Electro spinning of Nano fibers

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Abstract- **The importance of the Nano fiber webs increases rapidly due to their highly porous structure, narrow pore size, and distribution; specific surface area and compatibility with inorganics. Electro spinning has been introduced as one of the most efficient technique for the fabrication of polymeric Nano fibers due to its ability to fabricate nanostructures with unique properties such as a high surface area and porosity. The process and the operating parameters affect the Nano fiber fabrication and the application of Nano fibers in various fields, such as sensors, tissue engineering, wound dressing, protective clothes, filtration, desalination, and distillation. In this review, a comprehensive study is presented on the parameters of electro spinning system including applications. More emphasis is given to the application of Nano fibers in membrane distillation (MD). The research developments and the current situation of the Nano fiber webs in MD are also discussed.**

Index terms- **Electro spinning, Nano fiber, membrane distillation, desalination**

INTRODUCTION

The engineered materials have been gained huge interest during the last decades due to improvement in technology and increase in demands. Many of the applications commonly require mechanically strong, corrosion resistance, lightweight, long-lasting, recyclable, easy to process, easy to handle, reproductive, and low price materials. Polymeric materials can fulfill the general demands for upper qualified applications. Currently, polymers are used everywhere in our daily life. Beside inorganic materials, polymers are actively used in nanotechnology. Nanotechnology means the science and technology takes place in nanometer dimensions. The biggest importance of the nanotechnology is their aspect ratio which is related with the large surface area to volume ratios and their quantum effects. It is not simple to import polymer science into nanotechnology.

Electro spinning

Electro spinning basically requires a polymeric solution/ melt and an electrical field. In most of the electro spinning setup designs, there is a feeding unit which transports the polymeric solution/melt into the electrical field. There is a high-voltage supplier connected to the feed solution. On the opposite side of the feed solution, there is a metallic collector which can be oppositely charged or grounded. The electrical field is generated between the feed solution and the opposite side collector. If the generated electrical field overcomes the surfacetension of the polymeric solution,

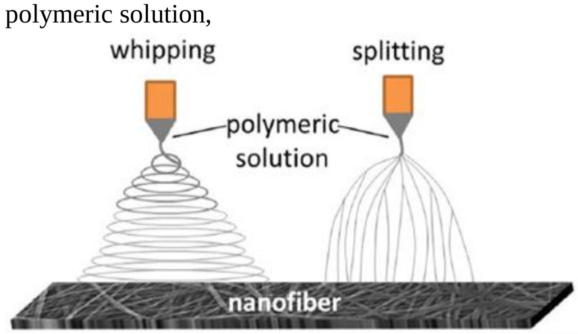

Figure 1. The whipping and splitting behavior of polymeric jet under the electrostatic field.

Taylor's cone16 is observed; then, the solution starts to move toward to collector and under the force and instability initiates, the whipping or splitting of the polymeric solution will be observed. Dur-ing the whipping, the drawing continues until the polymeric solution contacts to the collector. Whipping instability causes bending and stretching of the jet.17 On the other hand, if there is splitting, the polymeric solution splits into multiple filaments. The solvent starts to evaporate during whipping or splitting. The mechanism of the bending instability was explained by Yarin et al.18 They calculate the shape of the envelope cone which surrounds the bending loops of the jet during the whipping of polymeric solution. The image of whipping and splitting is shown in Figure

Table 2. Electrospun nanofibers and application using needle-free electrospinning system.

Nanofiber	Application
CS, PVA, cellulose acetate, and PUR/copper oxide	Air filtration[73–76]
CS/PCL, collagen, gelatin, PCL, and poly(L-lactide-co-glycolide)	Tissue engineering[77,78]
Cellulose, PA6, PVDF, PAN, PVDF/	Membrane for water
PAN, PVDF, PUR, and polypropylene	purification[79–84]
Gelatin, silk, PCL, CS-PEO, PA6, and dextran	Biomedical applications[37,83,85–88]
PVA and PA6	Acoustics[89,90]
PVA, polyvinyl butyral, PUR, and PAN	High-performanc apparels[91–94]e
PVDF	Piezo applications[95]

CS: chitosan; PEO: polyethylene oxide; PVA: polyvinyl alcohol; PUR: poly-urethane; PCL: polycaprolactone; PA6: polyamide 6; PVDF: polyvinylidene fluoride; PAN: polyacrylonitrile.

Table 1. Electrospun nanofibers and their application using needle electrospinning system.

Nanofiber	Application
SF, collagen/HA, PANI-chitosan, and PVA/gelatin	Tissue engineering scaffolds or wound dressings[35–38]; bone regeneration[39–41]
Poly(D,L-lactide-co-glycolide), starch/PCL, PLA	Tissue engineering scaffolds[42–44]
PLA, HA, FHA bioceramics, poly(vinylidene fluoride–trifluoroethylene), poly(hydroxybutyrate-co-hydroxyvalerate), PA6/lecithin, and PCL	Biomedical application[45–51]
PVA-Ag, vitamin E-loaded SF, and PVA-Au	Cosmetics[52–54]
PANI/CPI and PVA/PAA	High-performance energy storage devices[55]
MnO and hexagonal boron nitride/PAN	Lithium-ion batteries[56,57]
Graphite	X-ray radiography[58]
PSU amide/PUR	High-performance apparels[59]
Polyimide	Self-cleaning materials[60]
Fluorescent polymers PAA-poly(pyrene methanol)	Optical chemical sensors[61,62]
PVDF, Ag/TiO_2 nanofiber, PAN, PSU, and chitosan/PEO	Water purification[63–66]
PUR, chitosan/PEO, PVA, PA6, and PA66	Air filtration[66–70]
PVA/indium acetate	CO gas sensor[71]
PVA/nafilon	Fuel cell[72]

SF: silk fibroin; HA: hydroxyapatite; PANI: polyaniline; PVA: polyvinyl alcohol; PCL: polycaprolactone; PLA: poly(lactic acid); FHA: fluorhydroxyapa-tite; PA6: polyamide 6; CPI: carbonized polyimide; PAA: poly(- acrylic acid); PVDF: polyvinylidene fluoride; PAN: polyacrylonitrile; PSU: polysulfone; PEO: polyethylene oxide; PUR: polyurethane; PA66: polyamide 66; MnO: manganese monoxide; Ag: silver; Au: gold; TiO2: titanium dioxide; CO: carbon monoxide.

Nanofibers in water purification

Membrane distillation

MD is a water separation process which is one of the emerging desalination technologies for the production of fresh water. Compared to other membrane systems, MD has several advantages, such as higher salt rejection, lower operating temperature than conventional distillation processes, low energy consumption (when the alternative energy source is used), hence there are lower operating pressure requirement less requirements of membrane mechanical properties.

The principle is that vapor transport across the hydro-phobic microporous membrane driven by the vapor pressure gradient across the membrane due to a temperature gradient. The volatile solvent evaporates through the membrane via diffusion and/or convection. The vapor is transported to the compartment with low vapor pressure where they are condensed in the cold liquid/vapor phase (Figure 5).

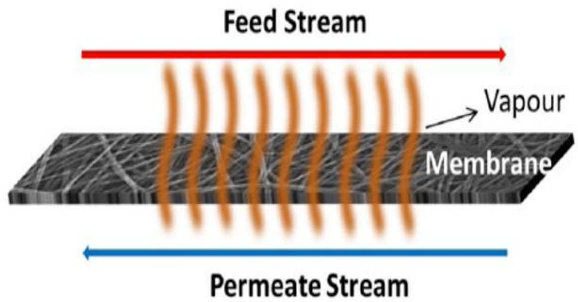

Figure 5. Illustration of membrane distillation process

MD technology is applicable for many application areas such as wastewater remediation, sea water distillation, and separation of volatile liquids. Even though the rejection of MD membranes is 100%, this technology has not found a place in the industrial stage. The reason is due to low flux and permeability of the membranes, possible pores wetting and water loss, energy consumption, and machinery cost. Besides disadvantages, there are several advantages of MD, such as full rejection, lower pressure-driven separation process as a result of low requirement for mechanical properties and low operating temperature. There are several configurations of MD unit reported in the literature by Khayet and Matsuura110 and Wang and Chung,111 such as direct contact membrane distillation (DCMD), air gap membrane distillation, sweeping gas membrane distillation (SGMD), and vacuum membrane distillation (VMD). The membrane is the most important part of the MD process (Figure 6).

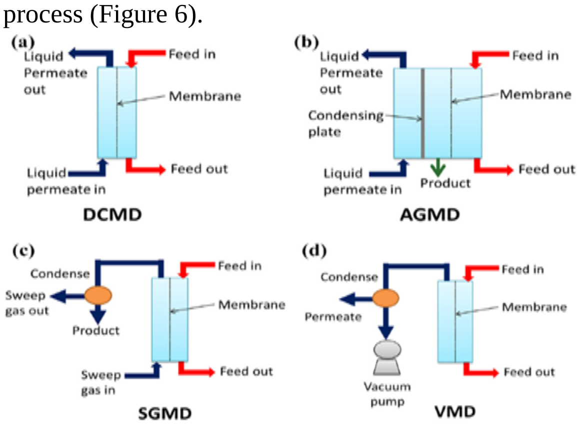

Figure 6. Some of MD process configurations. (a) DCMD, (b) AGMD, (c) SGMD, and (d) VMD (originate from110). MD: membrane distillation; DCMD: direct contact membrane distillation. AGMD: air gap membrane distillation; SGMD: sweeping gas membrane distillation; VMD: vacuum membrane distillation.

In DCMD, a membrane is placed between permeate and a hotter feed solution. It has to have a temperature gradient between feed and permeate. The membrane is in contact both feed and permeates side. A magnetic stirrer or circulating pumps are used to circulate feed and permeate solution to the membrane surfaces. As a result of heat difference on both sides of the membrane, vapor pressure is generated. The vapor of feed solution is passing through the membrane pores via diffusion or convection.

Drug Loading

One method to incorporate therapeutic drugs into nanofibers involves solubilizing the drug into the polymer solution to be spun62. Using this method, a loading efficiency of 90% into PDLA Nano fibers was reported for the antibiotic drug Mefoxin. Covalent conjugation to polymers represents another method to modulate drug release63. It has also been suggested that the high porosity of nanofibers allows for rapid diffusion of degradation by products64. However, the burst release may also be indicative of the drug being attached only on the surface. As the drug and carrier materials can be mixed together for electrospinning of nanofibers, the likely modes of the drug in the resulting nanostructed products are65:

1. Drug as particles attached to the surface of the carrier which is in the form of nanofibers, 2. Both drug and carrier are nanofiber-form, hence the end product will be the two kinds of nanofibers interlaced together,

3. The blend of drug and carrier materials integrated into one kind of fibers containing both components, and

4. The carrier material is electrospun into a tubular form in which the drug particles are encapsulated

MECHANISM OF DRUG DELIVERY Nanofiber drug delivery systems may provide insight into the direct incorporation of bioactive growth factors into scaffolds. Additionally, drug delivery systems can be combined with implantable tissue engineering scaffolds to prevent infection while repair and regeneration occur. Biodegradable polymers release drug in one of two ways66: erosion and diffusion. Release from biodegradable polymers in vivo is governed by a combination of both mechanisms, which depends on the relative rates of erosion and diffusion. Most biodegradable polymers used for drug delivery are degraded by hydrolysis. Hydrolysis is a reaction between water molecules and bonds in the polymer backbone, typically ester bonds, which repeatedly cuts the polymer chain until it is returned to monomers. Other biodegradable polymers are enzymatically degradable, which is also a type of chain scission. As water molecules break chemical bonds along the polymer chain, the physical integrity of the polymer degrades and allows drug to be released. The different mechanisms were given below.

1. Geometrical characterization
2. Chemical Characterization
3. physical Characterization
4. mechanical Characterization

Nanofibers in MD

Several types of membranes and filtration systems are employed in water treatment processes based on their pore sizes and particle filtration as shown in Figure 7. Polymeric materials are mainly used as commercial membranes. Nanofiber material is a relatively new approach to prepare nanofiber-based membranes for micro-filtration and ultrafiltration systems. In MD process, the polymeric membranes should demonstrate high permeability and hydrophobicity without wetting, narrow pores; as well as pore size distribution, thermal stability over a wide range of temperatures and a chemical stability, and possess strong mechanical strength.

CONCLUSION

In this review, the properties, the spinning parameters, and the application area of the electrospun nanofibers were discussed. Electro spinning method is a fascinating method to prepare membranes in micro or nanopore size. One can prepare porous structure using various polymeric electrospun nanofiber layers. Electrospun nanofiber layers have higher porosity with uniform pore size distribution compared to conventional membranes. The highly porous structure yields to increase the permeability of the membranes while high surface area allows membranes to be functionalized with ease. It was found that remarkable progress has been made in the fabrications of electrospun membranes for water treatment. MD is one of the most promising application fields for the electrospun nanofiber membranes. The porous structure, hydrophobicity, and the performance of the membrane are crucial for further developments in MD. This review reveals that possible application of nanofiber layers in MD.

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