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A Review: Nano-Fibers Application

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Abstract

The research papers and literatures focus, optimize in research fields of Nano sciences including with Nano fibers application in various ways use of Nano-Sciences and Nanotechnology considers nanofibers 1-100nm how much smaller nanofibers are compared to a human hair, which is 50-150 µm and the size of a pollen particle compared to nanofibersnannofibers develop by methods electrospinning, self-assembling, and other producing nanofibers is spinning bi-component fibers such as Islands-In-The-Sea fibers in 1-3 denier filaments who several value added applications such as tissue engineering, medical, filtration, barrier, wipes, personal care, composite, garments, insulation, DNA, protein, enzyme delivery and energy storage. Some major application of nanofibers given as Nano Fibers in Tissue Engineering, Nano Fibers in Filtration, Nano Fibers in Medicals,Nano Fibers in Industry composite construction, Some challenges for Nano Fibers like as Economic, Health hazards, Solvent vapor, Packaging shipping handling.

Key Words:Nanofibers, Electrospinning, Polymers, Tissue Engineering, Filtration, Industry Composite, Solvents… etc.

Introduction

Nanotechnology, the science, engineering, and technology conducted at the nanoscale or about 1-100Nanotechnology can be used in two different ways within fiber-based industries: as a chemical coating on current fiber structures, or to create fine nano-scale fibers which provide new geometries to enable new performance.(**www.tappi.org/Publications/Paper-360/online/MayJune-2012/Nano.aspx**). Nanometers, is frequently touted as an emerging science that can transform our world. Nano-Sciences and Nanotechnology considers nanofibers as having a diameter of less than one micrometer although the National Science Foundation (NSF) defines nanofibers as having at least one dimension of 100 nanometer (nm) or <100nm. The name derives from the nanometer a scientific measurement unit representing a billionth part of a meter.

Polymericnanofibers are produced by an electrospinning process. Electrospinning is a process that spins fibers of diameters ranging from 10nm to several hundred nanometers. This method has been known since 1934 when the first patent on electrospinning was filed. Fiber properties depend on field uniformity, polymer viscosity, electric field strength and distance between nozzle and collector. Advancements in microscopy such as scanning electron microscopy has enabled us to better understand the structure and morphology of nanofibers. At present the production rate of this process is low and measured in grams per hour.

Another technique for producing nanofibers is spinning bi-component fibers such as Islands-In-The-Sea fibers in 1-3 denier filaments with from 240 to possibly as much as 1120 filaments surrounded by dissolvable polymer. Dissolving the polymer leaves the matrix of nanofibers, which can be further separated by stretching or mechanical agitation(Raghavendra R Hegde*et. al.* 2005).

Nanofibers are an exciting new class of material used for several value added applications such as medical, filtration, barrier, wipes, personal care, composite, garments, insulation, and energy storage. Special properties of nanofibers make them suitable for a wide range 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 (GajananBhat*et. al.* 2003).

The most often used fibers in this technique are nylon, polystyrene, polyacrylonitrile, polycarbonate, PEO, PET and water-soluble polymers. The polymer ratio is generally 80% islands and 20% sea. The resulting nanofibers after dissolving the sea polymer component have a diameter of approximately 300 nm. Compared to electrospinning, nanofibers produced with this technique will have a very narrow diameter range but are coarser.

Bio-Nanofibers

Various concentrations of the globular protein hemoglobin were successfully electrospun to create micro-fibrous mats of varying physical and mechanical characteristics. The electrospinning parameters are reported. One concentration of myoglobin was electrospun into a mat for comparison to the hemoglobin mats. Scanning electron microscopy revealed ribbon-like morphologies for the hemoglobin and myoglobin structures. Mean fiber width and thickness for each mat electrospun from a different hemoglobin concentration increased from 2.68 ± 0.83 to 3.55 ± 1.49 μm and from 0.49 ± 0.08 to 0.99 ± 0.41 μm, respectively, for increasing hemoglobin solution concentrations (from 150 to 225 mg/mL). For calculations of surface area to volume ratio for the four different electrospun hemoglobin concentrations, there was a negative correlation (r = -0.84) with concentration; the surface area to volume ratio ranged between 0.50 ± 0.16 and 1.53 ± 0.24 m^2/cm^3. Also, there appears to be a positive correlation between electrospun hemoglobin concentration and porosity, which increased with increasing concentration from 69.5 to 83.3 %. Following cross-linking with glutaraldehyde, the mechanical properties of two constructs were evaluated via uniaxial tensile testing to demonstrate handling capability. Results indicated that increased cross-linking time produced stiffer structures, as peak stress and modulus increased while strain at break decreased when the mats were cross-linked for 30 minutes with glutaraldehyde versus the 20 minute cross-linking time (Catherine P. Barnes *et. al.* 2006).

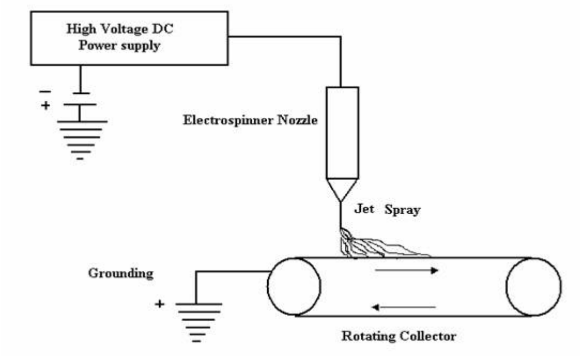
Electrospinning is an efficient method by which to produce scaffolds composed of nanoscale to microscale fibers, which are comparable to the fiber diameters of native components of the extracellular matrix. In electrospinning, a polymer solution is pumped through a syringe that is connected to a high voltage source. As a droplet forms at the tip of the needle, electrostatic repulsions form long fibers that are collected onto a grounded metal plate in the form of a nanofibrous mat. These structures can be used in tissue engineering and drug delivery applications. Natural polymers are candidate materials to develop as electrospun scaffolds. Fibrinogen is one such protein that is present in blood plasma. Physiologically, the reaction between fibrinogen and thrombin leads to the assembly of fibrous structures that play a key role in wound healing. Collagen is another natural polymer that is an essential component of the extracellular matrix. It is largely responsible for the mechanical integrity of the extracellular matrix, making it ideal to be electrospun as a scaffold. The feasibility of electrospinning fibrinogen and collagen into viable nanofibrous scaffolds was explored in this study. Both proteins were produced as nanofibrous mats when certain electrospinning parameters were applied. While nonuniformitieswere observed in these structures, the presence of nanofibersthroughout the mats and the versatility of the electrospinning process suggest that uniform Nano fibrous scaffolds can be formed from these proteins. Finally, because fibrinogen and collagen are naturally occurring, these scaffolds have much potential to support cell adhesion and growth for use in tissue engineering applications (Dawn M. Elliott, *Ph.D*).

The structural and mechanical properties of a surface often play an integral part in the determination of the cell adhesion strength and design parameters for creating a biodegradable electrospun scaffold. Nanofibers composed of the globular proteins bovine serum albumin (BSA) and fibronectin were produced by electrospinning with the electrospun protein scaffold serving as an extracellular matrix to which adhesion interaction will exist with cells via cell surface integrin. This interaction is vital in regulation cell differentiation, growth and migration and cell adhesion. We will demonstrate the ability to manipulate ligand-receptor interaction, the properties of the electrospun fibers, control and the formation of focal adhesions sites in cells cultured on the fibers with the ultimate goal of developing a biomimetric scaffold to investigate how cell adhesion molecules modulate cell behavior in a 3-dimentional culture (Nwachukwu, Cynthia Chinwe*et. al.* 2010).

Tissue-engineering scaffolds should be analogous to native extracellular matrix (ECM) in terms of both chemical composition and physical structure. Polymeric nanofiber matrix is similar, with its nanoscaled nonwoven fibrous ECM proteins, and thus is a candidate ECM-mimetic material. Techniques such as electrospinning to produce polymeric nanofibers have stimulated researchers to explore the application of nanofiber matrix as a tissue-engineering scaffold. This review covers the preparation and modification of polymeric nanofiber matrix in the development of future tissue-engineering scaffolds. Major emphasis is also given to the development and applications of aligned, core shell-structured, or surface-functionalized polymer nanofibers. The potential application of polymer nanofibers extends far beyond tissue engineering. Owing to their high surface area, functionalized polymer nanofibers will find broad applications as drug delivery carriers, biosensors, and molecular filtration membranes in future.(ZUWEI MA *et. al.* 2005)

Techniques of Electrospinning for Nano Fibers:-

The process makes use of electrostatic and mechanical force to spin fibers from the tip of a fine orifice or spinneret. The spinneret is maintained at positive or negative charge by a DC power supply. When the electrostatic repelling force overcomes the surface tension force of the polymer solution, the liquid spills out of the spinneret and forms an extremely fine continuous filament. It has the misleading appearance of forming multiple filaments from one spinneret nozzle, but current theory is that the filaments do not split.These filaments are collected onto a rotating or stationary collector with an electrode beneath of the opposite charge to that of the spinneret where they accumulate and bond together to form nanofiberfabric.The distance between the spinneret nozzle and the collector generally varies from 15 –30 cm. The process can be carried out at room temperature unless heat is required to keep the polymer in liquid state. The final fiber properties depend on polymer type and operating conditions. Fiber fineness can be generally regulated from ten to a thousand nanometers in diameter(Z.-M. Huang *et. al.*2003)



Schematic representation of electrospinning process

Polymer- Solvents Used For Nano Fibers:-

The polymer is usually dissolved in suitable solvent and spun from solution. Nanofibers in the range of 10-to 2000 nm diameter can be achieved by choosing the appropriate polymer solvent system such as Nylon 6 and nylon 66- Formic Acid, Polyacrylonitrile- Dimethyl formaldehyde, PET- Trifluoroacetic acid/Dimethyl chloride, PVA- Water, Polystyrene- DMF/Toluene, Nylon-6-co-polyamide- Formic acid, Polybenzimidazole- Dimethyl acetamide, Polyramide- Sulfuric acid, Polyimides- Phenol (Timothy Grafe, *et. al.* 2002).

Properties of Nano Fibers:-

Nanofibers exhibit special properties mainly due to extremely high surface to weight ratio compared to conventional nonwovens.how much smaller nanofibers are compared to a human hair, which is 50-150 µm and the size of a pollen particle compared to nanofibers. The elastic modulus of polymeric nanofibers of less than 350 nm is found to be 1.0±0.2 Gpa. Low density, large surface area to mass, high pore volume, and tight pore size make the nanofiber nonwoven appropriate for a wide range of filtration applications (Peter P Tsai, *et. al.* 2001).

Application of Nano Fibers

Some major application of Nano fibers given below

1. Nano Fibers in Tissue Engineering
2. Nano Fibers in Air and liquid filters
3. Nano Fibers in Medicals
4. Nano Fibers in Industry composite construction
5. Nano Fibers inWound dressings
6. Nano Fibers inSurface modifications
7. Nano Fibers inSound absorptive materials
8. Nano Fibers in Textile

Nano Fibers in Tissue Engineering:-

Developing scaffolds that mimic the architecture of tissue at the nanoscale is one of the major challenges in the field of tissue engineering. The development of nanofibers has greatly enhanced the scope for fabricating scaffolds that can potentially meet this challenge. Currently, there are three techniques available for the synthesis of nanofibers: electrospinning, self-assembly, and phase separation. Of these techniques, electrospinning is the most widely studied technique and has also demonstrated the most promising results in terms of tissue engineering applications. The availability of a wide range of natural and synthetic biomaterials has broadened the scope for development of nanofibrous scaffolds, especially using the electrospinning technique. The three dimensional synthetic biodegradable scaffolds designed using nanofibers serve as an excellent framework for cell adhesion, proliferation, and differentiation. Therefore, nanofibers, irrespective of their method of synthesis, have been used as scaffolds for musculoskeletal tissue engineering (including bone, cartilage, ligament, and skeletal muscle), skin tissue engineering such as (Cosmetic Skin Masks ,Skin Cleansing, Skin Healing, Skin Therapy) , vascular tissue engineering, neural tissue engineering, and as carriers for the controlled delivery of drugs, proteins, and DNA. This review summarizes the currently available techniques for nanofiber synthesis and discusses the use of nanofibers in tissue engineering and drug delivery applications.

Biomaterials play a crucial role in tissue engineering by serving as 3D synthetic frameworks (commonly referred to as scaffolds, matrices, or constructs) for cellular attachment, proliferation, and in growth ultimately leading to new tissue formation. A number of novel approaches have been developed for the fabrication of biomaterial-based 3D scaffolds (**Atala and Lanza 2002**). More recently, nanofiber-based scaffolding systems are being explored as scaffolds for tissue engineering (**Ma and Zhang 1999**).

The development of nanofibers has enhanced the scope for fabricating scaffolds that can potentially mimic the architecture of natural human tissue at the nanometer scale. The high surface area to volume ratio of the nanofibers combined with their microporous structure favors cell adhesion, proliferation, migration, and differentiation, all of which are highly desired properties for tissue engineering applications (Bhattari*et. al.* 2004; **Ma *et. al.* 2005**). Therefore, current research in this area is driven towards the fabrication, characterization, and applications of nanofibrous systems as scaffolds for tissue engineering. Due to their potential, the nanofiber-based systems are also being pursued for a variety of other biological and non-biological applications (**Li *et. al.* 2002**; **Wang *et. al.* 2002**, **Nair *et. al.* 2004**).

Nano Fibers in Air and liquid filters:-

Today mostly air filter required for automobile fume, Dust cake Filtration. Maintenance Decisions are largely made based on Economic factors and trained personnel provide oversight on Maintenance intervals and filter selection (Barris, Marty A. et al 1995). The use of Nano fiber filter media has provided extended service Life in a variety of on-road and off-Road Applications. In mining Applications, Nanofiber filters have provided four Times the Filter Life. In on-Road applications, Nanofiber Filters are available withtwice the filter Life of Conventional Cellulose Filters (Timothy Grafe, et al 2001). the application of nanofibers is enormous and one of the breakthrough domainsin future will be to use them as filter media in clean air applications in hospitals and research laboratory where maintain to aseptic environmen . This idea is based on the fact that Ahn*et al.* have studied the filtration efficiency of nylon-6 nanofibrous membranes, which is better than the commercialized high-efficiency particulate air filter (HEPA). One of the drawbacks is that they observed high pressure drop across the membrane (Ahn*et al. 2006*)However, this study suggests that they can be potentially employed as HEPA filter with high efficiency in clean air applications such as in hospitals (and other applications) wherein the contaminated air (bacteria and other pathogens) in a room can be filtered before entering into other rooms due to centralized air conditioning systems(RamalingamBalamurugan et al 2011).

Nanofibers have significant applications in the area of filtration since their surface area is substantially greater and have smaller micropores than melt blown (MB) webs. High porous structure with high surface area makes them ideally suited for many filtration applications. Nanofibers are ideally suited for filtering submicron particles from air or water.

Electrospun fibers have diameters three or more times smaller than that of MB fibers. This leads to a corresponding increase in surface area and decrease in basis weight. The fiber surface area per mass of nanofiber material compared to MB and SB fibers (Kristine Graham *et. al.* 2004).Nanofiber combined with other nonwoven products have potential uses in a wide range of filtration applications such as aerosol filters, facemasks, and protective clothing. At present, military fabrics under development designed for chemical and biological protection have been enhanced by laminating a layer of nanofiber between the body side layer and the carbon fibers(Phillip Gibson *et.al.* 2004).e-Spin Technologies, Inc has produced a prototype of activated carbon nanofiber web. PAN- based nanofibers were electrospun. Then these webs were stabilized, carbonized, and activated. These activated PAN nanofibers gave excellent results for both aerosol and chemical filtration(J.Doshi,*et. al.* 2000).Electrospunnanofiber webs are used for very specialized filtration applications. Donaldson is making and marketing filter media that incorporate electrospun nylon fibers for gas turbines, compressor and generators

Nano Fibers in Medicals:-

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.

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 Genzyme Corporation(GajananBhat*et. al.* 2003). 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 To meet these varied requirements a layered composite structure is used. The bulk of the filter is generally made of one or multiple MB layers designed from coarse to fine filaments. This is then combined with a nanofiber web. The MB layer provides fluid resistance while the outer Nano fiber layer improves smoothness for health, wear and comfort.

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 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 (H. Schreuder-Gibson*et. al.* 2002).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(T.Grage,*et. al.* 2003).

Nano Fibers in Industry composite construction:-

Nanofibers were applied to 0.6 ounces per square yard (osy) nylon SB material and to 1.0 osy nylon SB Then two such layers were laminated together Three different types of nanofiber composite fibers designed by altering the thickness and weight of base cloth. The performance and the durability of the composite structure depends on the finished fabric architecture. The final nanofiber fabric architecture is as two type of constructions are;*First*Thenanofiber/SB layer between outer shell layer fabric and chemical filtration layer.*Second* Nanofiber /SB layer is impregnated over the shell fabric and free floats against chemical filtration layer.Polymeric nanofiber composites can provide enhanced protection against chemical agent micro droplets, biological aerosols, radioactive ducts, etc. some significantly use of nano fibers at Industrial applications as electronic, optical instruments are Micro/nano electronic devices, Electrostatic dissipation, Electromagnetic interference shielding, Photovoltaic devices (nano-solar cell), LCD devices, Higher-efficiency catalyst carriers etc.

Nano Fibers in Wound dressings:-

On traditional time wound care and dressing by some plants fibers in which contained cellulose polymers,now advanced wound care dressings operate in moist environments, require less frequent changing and help reduce the pain of dressing changes and lessen scarring. Acute wounds, including those caused by burns, surgical or traumatic woundsChronic wounds, such as ulcers, not proceeding through the normal stages of healingPermeability of gases and liquids High absorption capacity of liquids (exudate) High filtration efficiency for bacteria resulting in decreased infections Possibility to add drugs – haemostatic or antimicrobial dressing Swelling and gel forming capability to keep moist environs Anti adhesive effect to the derma - painless removal of the dressing without destroying newly formed tissue Contribution Of Nanofibers In Advanced Wound Care Relevant polymers produced with technology include, Polyvinylalcohol, Chitosan, Carboxymethylcelulose, Gelatine, Collagen, Hyaluronic acid, Polyurethane and others.

Polymer nanofibers can also be used for the treatmentof wounds or burns of a human skin, as well as designedfor haemostatic devices with some unique characteristics. which can let wounds heal by encouragingthe formation of normal skin growth and eliminate theformation of scar tissue which would occur in a traditional treatment. wound dressing usually havepore sizes ranging from 500 nm to 1 mm, small enoughto protect the wound from bacterial penetration viaaerosol particle capturing mechanisms(Zheng-Ming Huang, et al 2003).

Nano Fibers in Surface modifications:-

Generally, surface modify by hydrophobic membranes can be modified to hydrophilic membranes by using various methods such as Plasma induced surface grafting (PISG) treatment, Chemical oxidation, Organic chemical surface functionalization and Radiation induced surface grafting method((RamalingamBalamurugan et al 2011)).

Nano Fibers in Sound absorptive materials:-

Traditional sound absorption materials include paper, cotton, cork, foams, fibers, membranes, perforated panels and so on. Among these acoustical materials, fibers are the most commonly used due to their good noise reduction performance. Researches on the fibrous sound absorption materials involve natural fibers, metal fibers, inorganic fibers and synthetic fibers. These traditional acoustical fibrous materials have good noise reduction abilities in the highfrequency range, but exhibit little sound absorption properties in the low and medium frequency range (250̃2000 Hz) in which human sensitivity to noise is high.Thenanofibrous materials are promising alternatives in the noise reduction field. However, there are few reports about nanofibrous membranes for acoustical application.Herein, PAN nanofibrous membranes were prepared by electrospinning and the sound absorption behavior of the nanofibrous membranes and their composites with traditional acoustical materials (perforated panel, foam and fiber) were evaluated. The results demonstrate that the nanofibrous membrane has a promising acoustical damping performance, especially in the low and medium frequency range (Hai-Fan Xianga, et al 2001).

Nano Fiber in textile's:-

More Textiles materials like as clothes is generating at the industries level, wherein nanotechnology products are commercially applied to protect humans through harmfully effects and their environment. The nanomaterials are embedded into textile products to impart antimicrobial properties, decrease luster, and protect against UV rays. When compared to conventional materials, nanomaterials offer several advantages such as needing lesser amounts of nanomaterials and enhancing product's performance. To cite a few: metal oxide nanoparticles to decrease luster or provide UV protection. Alkoxysilane-modified TiO2 nanoparticles to absorb UV radiation,and Ag, TiO2, and ZnO nanoparticles to provide antimicrobial and UV protection propertiesandmonazite as thermal protection blankets for reentry space craft application (RamalingamBalamurugan et al 2011).

Limitation of Nano Fibers:-

The process of making nanofibers is quite expensive compared to conventional fibers due to low production rate and high cost of technology. In addition the vapors emitting from electrospinning solution while forming the web need to be recovered or disposed of in an environmental friendly manner. This involves additional equipment and cost. The fineness of fiber and evaporated vapor also raises much concern over possible health hazard due to inhalation of fibers. Thus the challenges faced can be summarized as (Raghavendra R Hegde et al 2005):

1. Economics
2. Health hazards
3. Solvent vapor
4. Packaging shipping handling

Because of its exceptional qualities there is an ongoing effort to strike a balance between the advantages and the cost.

Conclusion

The long term goal of Nano technology use in various areas of science such as generate to Nano fibers and their application much in health like as will be develop for much variety of tissue engineering applications (musculoskeletal, bone, cartilage, ligament, skeletal muscle, skin, blood vessel, neural), medicine, drug delivery, DNA, protein, enzyme delivery, repairing of tissue and organs of bodies, allographting including immune response become increased by Nano fibers , there is a logical that begin in this broad argument for being suspicious about any new Nano fibers technology and end in the view that whether both biotechnology and nanotechnology discourses emerged.

References

[1] Ahn, Y.C.; Park, S.K.; Kim, G.T.; Hwang, Y.J.; Lee, C.G.; Shin, H.S. "Development of highefficiency nanofilters made of nanofibers". *Curr. Appl. Phys.* 2006, *6*, 1030–1035.

[2] Barris, Marty A. "Total Filtration Tm The Influence of Filter Selection on Engine Wear, Emissions, and Performance" SAE 952557 SAE Fuels and Lubricants Meeting & Exposition, October 16-19, 1995.

[3] Catherine P. Barnes[1], Matthew J. Smith[1], Gary L. Bowlin[1], Scott A. Sell[1], Teresa Tang[1], Jamil A. Matthews[2], David G. Simpson[3], Jared C. Nimtz[2]" Feasibility of Electrospinning the Globular Proteins Hemoglobin and Myoglobin"*Journal of Engineered Fibers and Fabrics, Volume 1, Issue 2 - 2006* pp16-29.

[4] Dawn Elliott, Robert Mauck, NandanNerurkar, Jan Van der Spiegel, " Electrospinning natural polymers for Tissue Egineering application " Dawn M. Elliott, Ph.D.

[5] GajananBhat and Youneung Lee, "Recent advancements in Electrospunnanofibers."Proceedings of the twelfth international symposium of Processing and Fabrication of Advanced materials, Ed TS Srivatsan& RA Vain, TMS, 2003.

[6] H. Schreuder-Gibson and P Gibson, 23rd Army science conference, Florida, December 2002.

[7] Hai-Fan Xianga, B, Shuai-Xia Tana, Xiao-LanYua, B, Yu-Hua Longa, B, Xiao-Li Zhanga, NingZhaoa And JianXua"Sound Absorption Behavior Of ElectrospunPolyacrylonitrileNanofibrous Membranes" *Chinese Journal Of Polymer Science Vol. 29, No. 6, (2011), 650-657*

[8] Heidi Schreuder-Gibson, Phillip Gibson, "Use of ElectrospunNanofibers for aerosol Filtration in textile structures". US Army Soldier Systems Center AMSSB-RSS-MS (N) Natick, Massachusetts, http://www.asc2004.com/23rdASC/oral_summaries/L/LO-05.PDF.

[9] J.Doshi, MH Mainz and GS Bhat, Proceedings of the Tenth TANDEC Nonwoven Conference, Knoxville, TN (2000).

[10] Kristine Graham, Heidi Schreuder-Gibson and Mark Gibson "Incorporation of Electrospunnanofibers in to Functional Structures."US Army Soldiers Systems Center, Natick, Massachusetts, http://www.inda.org/subscrip/inj04_2/p21-27-graham.pdf

[11] Nwachukwu, Cynthia Chinwe, "Electrospinning protein nanofibers to control cell adhesion" (2010).*Graduate School Theses and Dissertations.*Paper 1727.

[12] Peter P Tsai, "Effect of Electro spinning Material and Conditions upon Residual Electrostatic Charge of Polymer nanofibers". Proceedings of the 11th Annual international TANDEC Nonwoven conference, Nov.6-8, 2001, Knoxville, TN, USA
[13] Raghavendra R Hegde, AtulDahiya, M. G. Kamath`Nanofiber Nonwovens Updated: June 13, 2005.
[14] Rajesh Vasita and Dhirendra S KattiNanofibers and their applications in tissue engineeringInt J Nanomedicine. 2006 March; 1(1): 15–30
[15] RamalingamBalamurugan, Subramanian Sundarrajan and Seeram Ramakrishna "Recent Trends in Nanofibrous Membranes and Their Suitability for Air and Water Filtrations"*Membranes*2011, *1*, 232-248;
[16] T.Grage, and Kgraham, Int.Non.J.51, 2003.
[17] Timothy Grafe, Kristine Graham, "Polymeric nanofibers and nanofiber webs: A New class of Nonwoven"Presented at INTC 2002:International Technical Conference Atlanta, Georgia, September 24-26,2002.
[18] Timothy Grafe, Mark Gogins, Marty Barris, James Schaefer, RicCanepa "Nanofibers in Filtration Applications in Transportation" Presented at Filtration 2001 International Conference and Exposition of the INDA (Association of the Nowovens Fabric Industry), Chicago, Illinois, December 3-5, 2001.
[19] www.tappi.org/Publications/Paper-360/online/MayJune-2012/Nano.aspx
[20] Zheng-Ming Huang Y.-Z. Zhang, M. Kotaki, S. Ramakrishna "A review on polymer nanofibers by electrospinning and their applications in nanocomposites, Composites Science and Technology 63 (2003) 2223–225
[21] Zheng-Ming Huang, Y.-Z.Zhang, M. Kotaki, S. Ramakrishna"A review on polymer nanofibers by electrospinning and their applications in nanocomposites"Composites Science and Technology 63 (2003) 2223–2253.
[22] Zuwei MA, Masaya Kotaki, Ryuji Inai, and Seeram Ramakrishna, " Potential of Nanofiber Matrix as Tissue-Engineering Scaffolds " Tissue Engineering Volume 11, Number 1/2, 2005pp101-109