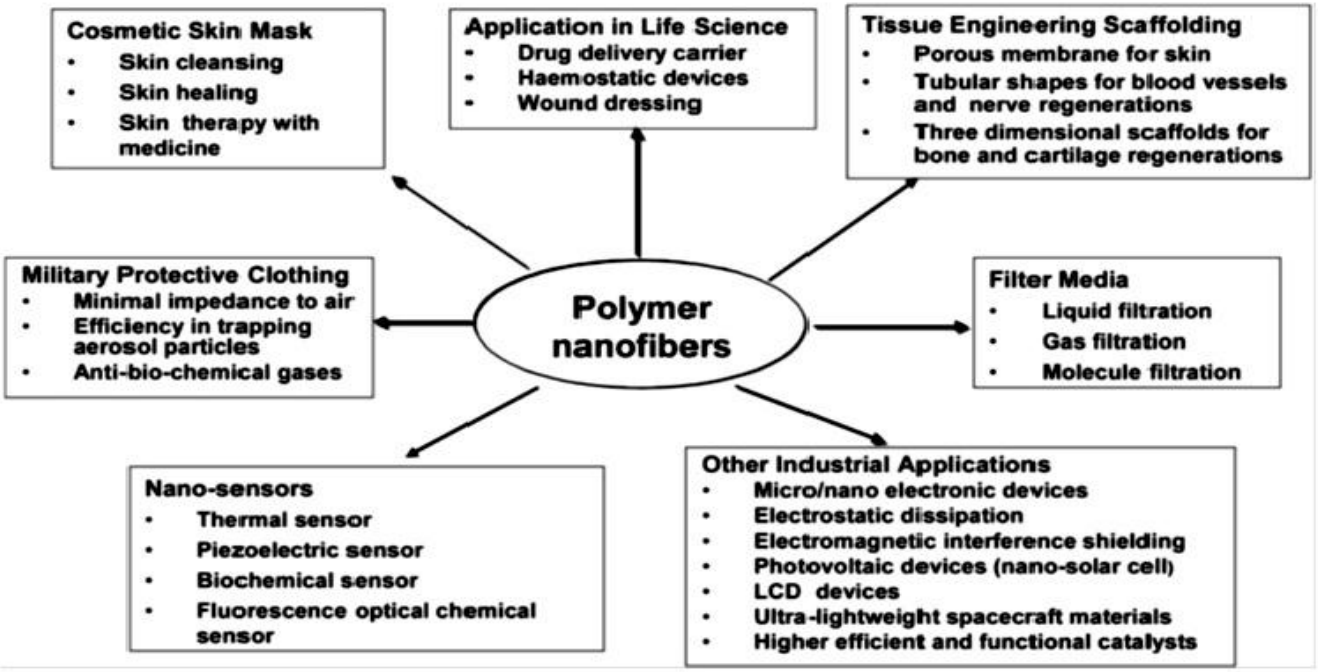

Fig. 8. Nanofibers for wound dressings

Fig 9. Comparison of red blood cell with nanofibers

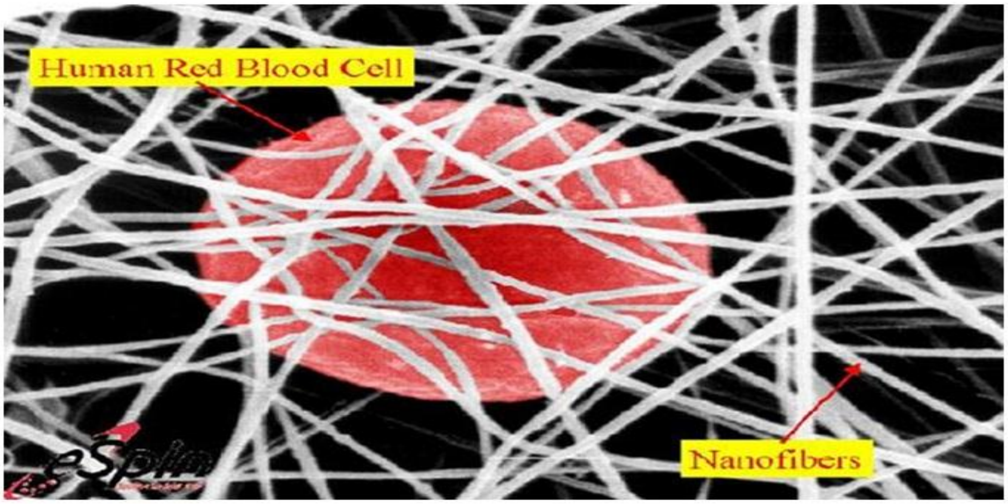

Table 1. Fiber surface area per mass of fiber material for different fiber size

Fiber Type	Fiber size, in Micrometer	Fiber surface area per mass of fiber material m2/g
Nanofibers	0.05	80
Spunbond fiber	20	0.2
Melt blown fiber	2.0	2

Biomedical application

From a biological viewpoint, almost all of the human tissues and organs are deposited in nanofibrous forms or structures. Examples include: bone, dentin, collagen, cartilage, and skin. All of them are characterized by well-organized hierarchical fibrous structures realigning in nanometer scale. As such, current research in electro spun polymer nanofibers has focused one of their major applications on bioengineering. We can easily find their promising potential in various biomedical areas. Some Examples are listed later.

Tissue template

For the treatment of tissues or organs in malfunction in a human body, one of the challenges to the field of tissue engineering/biomaterials is the design of ideal scaffolds/synthetic matrices that can mimic the structure and biological functions of the natural extracellular matrix (ECM). Human cells can attach and organize well around fibers with diameters smaller than those of the cells [30]. In this regard, nano scale fibrous scaffolds can provide an optimal template for cells to seed, migrate, and grow. A successful regeneration of biological tissues and organs calls for the development of fibrous structures with fiber architectures beneficial for cell deposition and cell proliferation [31-33].

Wound dressing

Polymer nanofibers can also be used for the treatment of wounds or burns of a human skin, as well as designed for haemostatic devices with some unique characteristics .With the aid of electric field, fine fibers 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 by encouraging the formation of normal skin growth and eliminate the formation of scar tissue which would occur in a traditional treatment [34, 35]. Non-woven nanofibrous membrane mats for wound dressing usually have pore sizes ranging from 500 nm to 1 mm, small enough to protect the wound from bacterial penetration via aerosol particle capturing mechanisms. High surface area of 5–100 m2/g is extremely efficient for fluid sorption and dermal delivery.

Cosmetics

The current skin care masks applied as topical creams, lotions or ointments may include dusts or liquids prays which may be more likely than fibrous materials to migrate into sensitive areas of the body such as the nose and eyes where the skin mask is being applied to the face. Electro spun polymer nanofibers have been attempted as a cosmetic skin care mask for the treatment of skin healing, skin cleansing, or other therapeuticalor medical properties with or without various additives [35]. This nanofibrous skin mask with very small interstices and high surface area can facilitate far greater utilization and speed up the rate of transfer of the additives to the skin for the fullest potential of the additive. The cosmetic skin mask from the electro spun nanofibers can be applied gently and painlessly as well as directly to the three-dimensional topography of the skin to provide healing or care treatment to the skin.

Medical Application

Nanofibers are also used in medical applications, which include, drug and gene delivery, artificial blood vessels, artificial organs, and medical facemasks. For example, carbon fiber hollow Nano tubes, smaller than blood cells, have potential to carry drugs in to blood cells [36].

CONCLUSION

Nanofibers and webs are capable of delivering medicines directly to internal tissues. Anti-adhesion materials made of cellulose are already available from companies such as Johnson & Johnson and Enzyme Corporation. Researchers have spun a fiber from a compound naturally present in blood. This nanofiber can be used as varieties of medical applications such as bandages or sutures that ultimately dissolve in to body. This Nano fiber minimizes infection rate, blood lose and is also absorbed by the body. Nanofibers greatly enhance filtration efficiency (FE). Scientists at the U.S. Army Natick Soldier Center studied the effectiveness of nanofibers on filter substrates for aerosol filtration. They compared with most of the nanofiber filter media, a substrate fabric such as SB or MB fabric is used to provide mechanical strength, stabilization, pleating, while nanofiber web component is used to increase filtration performance. Filtration and filter media deformation with and without a nanofiber coating of elastic MB and found that the coating of nanofiber on the substrate substantially increases FE.

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