# DESIGN AND EVALUATION OF A PORTABLE NANOFILTER SYSTEM FOR CONTINUOUS WATER SUPPLIES IN WATER-SCARCE LOCATIONS

A Thesis by

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Submitted to the Department of Mechanical Engineering
and the faculty of the Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Science

December 2018

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Mechanical Engineering.

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# DEDICATION

To all my family and friends

ACKNOWLEDGEMENTS

There are many people to thank for helping me during the last two years. They have made my short stay in Wichita State University much easier than I thought it would be.

First, I would like to thank my advisor, Dr. Ramazan Asmatulu, for his guidance, encouragement, and patience. Thank you so much for pushing me hard to work on my thesis and make it understood in different ways.

I would like to thank Dr. Rajeev Nair and Dr. Bayram Yildirim for serving on my committee, and for their good comments and suggestions on this research work. I also thank members of the Department of Mechanical Engineering.

I am grateful to my parents, Bhim bahadur Nepal and Durga kumara Nepal, and my friends Raj Kumar Bhatta and Rajan Shrestha for motivating me during this difficult time to complete my thesis.

ABSTRACT

Water is a very essential and necessary element in human life. About 70% of water found in the human body is located in the cells. Lack of pure water in developing countries creates many health problems, such as diarrhea, cholera, typhoid, dysentery, malaria, jaundice, and water borne disease; therefore, it is very important that water is pure. Nanofibers are produced by the electrospinning process, a valuable technique based on the use of electrostatic forces to produce continuous nanofibers with a diameter of about 10 nanometers to some micrometers. Nanofiber can remove impurities such as metals, salts, viruses, algae, and pathogens from water. In this research, nanofibers were produced from two polymers—polyacrylonitrile (PAN) and polyethylene glycol (PEG). Dimethylformamide (DMF) was used as the solvent. An amount of 0.1 gram of PEG and 1.8 gram of PAN was mixed with 18 grams of DMF to form a polymer solution. Nanofibers were produced from this polymer solution by the electrospinning process. Due to its superhydrophilic property, nanofiber can easily pass water and then filter it. In this research, impurities such as salts, pathogens, and chemicals were removed from the contaminated water by using a nanofilter. Various water samples—pond water, water jet cutter water, tap water, deionized (DI) water, and carbon black (CB) deionized water—were used for the experiment. The purpose of this study was to remove the impurities such as arsenic, pathogens, bacteria, viruses, and salts from the water using nanofilters that were developed for this purpose. Activated carbon was added to the nanofilter, which increased the surface area for adoption of the water. The water samples were tested for turbidity, total dissolved solids (TDS), electrical conductivity (EC), pH, and refractive index.

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LIST OFABBREVIATIONS

| | |
|---|---|
| BET | Brunauer-Emmett-Teller |
| BOD | Bacteria Oxygen Demand |
| C | Celsius |
| CB | Carbon Black |
| COD | Chemical Oxygen Demand |
| DI | Deionized |
| DMF | Dimethylformamide |
| EC | Electrical Conductivity |
| FTIR | Fourier Transform Infrared |
| JTU | Jackson Turbidity |
| NIAR | National Institute for Aviation Research |
| NTU | Nephelometric Turbidity Units |
| PAN | Polyacrylonitrile |
| PEG | Polyethylene Glycol |
| SEM | Scanning Electron Microscopy |
| TDS | Total Dissolved Solids |
| WSU | Wichita State University |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The primary objective of this research was to produce nanofiber, which has the capability of removing pathogens and other contaminants from water, and to study different water parameters such as pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), and refractive index. Nanofibers with fine diameters are produced by the electrospinning process using high voltage. Nanofibers are used for water filtration, and polyacrylonitrile (PAN), polyethylene glycol (PEG), and dimethylformamide (DMF) are the chemicals used for their preparation. The four types of water filtration systems are microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, as shown in Figure 1.1.

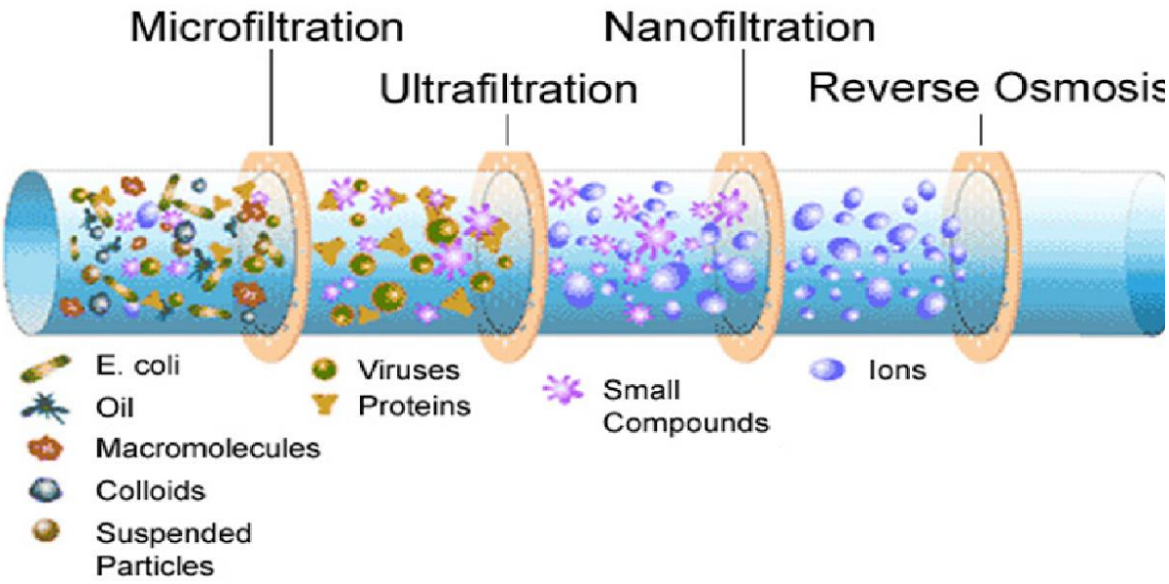


Figure 1.1. Different water filtration systems [1]

### 1.1.1 Microfiltration

Microfiltration is the process of removing microorganisms from contaminated fluid using a pore size between 0.01 and 1 µm. This type of filtration can separate particles with a molecular

weight less than 100,000 gm/mole. The filters used in microfiltration are designed to remove clay, bacteria, viruses, and suspended solids from water. The materials used for producing membranes in the microfiltration process are ceramics, polypropylene, polysulfide, and polyvinylidene difluoride. The main areas of microfiltration application are water purification, sterilization, petroleum refining, and dairy processing. Figure 1.2 shows the microfiltration process.

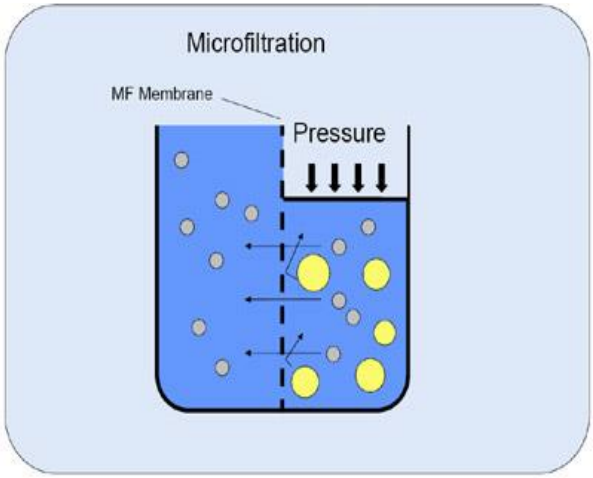


Figure 1.2. Microfiltration process [2]

### 1.1.2 Ultrafiltration

Ultrafiltration is the process of removing materials such as proteins, starch viruses, colloid silica, organics, dyes, fats, and paint solids from water with the help of filters with pore sizes between 0.001 and 0.01 μm. These filters can separate macromolecules of a molecular weight between 1000 and 300,000 gm/mole. The materials for producing membranes in the ultrafiltration process are ceramics, polysulfone, polyvinylidene difluoride, cellulose acetate, and thin film composite. Ultrafiltration applications are mainly used in water purification, chemical and pharmaceutical manufacturing industries, and dairy products. Figure 1.3 shows the ultrafiltration process.

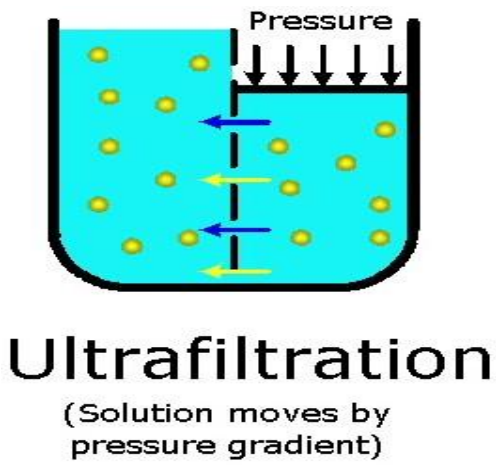


Figure 1.3. Ultrafiltration process [3]

### 1.1.3 Nanofiltration

Nanofiltration is the process of removing bacteria from low total dissolved solids in water such as surface water and fresh water. The pore size of this filtration system is between 0.0001 and 0.001 µm. The system can separate macromolecules of molecular weight between 300 and 1,000 gm/mole. The materials used for producing membranes in the nanofiltration process are cellulose acetate and thin film composite. The nanofiltration filters starch, sugar, pesticides, detergents, bacteria oxygen demand (BOD), and chemical oxygen demand (COD). Nanofiltration applications are mainly used in water purification, water softening, and amino acid and lipid extraction from blood and other cell cultures. Figure 1.4 shows the nanofiltration process.

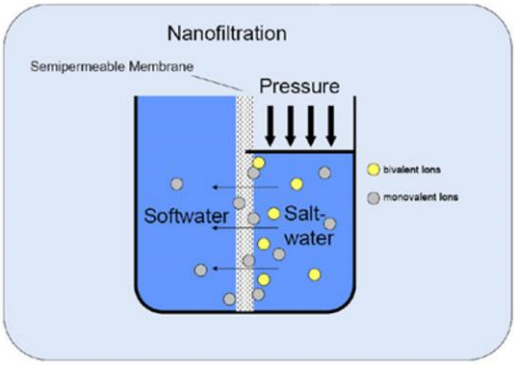


Figure 1.4. Nanofiltration process [4]

### 1.1.4 Reverse Osmosis

Reverse osmosis is the process of removing ion molecules and larger particles from water using a semipermeable membrane. The pore size of this filtration is smaller than 0.0001 µm. This type of filtration can separate macromolecules of a molecular weight between 100 and 300 gm/mole. The materials used for producing membranes in the reverse osmosis system are cellulose acetate, thin film composites, and polysulfonated polysulfone. Reverse osmosis filtration removes metal cations, sugars, acids, aqueous salts, amino acids, monovalent salts, biochemical oxygen demand, and chemical oxygen demand from water. The main areas of application are water and waste water purification, food industry, and maple syrup production (where reverse osmosis is used to remove water from the sap before it is boiled down to syrup). Hydrogen is produced where reverse osmosis is used to prevent the formation of minerals on the surface of electrodes. Figure 1.5 shows the reverse osmosis process.

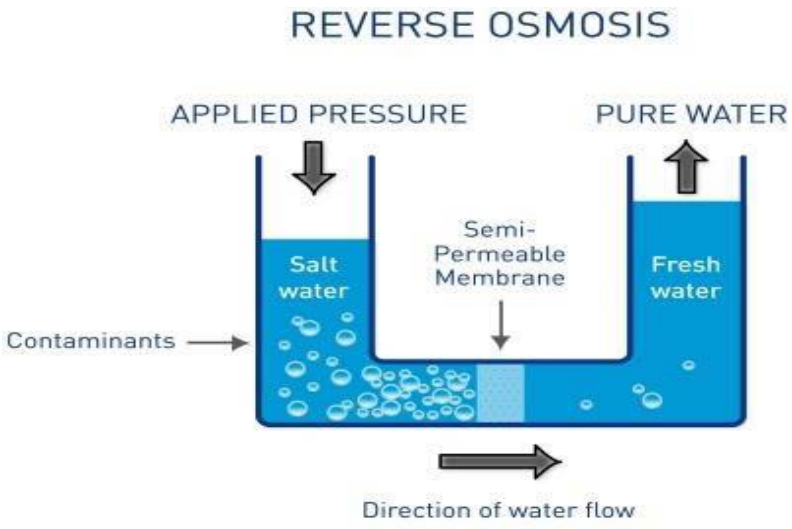


Figure 1.5. Reverse osmosis process [5]

## 1.2 Motivation

About 71% of the Earth is covered with water, and the oceans hold about 96.5% of water. In today's world, the main problem is having pure water. Most developing countries such as India,

China, Bangladesh, and Nepal are facing problems of lack of pure water. Various filtration processes can purify water and make it drinkable, but in most cases, these processes are expensive, and people from developing countries cannot afford them. The lack of pure water can create severe problems and lead to various disease such as waterborne illness, diarrhea, cholera, typhoid, and dysentery. The problem of pure water can be solved by various methods, but new technology involving nanofibers can purify the water by removing harmful contaminants, and nanofiber technology is cheaper than other filtration processes.

## 1.3 Objectives of Research

The main objective of this research was to design a portable nanofilter for removing bacteria and other harmful impurities from water and in turn purifying it. The first step in this research was to produce the nanofiber using different materials such as polyacrylonitrile, polyethylene glycol, and dimethylformamide with the help of electrospinning. The goal here was to evaluate different layers of filtration and reduce the total dissolved solids, pH, electrical conductivity, and turbidity and increase the refractive index of water. After filtration, each parameter was compared to evaluate the different layers of nanofiber.

## 1.3 Scope of Research

Most underdeveloped and developing nations are facing the problem of lack of pure drinking water. This important research aims to help those nations obtain clean and pure water. People from the poor countries are not able to afford expensive filters to purify their water, so they have no option but to drink contaminated water. However, nanofilters are cheaper than other filtration methods, and they can benefit the people of poor countries.

# CHAPTER 2

# LITERATURE REVIEW

Various methods that are used to prepare nanofibers will be explained in this chapter. One of the best methods is electrospinning, which makes it very easy to produce nanofibers, and the setup for it is very simple. The process of electrospinning has generated considerable interest in recent times due to its flexibility and consistency in producing fiber. Polyacrylonitrile is used widely for nanofiber production and improves the mechanical strength of the fiber.

## 2.1 Introduction to Nanofibers

Electrospinning is the best way of producing continuous fiber. A nanofiber is a one-dimensional material, the diameter of which is less than 1 μm, and the length-to-diameter aspect ratio is larger than 100:1[6]. Due to the enhanced properties of nanofiber, it is a good material for use in filters to purify contaminated water. Nanofibers are also used in other areas:

- Wound treatment
- Scaffold and tissue engineering
- Drug delivery
- Catalyst and enzyme carriers
- Energy conversion and storage
- Sensors
- Composite reinforcement

Generally, polymeric nanofibers are produced by the electrospinning process, and polyacrylonitrile is used as the main polymer in this process. Figure 2.1 shows a SEM image of nanofibers electrospun using polyacrylonitrile and dimethylformamide.

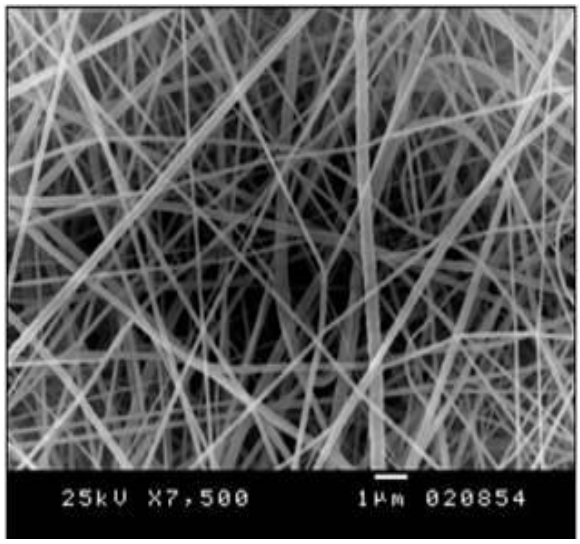


Figure 2.1. SEM image of electrospun of PAN with DMF [7]

Many processing techniques such as drawing out, molecular self-assembly, or thermally induced phase separation have been used to produce nanofibers, but the electrospinning process is the best technique to produce continuous polymeric nanofibers by controlling the surface area, fiber diameter, fiber weight per area, and porosity of the nanofibrous layer. Electrospinning is a technique of producing continuous fiber by applying a high-voltage electrostatic field to a polymer solution in order to produce a polymeric nanofiber with a diameter ranging from 10 nm to several micrometers [8]. Different methods can be used to obtain information about a specific surface area and the diameter of the nanofibers. Widely used methods are imaging, mercury porosimetry, Brunauer-Emmett-Teller (BET) surface area measurements, and contact angle measurements. Imaging methods are used to evaluate the structure and determine the important parts of characterization of most materials including nanofibers. In this research, the primary imaging method was scanning electron microscopy (SEM) following heat treatment. With the help of heat treatment, the SEM images showed better thermal properties, but SEM does not provide a quantitative comparison of the different nanofibers.

## 2.2 Electrospinning Process

The electrospinning process is a method of producing continuous fiber with the aid of an electric current. This process is widely used for producing nanofibers throughout the world. When voltage in the polymer solution is sufficient, the polymer becomes charged, and the charged polymer forms liquid jets, which in turn forms nanofibers at the collector site. Figure 2.2 shows a schematic representation of the electrospinning process .

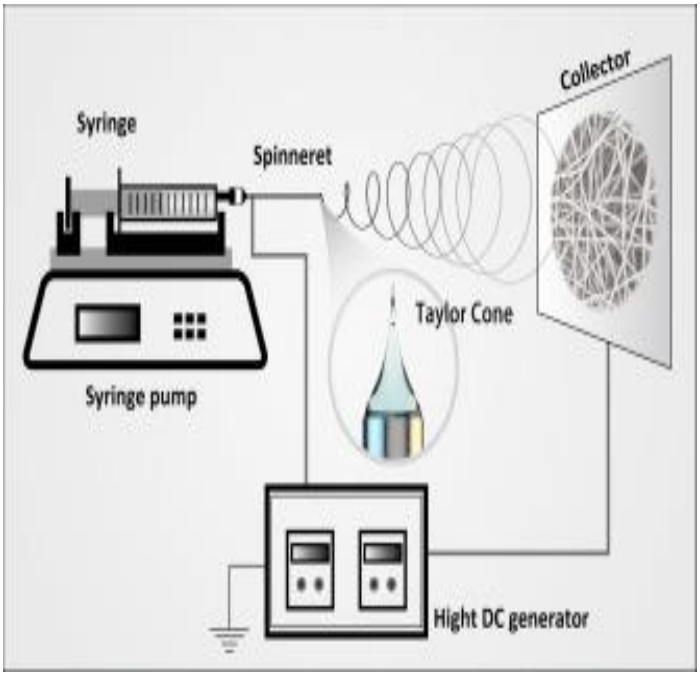


Figure 2.2. Schematic representation of electrospinning process [9]

## 2.3 Factors Affecting Electrospinning

Factors that affect electrospinning are voltage, flow rate, collector, distance between the collector and the tip of the syringe, surface tension, solution conductivity, and humidity [10].

### 2.3.1 Voltage

Voltage plays an important role in the electrospinning process. The charged jets will eject from the tip of the syringe when the applied voltage on the syringe is more than the threshold voltage. When the applied voltage is increased in the tip of the needle, the fiber diameter initially

increases but the diameter of the fiber will start decreasing since the applied voltage is inversely proportional to the fiber diameter. Voltage affects the fiber diameter, but the polymer concentration and distance between the tip and the collector affects it more [11].

### 2.3.2 Flow Rate

Flow rate is another important factor that affects the diameter of the fiber. As the flow rate increases the fiber diameter will also increase; therefore, a low flow rate is recommended in order to provide sufficient time for the polarization [12].

### 2.3.3 Collector

The collector behaves as a conductive substrate to collect the charged fibers coming out of the tip of needle. In this research, aluminum foil was used to collect the charged fiber.

### 2.3.4 Distance between Collector and Tip of Syringe

The distance between the collector and the tip of the syringe also plays a significant role in the production of nanofiber. When the distance between the collector and the tip of the syringe is too short, the fiber will not have sufficient time to solidify before reaching the collector, and if the distance between the collector and the tip of the syringe is too long, then a bead fiber is formed [13,14]. A distance of 25 cm between the collector and the tip of the syringe was used in this research.

### 2.3.5 Surface Tension

The charge on the polymer solution in the syringe must be high so that the electric current can overcome the surface tension on the solution [15]. During the electrospinning process, the charged polymer accelerates towards the collector, and the surface tension of the solution might affect the polymer solution, causing the solution to break down into droplets. Therefore, polyethylene glycol was added to form the good fiber diameter.

### 2.3.6 Solution Conductivity and Humidity

The conductivity of the polymer solution determines the charge-carrying capacity of the polymer solution, which influences the tensile force experienced on the jet by the electric field. A higher solution conductivity induces more stress on the jet, which helps in reducing the fiber diameter [16]. Higher humidity also influences the polymer solution on the syringe, which causes more water molecules between the tip of the syringe and the collector. These water molecules increase the conductivity in the region between the tip and collector, which leads to larger fiber diameter.

## 2.4 Properties of Nanofibers

Nanofibers have unique mechanical and thermal properties compared to normal fibers, due to their surface areas and morphologies.

### 2.4.1 Mechanical Properties

The mechanical properties of nanofibers along with tensile strength and Young's modulus are affected by the small pores of the nanostructure surface, but this information is very limited. Generally, the mechanical properties of nanofibers are worst with respect to the mechanical properties of the textile fiber, even when both are made of the same material. Therefore, heat treatment is applied to nanofibers in order to enhance their mechanical properties.

### 2.4.2 Other Properties

Other properties of nanofibers are as follows:

- High surface area
- High tensile strength
- Reduced crack propagation
- Good thermal properties

- High electrical properties

## 2.5 Applications of Nanofibers

Nanofibers are mainly used in tissue engineering, drug delivery, cancer diagnosis, lithium air batteries, optical sensors, air filtration, and water filtration [17].This research primarily discusses water filtration. Figure 2.3 shows the many application of nanofibers.

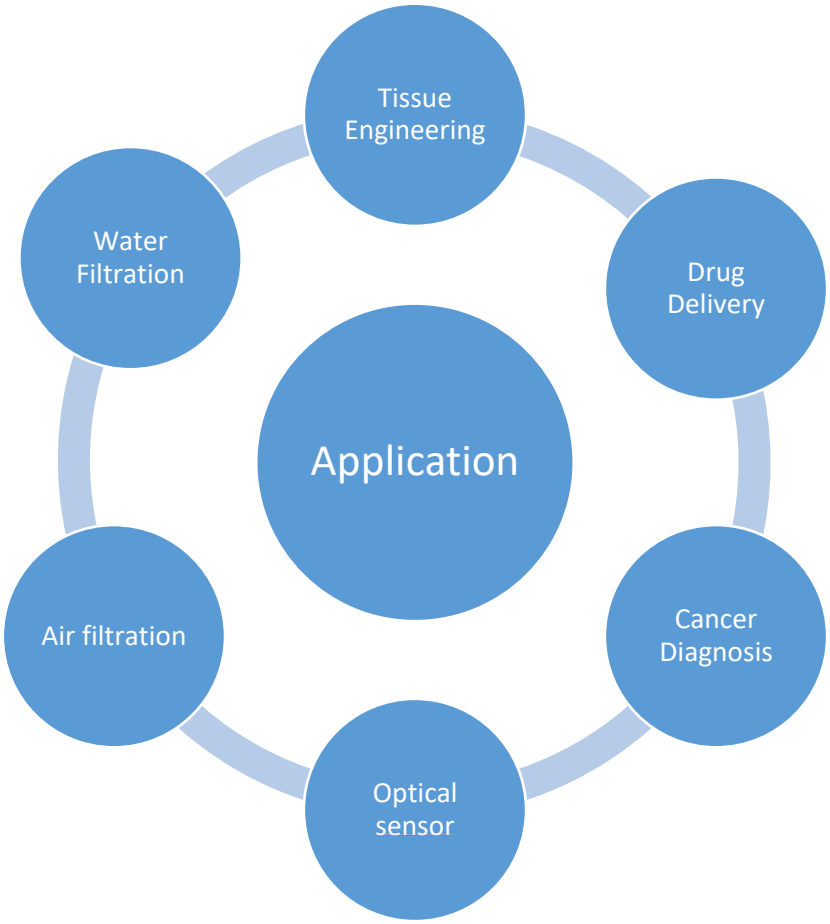


Figure 2.3. Applications of nanofibers

### 2.5.1 Tissue Engineering

Tissue engineering is the method of replacing or improving biological tissue with a combination of cells, engineering, and materials. The development of nanofibers has improved the scope of the fabricating scaffold, which can replace damaged tissue. The availability of different

synthetic and natural biomaterials, especially using the electrospinning process, has increased the chances of developing a nanofibrous scaffold. This type of scaffold has been used for tissues such as bone, cartilage, and ligaments. Skin tissue can also be replaced by a nanofibrous scaffold [18, 19]. Figure 2.4 shows the steps involved in tissue engineering.

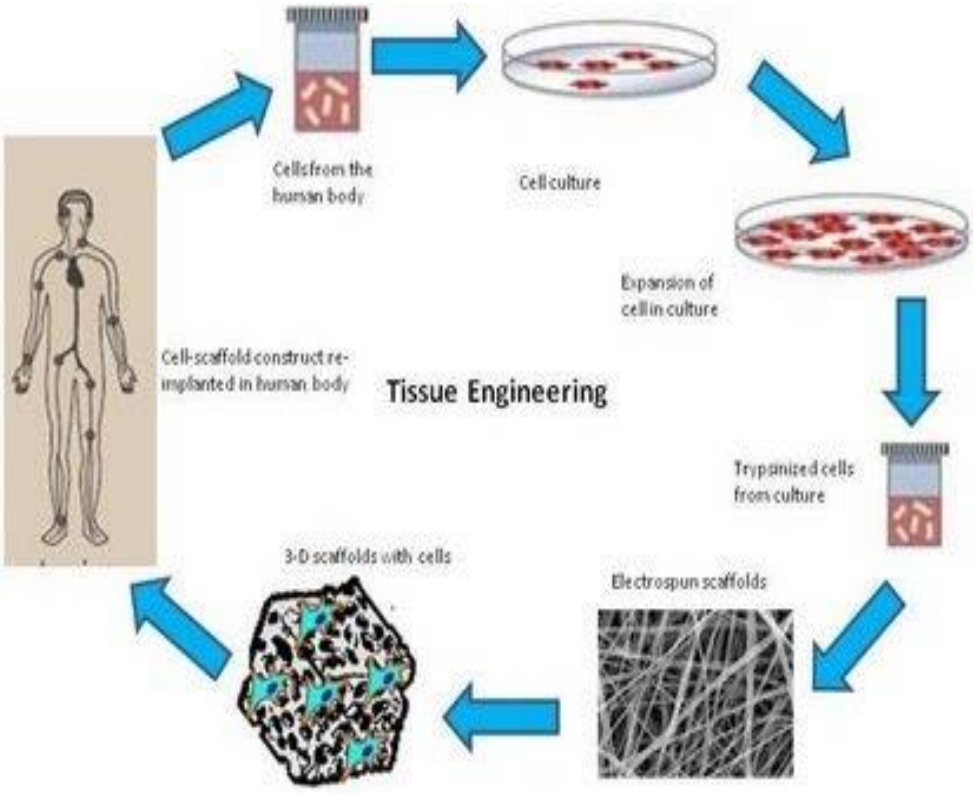


Figure 2.4. Steps involved in tissue engineering [20]

### 2.5.2 Drug Delivery

Biopolymers that are made from nanofiber membranes can be used as biomaterial for drug delivery [21]. The electrospun nanofiber helps to carry the activated pharma ingredient into the polymeric biodegradable nanofiber, which naturally allows the drug delivery system to release the drug as soon as possible.

### 2.5.3 Cancer Diagnosis

The various characteristics of electrospun nanofibers help the medical field to identify cancer. Their high surface area and ease of releasing biomolecules make nanofibers very sensitive devices. Circulating tumor cells are very difficult to detect due to their low numbers in the blood stream. However, electrospun nanofiber helps to detect the circulating tumor cells by releasing the cell adhesion and biomolecules into the fiber for selective cell capturing. The ability to release biomolecules into the cell and identify the tumor makes nanofibers very important in cancer diagnosis [22].

### 2.5.4 Lithium Air Batteries

Porous carbon nanofibers are produced by the electrospinning process with the use of PAN and PEG polymers along with the DMF solvent. Heat treatment on the nanofiber helps to transform the solid structure to a porous structure. The fiber produced by electrospinning are used as anodes for lithium batteries.

### 2.5.5 Optical Sensors

The very small diameter of electrospun nanofibers makes them suitable for optical sensors. When the small diameter of the nanofiber is very close to or below the wavelength of light, the optical nanofiber will have a various necessary properties for different sensing applications such as physical, chemical, and biological sensors.

### 2.5.6 Air Filtration

Air is very important for the survival of living beings. Air pollution is a very common problem. Air contains many contaminants such as carbon monoxide, nitrogen dioxide, sulphur dioxide, and other harmful substances that are poisonous to living beings. Electrospun nanofiber can be used as a nanofilter to remove harmful substances and provide pure air for breathing.

Considerable research has been done on the use of nanofibers for air filtration. The diameter of electrospun nanofibers is very small, making it impossible for contaminants to pass through them and thus making them very important for air filtration. Figure 2.5 shows the personal N95 facemask, which is comprised of nanofibers.

Figure 2.5. Personal N95 facemask made of nanofibers [23]

### 2.5.7 Water Filtration

Water filtration is one of the main applications of nanofibers. Various steps are involved in water filtration in order to collect drinkable water. First, unwanted matter, pathogens, and ions must be removed. Because of the increase of pollution in both surface and underground water, the requirement of technology to be able to purify water becomes even more essential. There has been considerable research on the use of electrospun membranes in the various stage of water treatment and purification [24]. This research involves specific filtration to the removing of selective contaminants like arsenic and other heavy metals. Water filtration removes the various materials such as hazardous compounds, salts, and other unwanted particles.

## 2.6 Removal of Various Compounds from Water

### 2.6.1 Hazardous Compound Removal

Most of the underdeveloped countries, many pharmaceutical industries, mining operations, and other chemical industries are the main reasons for water pollution. The waste from these industries is connected to the source of water and results in contaminated water. Some chemicals contain heavy metal ions, which cannot be filtered using a microfiltration process because the ions on the metal are too small. Therefore, nanofiber through electrospinning has been developed for filtering any small ions from the chemicals. Arsenic is one of the very harmful chemicals that contaminates water and causes cancer. The purpose of using nanofiber in a water filtration system is to remove arsenic and other hazardous compounds.

### 2.6.2 Unwanted Particle Removal

Water contains many unwanted particles such as iron, sulphur, calcium, magnesium, etc. Electrospun nanofibers are suitable for removing these particles from the water. The size of nanofibers are typically a few microns. Their small size is suitable for removing particles that are more than a few microns. The heat treatment of nanofiber enhances its mechanical properties, which in turn helps in removing particles that are typically very small.

### 2.6.3 Salt Removal

Many countries are facing the problem of safe drinking water. In some countries, people lack water from the land but have access to a very large volume of water from the sea. However, seawater contains huge amounts of salt, which makes it impossible to drink. Distillation helps to remove salt from the water and make it more drinkable. The use of nanofiber in a water filtration membrane is only possible if there is a separation between the permeate and the feed. Therefore, a superhydrophobic membrane is recommended. Some factors affect the rate and efficiency of

membrane distillation. The temperature gradient between the permeate and the feed helps the separation layer become thicker, but only if the heat is less between the feed and the permeate.

## 2.7 Advantages of Nanofiber

The advantages of nanofiber are the following:

- Low cost for operation.
- Removes viruses, bacteria, and pesticides.
- Removes heavy metals.
- Removes water hardness
- Requires less electricity.
- Can be used anywhere

## 2.8 Disadvantages of Nanofiber

The disadvantages of nanofiber are the following:

- Limited choice of polymers to produce nanofibers by electrospinning.
- Very difficult to produce nanofiber with diameters less than 10 nm with electrospinning.
- Challenge of reusing the nanofiber because used nanofiber does not last long in order to use it in another operation.
- Its production requires considerable time.

## 2.9 Classification of Surfaces

The surface of nanofiber can be classified as superhydrophilic, hydrophilic, superhydrophobic, or hydrophobic. Table 2.1 shows nanofiber surface classifications based on contact angle.

TABLE 2.1

CONTACT ANGLES FOR DIFFERENT NANOFIBER SURFACES

| Surface Classification | Contact Angle (degrees) |
|---|---|
| Superhydrophilic | 0 |
| Hydrophilic | Below 90 |
| Superhydrophobic | Above 150 |
| Hydrophobic | 90–150 |

### 2.9.1 Superhydrophilic Surface

A superhydrophilic surface occurs when the contact angle of water is equal to zero [25], or there is complete wetting. This type of surface is typically found in door mirrors for cars, self-cleaning glass, coatings for buildings, and water filtration. Figure 2.6 shows the complete wetting on a superhydrophilic surface.

Figure 2.6. Water droplet on superhydrophilic surface

### 2.9.2 Hydrophilic Surface

A hydrophilic surface is the type of surface in which the contact angle of water is less than 90 degrees, and a water droplet spreads over a large area of the surface [25]. This type of surface is used in medical devices, treatment for display applications, and industrial applications. Figure 2.7 shows a water droplet on a hydrophilic surface.

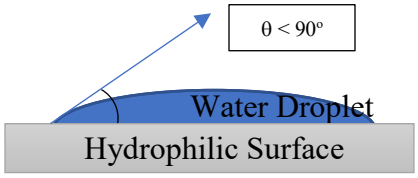


Figure 2.7. Water droplet on hydrophilic surface

### 2.9.3 Superhydrophobic Surface

A superhydrophobic surface occurs when the contact angle is more than 150 degrees. This property is referred to as the lotus effect. A drop of water on this type of surface tends to rebound like an elastic ball [26]. Figure 2.8 shows a lotus leaf displaying the superhydrophobic property, and Figure 2.9 shows a water droplet on a superhydrophobic surface.

Figure 2.8. Lotus effect [27]

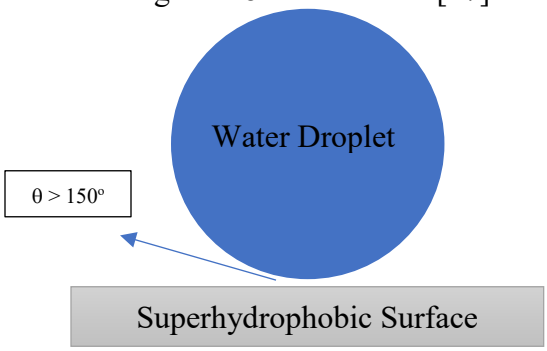


Figure 2.9. Water droplet on superhydrophobic surface

### 2.9.4 Hydrophobic Surface

On a hydrophobic surface, the water contact angle lies between 90 degrees and 150 degrees [25]. This type of surface has the property of repelling water and is not easily wetted when coming in contact with water. This is because of the unbalanced molecular forces at the water interface that cause surface tension. Hydrophobic surfaces are used to remove oil from water. Figure 2.10 shows an image of a water droplet on a hydrophobic surface.

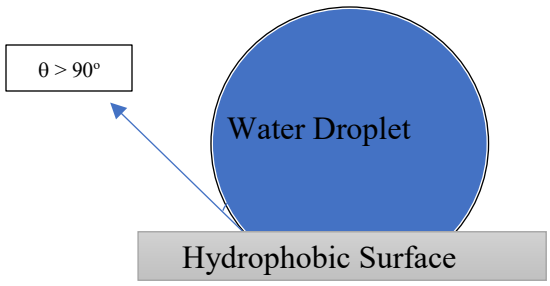


Figure 2.10. Water droplet on hydrophobic surface

## 2.10 Contact Angle

The contact angle is an angle that measures the angle of where the liquid vapor meets a solid surface. [25] In other words, when there exists an interface between a liquid and a solid, the angle between the surface of the liquid and the contact surface is called the contact angle. It is one of the common methods to measure the wettability of a surface or material. Wetting refers to the study of a liquid's ability to form a boundary surface with a solid state. An individual system of solid, liquid, and gas at a specific temperature and pressure has a unique contact angle.

### 2.10.1 Thermodynamics

Thomas Young proposed treating the contact angle of a liquid with mechanical equilibrium of a drop resting on a plane surface under the influence of three surface tensions [25]. In this research, a water droplet was dropped onto a nanofiber to measure the contact angle. The Young-Laplace equation was used to determine the shape of the liquid-vapor interface. The contact angle is denoted by theta, θ. Figure 2.11 shows an image of a water droplet on a solid surface at a contact angle θ.

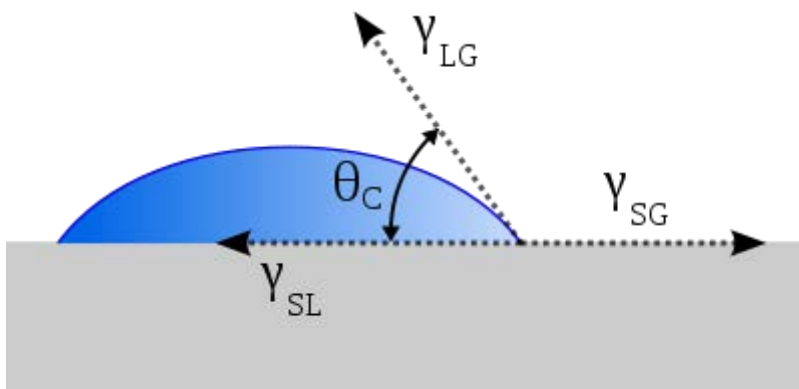


Figure 2.11. Contact angle for wetting of surface [28]

The equilibrium contact angle is expressed by Young's equation as

$$\gamma_{SG} - \gamma_{SL} = \gamma_{LG} \cos\theta \tag{2.1}$$

Where $\gamma_{SG}$ is the interface between the solid and gas phases, $\gamma_{SL}$ is the interface between the solid and liquid phases, and $\gamma_{LG}$ is the interface between the liquid and gas phases. This equation is very simple, but some difficulties arise due to surface tension between the solid and liquid phases and between the solid and vapor phases. The intermolecular force between solids and liquids offers a thermodynamic solution that leads to the Young and Dupré equation, which gives the reversible work of adhesion of a liquid and a solid. The relation to the surface tension between liquid and vapor and contact angle is given by

$$WA = \gamma_{LG} (1-\cos\theta) \tag{2.2}$$

where WA is the reversible work of adhesion of the liquid to the solid.

If the contact angle is zero, then the material will have complete wetting. If the contact angle is between 0 and 90 degrees, then the solid is wettable, and if the contact angle is above 90 degrees, then the solid experiences poor wetting. Figure 2.12 show the different wetting properties on a surface.

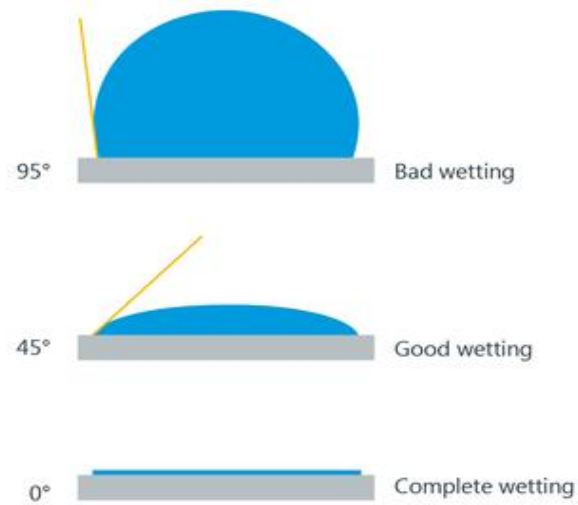


Figure 2.12. Contact angles and wetting responses on different surfaces [29]

### 2.10.2 Contact Angle Hysteresis

The difference between an advancing contact angle and the contact angle for a contact line moving in the opposite direction at the same velocity is known as contact angle hysteresis [30]. From Young's equation, for a specific liquid-solid system, the three-interface phase determines the contact angle. The surface roughness directly affects the contact angle and wettability of the surface. The effect of roughness depends upon either how the droplet wets the surface grooves or the air pocket left between the surface and the droplet. Hysteresis is the difference between the advancing contact angle and the receding contact angle:

$$H = \theta_a - \theta_r \tag{2.3}$$

## 2.11 Water Quality

The quality of water refers to its different characteristics: physical, chemical, biological, and radiological. Water is colorless, odorless, and tasteless. Water molecules are formed by one atom of oxygen and two atoms of hydrogen. The chemical formula of water is $H_2O$. The Earth's surface is covered by 71% of water, 96.5% is which is found in the seas and the ocean. The water in both contains salt, which makes them not suitable for drinking. Water has different forms: solid,

liquid, and vapor. The various sources of water include rainwater, glacial or ice water, surface water, and groundwater. The various contaminants that are present in water include pathogens as well as arsenic, which will impact the physical appearance of water and change its physical and chemical properties.

## 2.12 Water Contaminants

Various types of contaminants have a large impact on the quality of water, and water with contaminants will negatively impact health. The types of contaminants in drinking water are physical, chemical, biological, and radiological.

### 2.12.1 Physical Contaminants

Physical contaminants in water are those contaminants that occurs as a result of the presence of bacteria and viruses. Generally, these contaminants can change the physical properties and appearance of water. The main sources of physical contaminants are lakes, ponds, rivers, swimming pools, and so on. These contaminants not only change the physical appearance of water but also its taste [31].

### 2.12.2 Chemical Contaminants

Chemical contaminants in water are chemicals that are toxic to both plants and animals and are found in waterways. The two types of chemical contaminants are organic and inorganic. Organic contaminants, which include oil and petrol from roads, hormones, and herbicides and pesticides from agricultural industries, are responsible for water contamination. Inorganic contaminants include nitrogen, potassium, phosphorous, and metals, and can also be found in water. Water containing both organic and inorganic contaminants cause severe health hazards [31].

### 2.12.3 Biological Contaminants

Water generally contains various biological organisms that affect human health. These organisms include bacteria, algae and plant-like flagellate protozoa, and pathogenic protozoa. Bacteria, which are widely distributed organisms in water, are the most numerous of all livings things. Bacteria cause various disease such as typhoid, gastroenteritis, dysentery, cholera, enteritis, and tuberculosis. Microorganisms such as salmonella typhi, salmonella choleraesuis, shigella sp, and vibrio cholera are common bacteria that are present in sewage. Algae and plant-like flagellate protozoa are widely present in surface water, rainwater, and groundwater. Rotavirus and poliovirus are the common viruses present in water. Microcystis, aphanizomenon, anabaena, and cylindrospermopsis are dangerous algae that cause liver and nervous disorders [31].

### 2.12.4 Radiological Contaminants

Radiological water contaminants occur as a result of the presence of radionuclides, which are known as atoms having unstable nuclei. A radionuclide releases energy in the form of rays and high-speed particles thus causing the atoms to become more unstable. Radionuclides form naturally in small quantities. Various radiological contaminants that are present in water include radium, uranium, alpha emitters, beta emitters, and photon emitters. Radon is present in water as deposits of uranium decay in the Earth's crust. Radium is found in granite and water that is deep in rocks and can be influenced by radium, which causes severe health problems. Other elements such as uranium and alpha emitters are harmful radiological contaminants that cause severe health problem [31].

## 2.13 Water Quality Parameters

Safe and clean drinking water is essential to human health. Low-quality water can cause severe disease such as cholera, typhoid, and gastroenteritis, which affect various organs of the

human body such as the liver and kidney. The quality of water can be measured by various parameters such as total dissolved solids, electrical conductivity, pH, refractive index, and turbidity.

### 2.13.1 Total Dissolved Solids

Total dissolved solids are the total concentration of dissolved substances in water. TDS are made up of both inorganic salts and small quantities of organic matter. Inorganic salts such as calcium, magnesium, potassium, and sodium are present in water. These inorganic salts are all cations, while carbonates, nitrates, bicarbonates, and chlorides are all anions. Cations are positively charged ions, while anions are negatively charged ions. Generally, the TDS concentration is the total of positive and negative ions. Therefore, a TDS meter gives a qualitative measurement of the total amount of dissolved ions, and a TDS test is required to determine the general quality of water. The level of TDS present in water causes turbidity in drinking water. Water from springs and lakes has numerous microorganisms such as bacteria and viruses, and contains minerals that will increase the TDS that affect human health. Total dissolved solids are measured in milligrams per unit volume of water (mg/L) or parts per million (ppm). Due to the presence of salts and metals, the TDS in water is high, which is not good for safe drinking. Using a nanofilter results in a drop in the TDS level in the water, thus making it safe for drinking. Table 2.2 shows the quality of water based on total dissolved solids and according to the taste of the water [32]

TABLE 2.2

RATING OF QUALITY OF WATER WITH DIFFERENT TOTAL DISSOLVED SOLIDS

| TDS Level (Milligrams/Liter) | Water Quality Rating |
|---|---|
| Less than 300 | Excellent |
| 300–500 | Good |
| 600–900 | Fair |
| 900–1200 | Poor |
| Above 1200 | Unacceptable |

### 2.13.2 Electrical Conductivity

Electrical conductivity is used to measure the inorganic materials in water, such as calcium, bicarbonate, nitrogen, phosphorus, sulphur, iron, and other dissolved ions. It measures water's capability to pass through an electrical flow [33]. EC depends upon various factors such as ion concentration, ion mobility, ion valence, and temperature. If water contains more impurities from minerals, which will increase its EC, then water with a higher EC is not safe for drinking. Pure water is a bad conductor of electricity since the metals ions are already removed from it. The EC of drinking water ranges between 50 and 500 µs/m.

### 2.13.3 pH

The pH value is a good indicator to determine whether water is hard or soft**.** It is the measurement used to determine whether a substance is acidic or basic. The pH value ranges between 0 and 14. If the pH value of water is below 7, then it is considered acidic; if it is more than 7, then it is considered alkaline. Water with a pH value between 6 and 8.5 is safe for drinking because the water in that pH range is neither acidic nor alkaline. If water has a pH value higher than 8.5, then it can be hard, while water with a pH value less than 6 can be toxic and corrosive.

Therefore, water with a pH value higher than 8.5 is better to drink than water with a pH value less than 6. The benefit of drinking alkaline water is that it can neutralize acid in the body, which in turn helps to increase oxygen levels in the blood, improve metabolism, support the immune system, and protect bones. Water with a higher pH tends to taste bitter and also makes detergents difficult to lather [32].

### 2.13.4 Refractive Index

The refractive index of water is a dimensionless number that describes how light or other radiation passes through it [34]. Water with contaminants has a low refractive index because the contaminants do not allow light to pass through it easily. Water with fewer contaminants has a high refractive index. The refractive index of water is 1.333.

### 2.13.5 Turbidity

Turbidity is the measure of cloudiness in the water. Turbidity can vary from a lake or river full of mud, which has high turbidity and makes it difficult to see through, to spring water, which has low turbidity and is completely clear [35]. Turbidity is affected by the presence of salt, sand and mud, bacteria and viruses, and chemical precipitates in the water. The turbidity of drinking water should be less than 5 nephelometric turbidity units (NTUs) or 5 Jackson Turbidity (JTU).

# CHAPTER 3

# EXPERIMENTAL PROCEDURE

## 3.1 Materials

Two polymers (polyacrylonitrile and polyethylene glycol) and one solvent (dimethylformamide) were selected for this research.

### 3.1.1 Polyacrylonitrile

Polyacrylonitrile is a semi-crystalline organic resin used to make other polymer-like carbon fibers. PAN fibers are used in hot gas filtration systems, clothing such as socks and sweaters, and fiber-reinforced concrete. It does not melt under normal conditions although it is a thermoplastic. Almost all PAN resins are made from a mixture of monomers with acrylonitrile as the main component. The melting point of this resin is above 300ºC when the heating rates are 50 degrees per minute and above. Figure 3.1 shows the hydrocarbon structure of PAN, and Figure 3.2 shows a container of PAN used in this research.

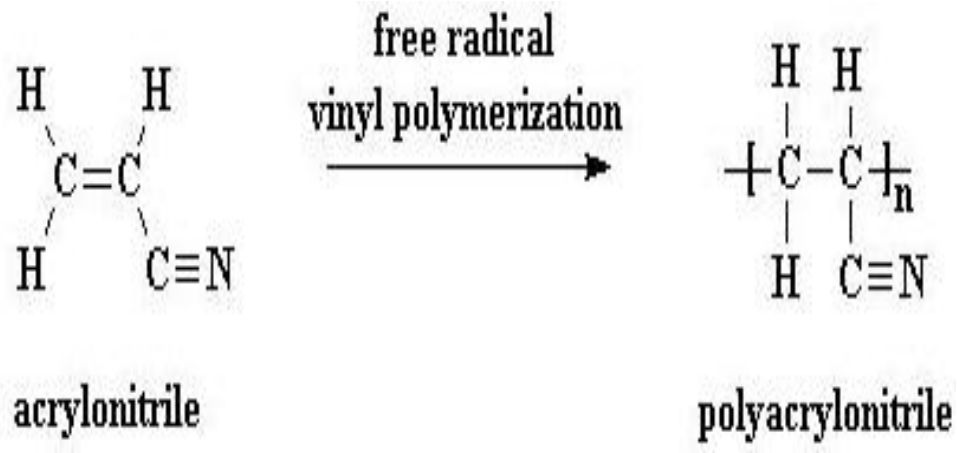


Figure 3.1. Structure of polyacrylonitrile [36]

Figure 3.2. Container of polyacrylonitrile

### 3.1.2 Polyethylene Glycol

Polyethylene glycol is a polyether compound that is used for industrial manufacturing and medicine. The chemical formula of PEG is C2nH4n + 2On + 1. In this research, PEG was added to make the fiber hydrophilic. A good property of PEG is its solubility in water. When the molecular weight of glycol increases, the solubility of water decreases. Figure 3.3 shows an image of a container of PEG used in this research.

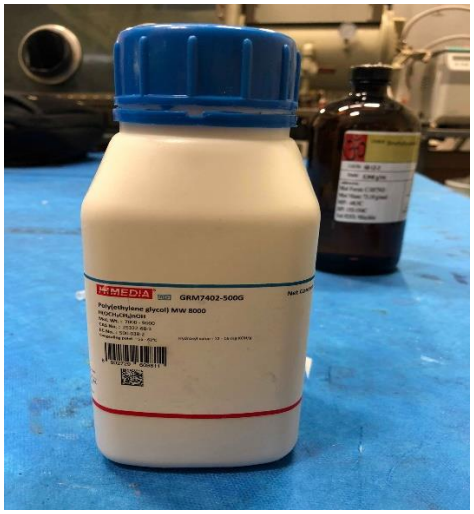


Figure 3.3. Container of polyethylene glycol

### 3.1.3 Dimethylformamide

Dimethylformamide, a common solvent, is an organic compound that comes as a colorless and water-soluble liquid with a faint ammonia-like odor. DMF has a fishy smell due to the dimethylamine. The chemical formula of DMF is $C_3H_7NO$. It is mainly used as a solvent for electrospinning to produce nanofibers that can be used in nanofiltration. Figure 3.4 shows an image of a container of DMF used in this research.

Figure 3.4. Container of dimethylformamide

### 3.1.4 Activated Charcoal

Activated charcoal is one form of activated carbon that has small and low-volume pores, which increase a surface area for available absorption. In this research, activated charcoal was used for water filtration. Figure 3.5 shows an image of activated charcoal used in this research.

Figure 3.5. Activated charcoal

## 3.2 Methods

### 3.2.1 Preparation of Polymer Solution

The procedure to produce nanofibers was as follows:

- A solution of 1.9 gram of PAN, 0.1 gram of PEG, and 18 grams of DMF was prepared.
- The solution of PAN, PEG, and DMF was mixed together in a beaker for 10 min.
- A magnetic stirrer was placed inside the mixture and then placed on a hot plate.
- A speed of 500 rpm and temperature of 75ºC was applied to the mixture for 30 min.
- The solution was placed in a syringe.

### 3.2.2 Production of Nanofiber by Electrospinning Process

The procedure to produce nanofiber using the electrospinning process was as follows:

- The solution of PAN, PEG, and DMF was held in a syringe.
- The syringe was placed in a feed rate machine, and a 1 ml/hr feed rate was applied on the syringe.
- Aluminum foil was used as a collector to gather the nanofiber.
- A 15-kV current was applied to the needle of the syringe and the collector.
- A period of 6–8 hours was necessary to complete production of the nanofiber since the feed rate was less on the syringe.
- The nanofiber was removed from the collector.

### 3.2.3 Heat Treatment

The nanofiber was kept in an oven for 30 min by applying heat at 90ºC. Heat treatment on the nanofiber helps to improve its mechanical properties and chemical stability. A Thelco Laboratory oven was used for this heat treatment.

## 3.3 Equipment/Devices

Various pieces of equipment and devices were used in this research.

### 3.3.1 Weighing Machine

A weighing machine was used to measure the various materials used in this experiment: 1.9 grams of PAN, 0.1 gram of PEG, and 18 grams of DMF. Figure 3.6 shows an image of the weighing machine to measure the different materials.

Figure 3.6. Weighing machine

### 3.3.2 Hot Plate/Magnetic Stirrer

The PAN/PEG/DMF solution was kept in on hot plate/magnetic stirrer. A temperature of 75ºC and speed of 500 rpm were applied. Figure 3.7 shows an image of the hot plate/magnetic stirrer that was used to mix the solution quickly.

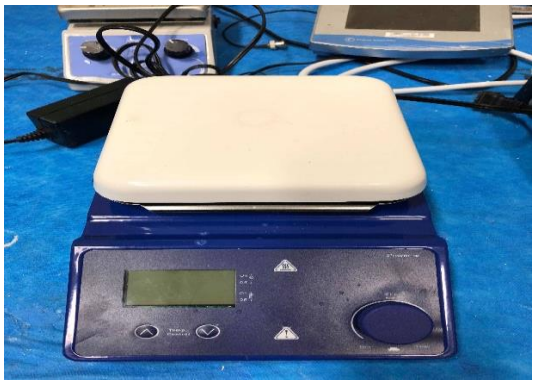

Figure 3.7. Hot plate/magnetic stirrer

### 3.3.3 Syringe

An amount of 8 ml of the PAN, PEG, and DMF mixture was held in solution in a syringe. Figure 3.8 shows the syringe where the solution was kept for the electrospinning process.

Figure 3.8. Syringe

### 3.3.4 Feed Rate Device

A feed rate device was used to maintain the feed rate of the syringe. A feed rate of 1 ml/hr was applied on the syringe. Figure 3.9 shows the feed rate device.

Figure 3.9. Feed rate device

### 3.3.5 Electrospinning Chamber

In the electrospinning chamber, the feed rate device was placed on the left side, and the collector was placed on the right side. Aluminum foil was used for the collector. Current was applied on the needle and the collector. Figure 3.9 shows the electrospinning chamber**.**

Figure 3.10. Electrospinning chamber

### 3.3.6 Hot Oven

The electrospun nanofiber was kept in a Thelco Laboratory oven for heat treatment at a temperature of 90ºC for 30 min. Heat treatment on the nanofiber helps to enhance its mechanical properties. Figure 3.10 shows the oven used in this experiment.

Figure 3.11. Oven

### 3.3.7 Optical Contact Angle Machine (Goniometer)

A goniometer was used to measure the contact angle of the fiber surface and a water droplet. Figure 3.12 shows the goniometer used in this experiment.

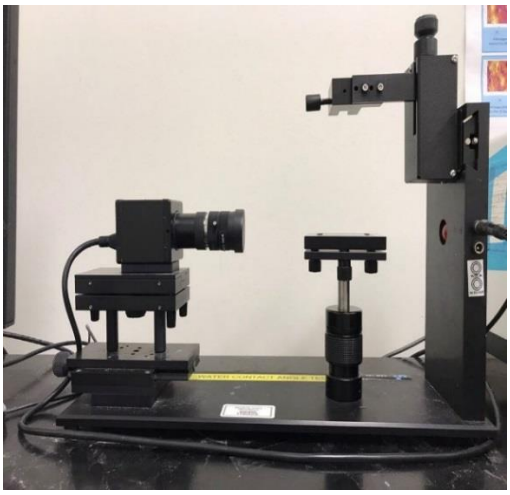

Figure 3.12. Goniometer

### 3.3.8 pH Meter

A pH meter is used to measure the pH of different water samples before and after filtration. This instrument measures the presence of hydrogen ions in a water-based solution in order to identify whether the water is acidic or basic. Electrodes of the pH meter immersed in the different water samples provided the different pH values. Figure 3.12 shows the pH meter used in this experiment.

Figure 3.13. pH meter

### 3.3.9 Total Dissolved Solids Meter

The total dissolved solids meter is an instrument used to measure the TDS of a solution. Electrodes of the TDS meter were immersed into different water solutions and the TDS was recorded in parts per million. Figure 3.13 shows the TDS meter used in this experiment.

Figure 3.14. Total dissolved solids meter

### 3.3.10 Electrical Conductivity Meter

The electrical conductivity meter is an instrument used to measure the EC in a solution by measuring the amount of nutrients, salts, or impurities. Electrodes of the meter were placed in water to measure the EC in µs/cm of different samples. Figure 3.14 shows the EC meter used in this experiment.

Figure 3.15. Electrical conductivity meter

### 3.3.11 Turbidity Meter

The turbidity meter is an instrument used to measure the turbidity of water in nephelometric turbidity units. Turbidity, or cloudiness of water, is formed as the result of impurities that can be seen by the naked eye. The turbidity meter was placed in different water samples to measure the turbidity of the water before and after filtration. Figure 3.15 shows the turbidity meter used in this experiment.

Figure 3.16. Turbidity meter

### 3.3.12 Refractometer

The refractrometer device shown in Figure 3.16 was used to measure the refractive index of different water samples. The refractive index of water is 1.3330.

Figure 3.17. Refractometer

### 3.3.13 Water Vacuum Pump

The water vacuum is a pump used to apply pressure on the portable nanofilter by pushing water into the pipe and filtering the water through the nanofiber. Figure 3.17 shows the water vacuum pump used in this experiment.

Figure 3.18. Water vacuum pump

### 3.3.14 Fourier Transform Infrared Spectroscopy

Fourier transform infrared (FTIR) spectroscopy is a technique that produces an infrared spectrum of the absorption or emission of a solid, liquid, or gas. An FTIR spectrometer, as shown in Figure 3.19, was used to identify the presence of specific functional groups. FTIR analysis can be used on many samples, including paints, resins, polymers, coatings, and drugs. It also provides crystalline structural information and the idenitification of polymorphs.

Figure 3.19. FTIR Spectrometer.

## 3.4 Production of Nanofibers

The production of nanofibers is extensively done using the electrospinning process. This process is very useful for producing continuous nanofibers. During fiber production, an electrostatic force is used to create a fiber with a diamter of 2 nm. The key principle in electrospinning is the use of a 15 KV current of eletrostatic force to produce the continuous nanofiber. A Taylor cone on the polymer is formed due to high volatge. Also because of high voltage, a charged polymer jet is ejected from the syringe needle. The charged polymer coming out from the needle is gathered on the collector, which in this experiment was aluminium foil. The collected nanofiber was removed from the collector and put into an oven for heat treatment for 30 minutes at 90$^{o}$C in order to enhance the mechanical properties. Figure 3.19 shows the electrospun nanofiber that was produced by electrospinning and used as a nanofilter to filter water.

Figure 3.20. Electrospun nanofiber

## 3.5 Design of Portable Nanofilters

The nanofilter is a device that removes unwanted materials from water, such as arsenic, ions, and pathogens. Three different designs for the portable nanofilters were employed in this research:

- Portable filter with one layer of nanofiber.
- Portable filter with two layers of nanofiber.

- Portable filter with three layers of nanofiber.

The three different filtration systems used in this research are shown in Figure 3.21. Individual water parameters—TDS, EC, turbidity, refractive index, and pH—for different water samples were measured using these filtration systems. The five water samples used in this study were contaminated pond water, contaminated water jet cutter water, tap water, deionized water, and carbon black deionized water.

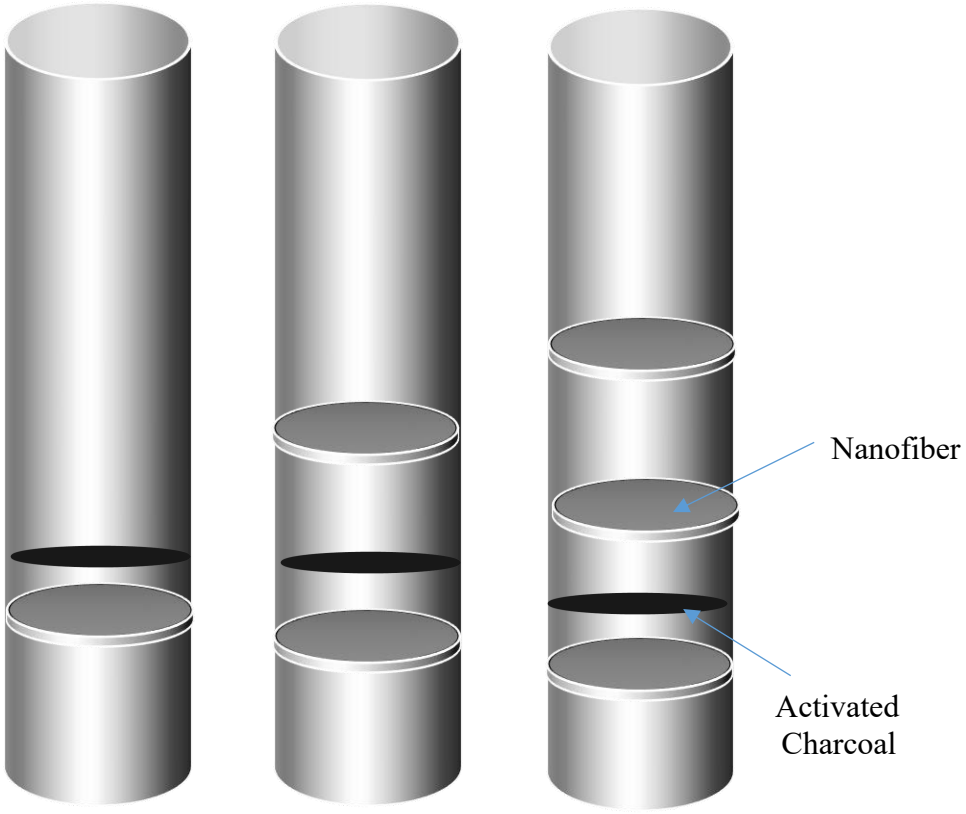


Figure 3.21.Three different nanofiltration systems

The portable nanofilters used in this research were made of plastic pipe, 8 inches in length and 0.5 inch for the inside diameter, as shown in Figure 3.22. Activated charcoal in the amount of 0.5 gram was placed inside the pipe to help remove chlorine from the water. For every design, the same length and diameter of pipe and the same 0.5 gram of activated charcoal were used, but the number of nanofibers varied. One layer of nanofilter was used for the first filtration system, while

two layers of nanofilters were used for the second filtration system, and three nanofilters for the third filtration system, as shown previously in Figure 3.21.

Figure 3.22. Portable Nanofilter

### 3.6 Experimental Procedure

Different water samples were collected for the water filtration experiment. Each sample was pushed into the filtration system using a vacuum pump, and the contaminated water was filtered by means of the nanofilter inside the portable filter. Activated charcoal was used to remove chlorine from the contaminated water. Water exiting the nanofilter was purified, and its quality after purification was measured.

Five different water samples were used in this research:

- 500 ml of contaminated pond water (Figure 3.23).
- 500 ml of contaminated water from a water jet cutter from the National Institute for Aviation Research (NIAR) (Figure 3.24).
- 500 ml of tap water from Wallace Hall Room 125, Wichita State University (WSU) (Figure 3.25).
- 500 ml of deionized water from Wallace Hall Room 125, WSU (Figure 3.26).
- 99.9 grams of sonicated deionized water with 0.1 gram of carbon black (Figure 3.27).

Figure 3.23. Contaminated pond water

Figure 3.24. Contaminated water jet cutter water

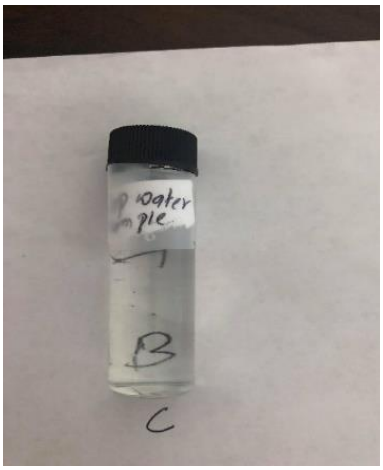

Figure 3.25. Tap water

Figure 3.26. Deionized water

Figure 3.27. Carbon black deionized water

All five water samples were filtered using the three different nanofiltration systems, and the water parameters of TDS, EC, turbidity, pH, and refractive index were measured and compared. All nanofiltration systems were able to filter the water and reduce the TDS, EC, turbidity, and pH of the water; however, the refractive index increased in all samples.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Superhydrophilic Behavior of Electrospun PAN Nanofibers with DMF

Heat treatment was applied on electrospun PAN nanofibers with DMF before measuring their water contact angles using a goniometer. The nanofibers displayed the behavior of a superhydrophilic surface, and the contact angles for the fibers were zero. Nanofiber displaying a superhydrophilic behavior is better for filtering water [37-40]. Figure 4.1 shows the superhydrophilic property of nanofiber.

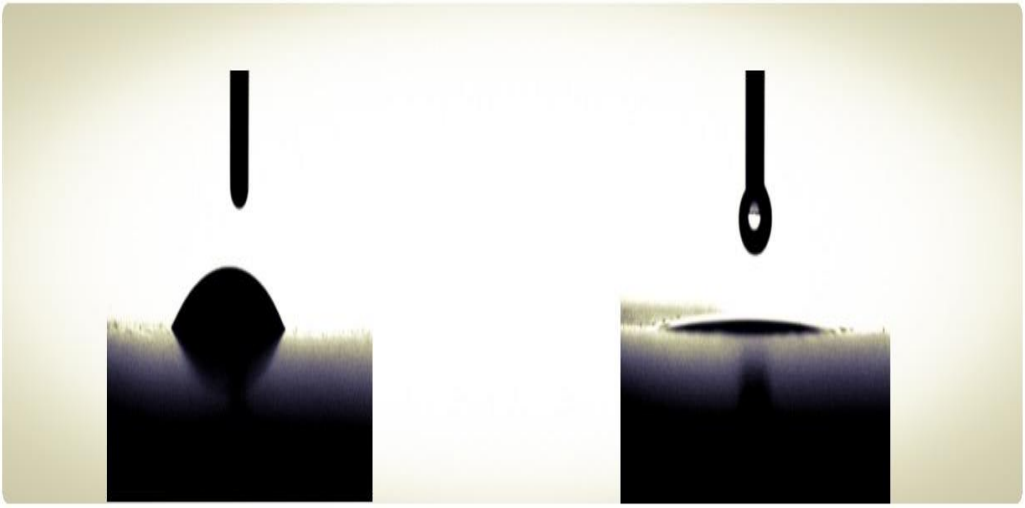

Figure 4.1. Superhydrophilic surface of nanofiber [37]

## 4.2 Scanning Electrospun Microscope Images of Nanofibers

Two different samples of nanofibers were taken to the NIAR laboratory at WSU to obtain SEM images of the nanofibers. One SEM image was taken of the nanofiber without heat treatment, and one SEM image was taken of the nanofiber with heat treatment. Following heat treatment, the mechanical properties of the nanofiber were improved. Figures 4.2 and 4.3 show SEM images of nanofiber without and with heat treatment, respectively.

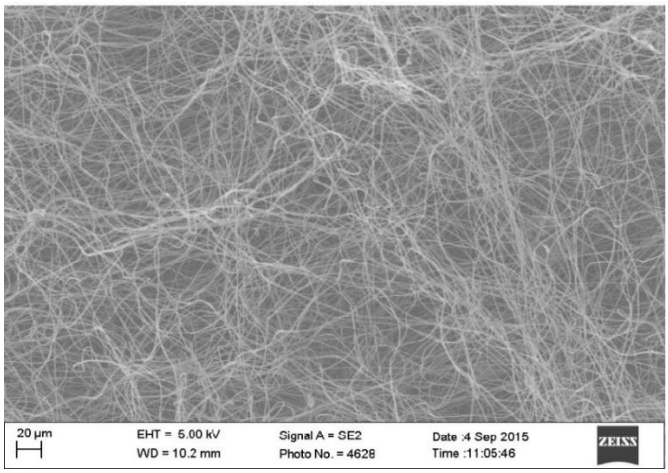


Figure 4.2. SEM image of nanofiber without heat treatment

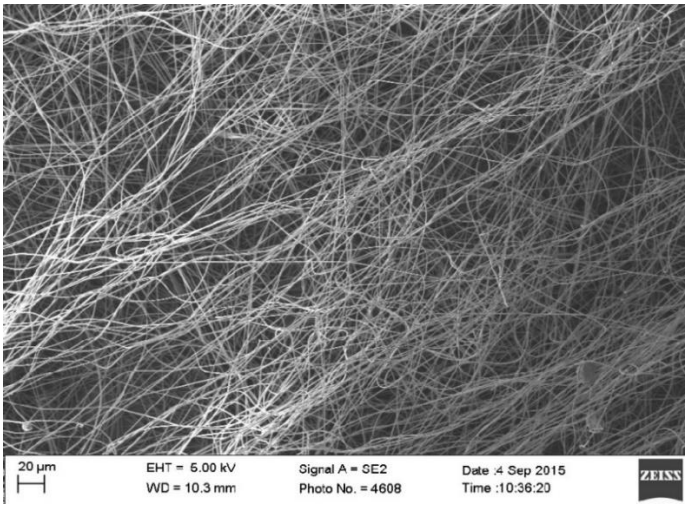


Figure 4.3. SEM image of nanofiber with heat treatment

From the SEM images shown in Figures 4.2 and 4.3, it can be seen that the structure of the nanofibers changes after heat treatment. Once the heat treatment is applied on the nanofiber, the thermal and chemical stability will have improved, in comparison to nanofiber without heat treatment. The SEM images are of nanofibers that are 20 micrometers in diameter.

## 4.3 Fourier-Transform Infrared Spectroscopy Analysis

FTIR spectroscopy analysis was used to obtain an infrared spectrum of absorption of the three different polymer samples. Figures 4.4(a), (b), and (c) show the spectrums for PEG, PAN,

and PAN/PEG nanofiber, respectively. The spectrum of those polymers were measured with the help of an FTIR spectrometer. As can be seen, the three samples show various peaks, most of which are due to noise. The functional group of nitriles is between wave numbers 2100 and 2200. As FTIR spectroscopy was performed on the nanofiber, peaks started to form in the region between wave numbers 2000 and 2500, which indicates the functional group of nitriles, meaning the presence of PAN in the nanofiber. The functional group of PEG is between wave numbers 1000 and 1200. When the FTIR was done, the peaks of PEG can also be seen in the nanofiber. A separate FTIR test was also done for PAN and PEG, and the peak of the individual wave number matched the FTIR peak done for the combined PAN/PEG polymer nanofiber.

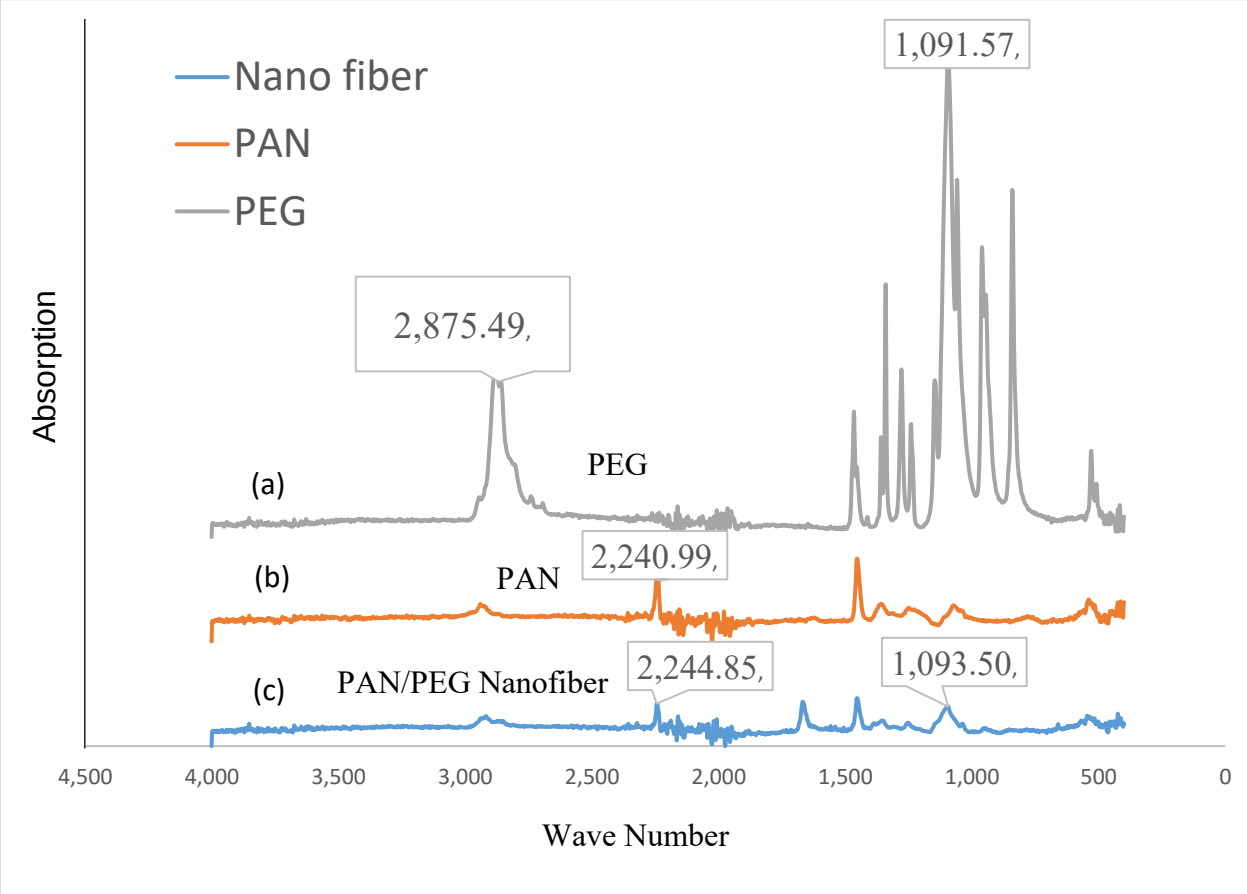


Figure 4.4. FTIR analysis: (a) PEG, (b) PAN, and (c) PAN/PEG nanofiber

## 4.4 Results and Discussion

The different water samples were filtered using three different layers of nanofiltration. The total dissolved solids, electrical conductivity, turbidity, pH, and refractive index of different water samples are discussed below.

### 4.4.1 Pond Water

The collected water sample from the pond contains many physical and chemical contaminants. The pH is a measure of the presence of hydrogen in a water solution. The pH of the collected pond water was found to be 8.7, which is high for drinking purposes, but after filtration, the pH was reduced to 8.57 for one layer of nanofiber, 8.36 for two layers of nanofiber, and 8.2 for three layers of nanofiber. The total dissolved solids of the pond water was 610 ppm before filtration, but after filtration, the TDS decreased to 248 ppm for one layer of nanofilter, 225 ppm for two layers of nanofiber, and 219 ppm for three layers of nanofiber, which are all acceptable for drinking purposes. Electrical conductivity of the pond water was 1220 µs/cm before filtration, but after filtration, the EC decreased to 496 µs/cm for one layer of nanofiber, 450 µs/cm for two layers of nanofiber, and 438 µs/cm for three layers of nanofiber, which are acceptable for drinking purposes. Turbidity of the pond water was 18 NTU before water filtration, but after filtration, the turbidity decreased to 4.8 NTU for one layer of nanofiber, 4.4 NTU for two layers of nanofiber, and 3.8 NTU for three layers of nanofiber, which are acceptable for drinking purposes. The refractive index of the pond water was 1.3329 before filtration, but after filtration, the turbidity increased to 1.3331 for one layer of nanofiber, 1.3331 for two layers of nanofiber, and 1.3332 for three layers of nanofiber, which are acceptable for drinking purposes. Table 4.1 shows the different water parameters for pond water. Figures 4.5 and 4.6 show pond water before and after filtration, respectively.

TABLE 4.1

DIFFERENT WATER QUALITY PARAMETERS FOR POND WATER

| Parameter | TDS (ppm) | EC (µs/cm) | Turbidity (NTU) | pH | Refractive Index |
|---|---|---|---|---|---|
| Before Filtration | 610 | 1220 | 18 | 8.7 | 1.3329 |
| One Layer Nanofiber | 248 | 496 | 4.8 | 8.57 | 1.3331 |
| Two Layers Nanofiber | 225 | 450 | 4.4 | 8.36 | 1.3331 |
| Three Layers Nanofiber | 219 | 438 | 3.8 | 8.2 | 1.3332 |

Figure 4.5. Pond water before filtration

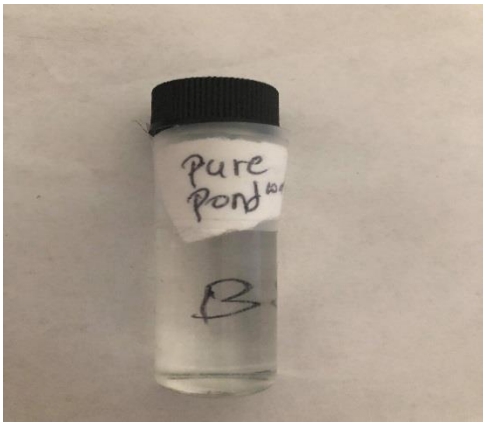


Figure 4.6. Pond water after filtration

### 4.4.2 Water from Water Jet Cutter

About 500 ml of contaminated water was collected from a water jet cutter at NIAR. This sample water contained many impurities, which can easily be seen. The pH of water from the water jet cutter was found to be 8.6, which was high for drinking purposes, but after filtration the pH was reduced to 8.45 for one layer of nanofiber, 8.31 for two layers of nanofiber, and 8.15 for three layers of nanofiber. The total dissolved solids of water from the water jet cutter was 435 ppm before filtration, but after filtration, the TDS decreased to 246 ppm for one layer of nanofilter, 232 ppm for two layers of nanofiber, and 220 ppm for three layers of nanofiber, which are acceptable for drinking purposes. The electrical conductivity of water from the water jet cutter was 870 µs/cm

before filtration, but after filtration, the EC decreased to 492 µs/cm for one layer of nanofiber, 464 µs/cm for two layers of nanofiber, and 440 µs/cm for three layers of nanofiber, which are acceptable for drinking purposes. The turbidity of water from the water jet cutter was 64 NTU before water filtration, but after filtration, turbidity decreased to 4.7 NTU for one layer of nanofiber, 4.4 NTU for two layers of nanofiber, and 4.1 NTU for three layers of nanofiber, which are acceptable for drinking purposes. The refractive index of water from the water jet cutter was 1.3327 before filtration, but after filtration, the refractive index increased to 1.3329 for one layer of nanofiber, 1.3331 for two layers of nanofiber, and 1.3332 for three layers of nanofiber, which are acceptable for drinking purposes. Table 4.2 shows the different parameters for water from the water jet cutter. Figures 4.7 and 4.8 show water from the water jet cutter before and after filtration, respectively.

TABLE 4.2

DIFFERENT WATER QUALITY PARAMETERS FOR WATER JET CUTTER WATER

| **Parameter** | **TDS (ppm)** | **EC (µs/cm)** | **Turbidity (NTU)** | **pH** | **Refractive Index** |
|---|---|---|---|---|---|
| Before Filtration | 435 | 870 | 64 | 8.6 | 1.3327 |
| One Layer Nanofiber | 246 | 492 | 4.7 | 8.45 | 1.3329 |
| Two Layers Nanofiber | 232 | 464 | 4.4 | 8.31 | 1.3331 |
| Three Layers Nanofiber | 220 | 440 | 4.1 | 8.15 | 1.3332 |

Figure 4.7. Water jet cutter water before filtration

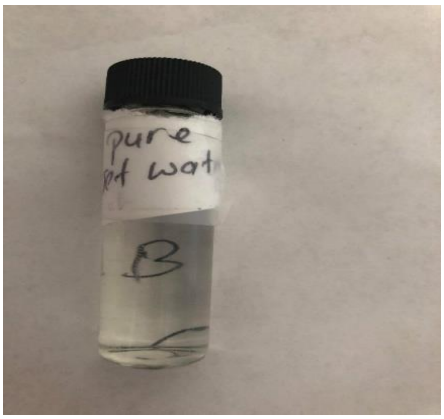


Figure 4.8. Water jet cutter water after filtration

### 4.4.3 Tap Water

Water was collected from a tap located in Wallace Hall Room 125 at WSU. The parameters of this tap water were good, but after nanofiltration, the water quality was even better. The pH of the tap water was found to be 8.2, but after filtration, the pH was reduced to 8.15 for one layer of nanofiber, 7.9 for two layers of nanofiber, and 7.7 for three layers of nanofiber. The total dissolved solids of the tap water was 367 ppm before filtration, but after filtration, the TDS decreased to 240 ppm for one layer of nanofilter, 225 ppm for two layers of nanofiber, and 205 ppm for three layers of nanofiber, which are acceptable for drinking purposes. The electrical conductivity of tap water was 734 µs/cm before filtration, but after filtration, the EC decreased to 480 µs/cm for one layer of nanofiber, 450 µs/cm for two layers of nanofiber, and 410 µs/cm for three layers of nanofiber, which are acceptable for drinking purposes. Turbidity of the tap water was 4.6 NTU before water filtration, but after filtration, turbidity decreased to 4.4 NTU for one layer of nanofiber, 4.2 NTU for two layers of nanofiber, and 3.9 NTU for three layers of nanofiber, which are acceptable for drinking purposes. The refractive index of tap water was 1.3328 before filtration, but after filtration, the refractive index increased to 1.3329 for one layer of nanofiber, 1.3331 for two layers of nanofiber, and 1.3332 for three layers of nanofiber, which are acceptable for drinking purposes.

Table 4.3 shows the different parameters for tap water. Figures 4.9 and 4.10 show tap water before and after filtration, respectively.

TABLE 4.3

DIFFERENT WATER QUALITY PARAMETERS FOR TAP WATER

| Parameter | TDS (ppm) | EC (µs/cm) | Turbidity (NTU) | pH | Refractive Index |
|---|---|---|---|---|---|
| Before Filtration | 367 | 734 | 4.6 | 8.2 | 1.3328 |
| One Layer Nanofiber | 240 | 480 | 4.4 | 8.15 | 1.3329 |
| Two Layers Nanofiber | 225 | 450 | 4.2 | 7.9 | 1.3331 |
| Three Layers Nanofiber | 205 | 410 | 3.9 | 7.7 | 1.3332 |

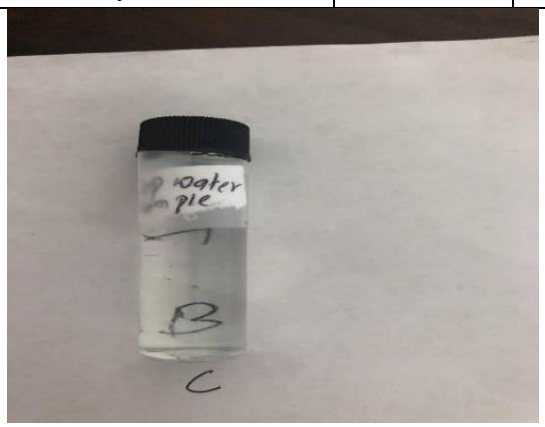

Figure 4.9. Tap water before filtration

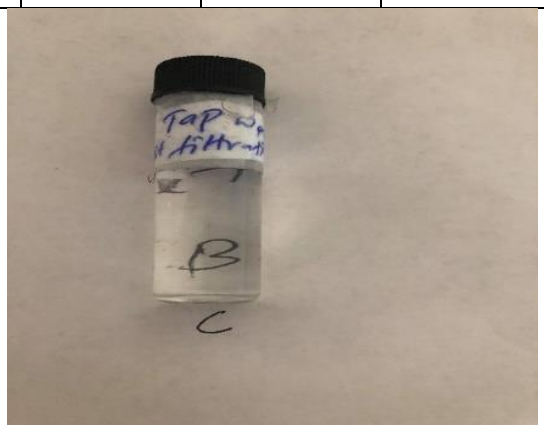

Figure 4.10. Tap water after filtration

### 4.4.4 Deionized Water

Deionized water has almost of all its minerals removed; therefore, its total dissolved solids and electrical conductivity are zero. The pH of the collected deionized water was found to be 6.68, which was higher for drinking purposes, but after filtration, the pH increased to 8.46 for one layer of nanofiber, due to the presence of the activated charcoal, but decreased to 8.30 for two layers of nanofiber, and 8.25 for three layers of nanofiber. The TDS was 0 ppm before filtration because of the lack of salt and other ions, but after filtration, the TDS increased to 13 ppm for one layer of nanofilter, 16 ppm for two layers of nanofiber, and 18 ppm for three layers of nanofiber, which are not acceptable for drinking purposes. The electrical conductivity of deionized water was 0 µs/cm

before filtration, but after filtration, the EC increased to 26 µs/cm for one layer of nanofiber, 32 µs/cm for two layers of nanofiber, and 36 µs/cm for three layers of nanofiber, which are not acceptable for drinking purposes. Turbidity of the deionized water was 0 NTU before filtration, but after filtration, turbidity decreased to 1.4 NTU for one layer of nanofiber, 1.1 NTU for two layers of nanofiber, and 0.9 NTU for three layers of nanofiber. The refractive index of deionized water was 1.3329 before filtration, but after filtration, the refractive index increased to 1.3328 for one layer of nanofiber, 1.3329 for two layers of nanofiber, and 1.3331 for three layers of nanofiber. Table 4.4 shows the different parameters for deionized water. Figures 4.11 and 4.12 show deionized water before and after filtration, respectively.

TABLE 4.4

DIFFERENT WATER QUALITY PARAMTERS FOR DEIONIZED WATER

| **Parameter** | **TDS (ppm)** | **EC (µs/cm)** | **Turbidity (NTU)** | **pH** | **Refractive Index** |
|---|---|---|---|---|---|
| Before Filtration | 0 | 0 | 0 | 6.68 | 1.3327 |
| One Layer Nanofiber | 13 | 26 | 1.4 | 8.46 | 1.3328 |
| Two Layers Nanofiber | 16 | 32 | 1.1 | 8.30 | 1.3329 |
| Three Layers Nanofiber | 18 | 36 | 0.9 | 8.25 | 1.3331 |

Figure 4.11. Deionized water before filtration

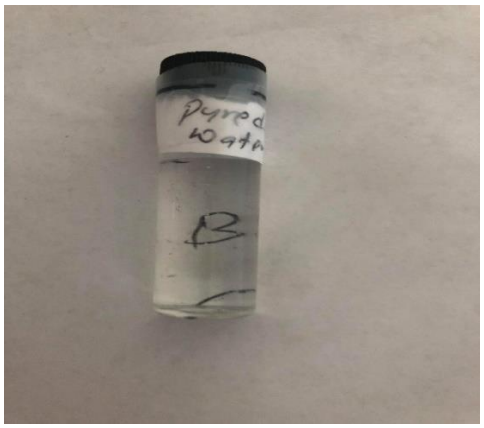

Figure 4.12. Deionized water after filtration

### 4.4.5 Carbon Black Deionized Water

An amount of 0.1 gram of carbon black was added to 99.9 grams of deionized water and then sonicated for 30 min. The carbon black deionized water had low TDS, EC, and pH, but turbidity was high due to the presence of the carbon black. The parameters of deionized water and carbon black deionized water after filtration were almost the same. The pH of carbon black deionized water was found to be 6.76 ppm, which was low for drinking purposes, but after filtration, the pH increased to 8.5 for one layer of nanofiber, but decreased to 8.41 for two layers of nanofiber and 8.35 for three layers of nanofiber. The total dissolved solids of carbon black deionized water was 5 ppm before filtration, but after filtration, the TDS increased to 15 ppm for one layer of nanofilter, 18 ppm for two layers of nanofiber, and 24 ppm for three layers of nanofiber, which are not acceptable for drinking purposes. The electrical conductivity of carbon black deionized water was 10 µs/cm before filtration, but after filtration, the EC increased to 30 µs/cm for one layer of nanofiber, 36 µs/cm for two layers of nanofiber, and 48 µs/cm for three layers of nanofiber, which are not acceptable for drinking purposes. The turbidity of carbon black deionized water was 17 NTU before water filtration, but after filtration, turbidity decreased to 4.7 NTU for one layer of nanofiber, 4.5 NTU for two layers of nanofiber, and 4.1 NTU for three layers of nanofiber respectively. The refractive index of carbon black deionized water was 1.3324 before filtration, but after filtration, the refractive index increased to 1.3327 for one layer of nanofiber, 1.3328 for two layers of nanofiber, and 1.3331 for three layers of nanofiber. Table 4.5 shows the different parameters for carbon black deionized water. Figures 4.13 and 4.14 show carbon black deionized water before and after filtration, respectively.

TABLE 4.5

DIFFERENT WATER QUALITY PARAMETERS FOR CARBON BLACK DEIONIZED WATER

| Parameter | TDS (ppm) | EC (µs/cm) | Turbidity (NTU) | pH | Refractive Index |
|---|---|---|---|---|---|
| Before Filtration | 5 | 10 | 17 | 6.76 | 1.3324 |
| One Layer Nanofiber | 15 | 30 | 4.7 | 8.5 | 1.3327 |
| Two Layers Nanofiber | 18 | 36 | 4.5 | 8.41 | 1.3328 |
| Three Layers Nanofiber | 24 | 48 | 4.1 | 8.35 | 1.3331 |

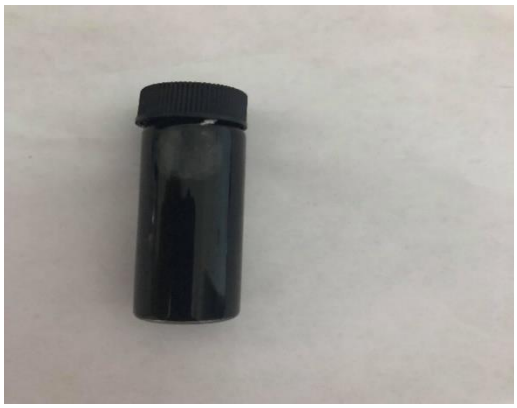

Figure 4.13. Carbon black deionized water before filtration

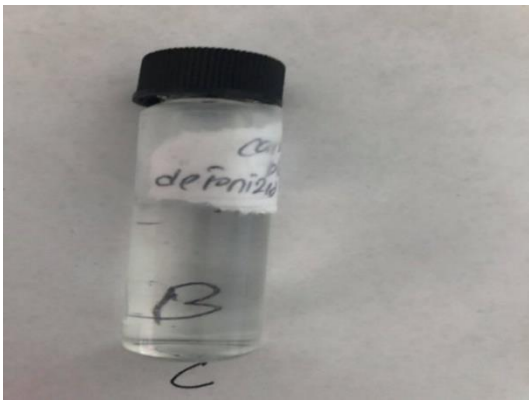

Figure 4.14. Carbon black deionized water after filtration.

## 4.5 Graphs of Different Water Quality Parameters

### 4.5.1 Total Dissolved Solids

The total dissolved solids of three different water samples (pond water, water jet cutter water, and tap water) were taken and filtered in different layers of nanofiber, and each layer was compared. Figure 4.15 shows a bar graph of the total dissolved solids in ppm of the different water samples before and after filtration.

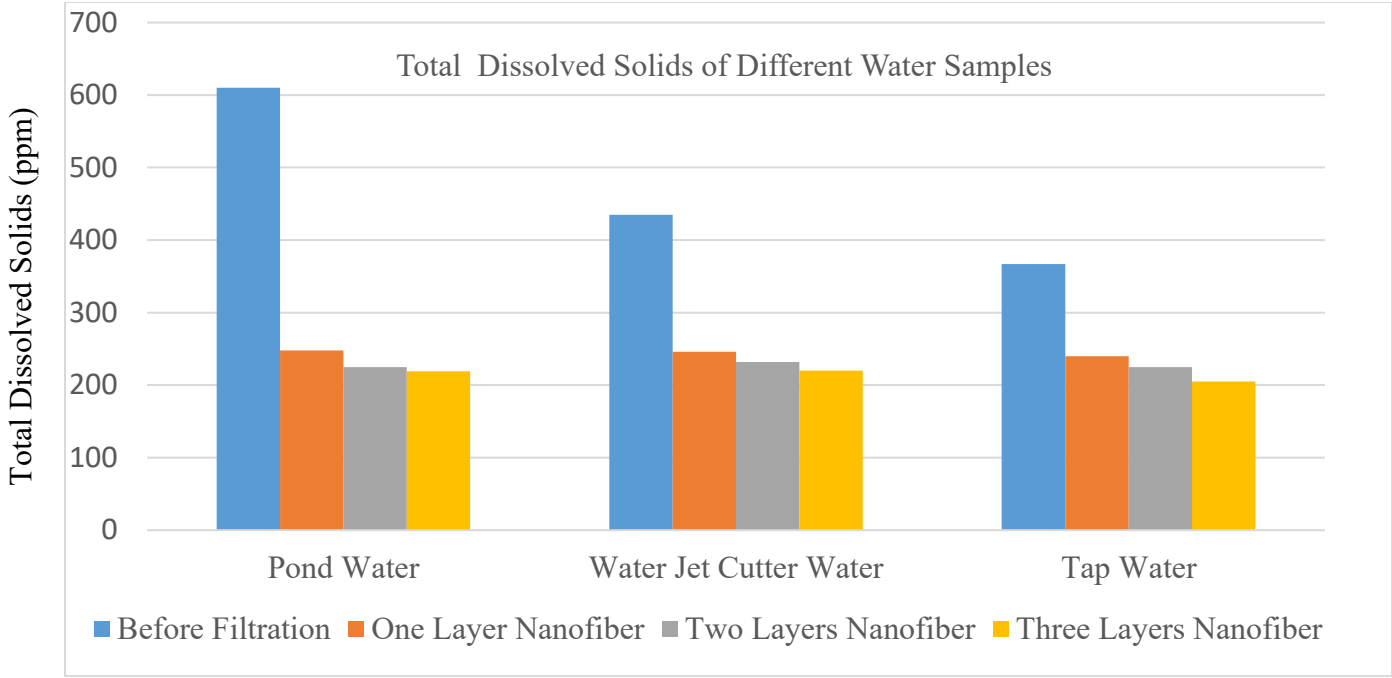


Figure 4.15. Total dissolved solids in three different water samples before and after filtration

Before filtration, the TDS of water was 610 ppm, 435 ppm, and 367 ppm for pond water, water jet cutter water, and tap water, respectively, which are not suitbale for drinking purposes. At first, different water samples were purified using only the one-layer nanofiltration system, where the TDS was reduced to 248 ppm for pond water, 246 ppm for water jet cutter water, and 240 ppm for tap water, which are suitable for drinking purposes. Further purification of the water samples was done using two layers of nanofiber and three layers of nanofiber. In the case of two layers of nanofiber, the TDS decreased to 225 ppm, 232 ppm, and 225 ppm for pond water, water jet cutter water, and tap water, respectively, while in the case of three layers of nanofiber, the TDS decreased to 219 ppm, 220 ppm, and 205 ppm, respectively. This decrease of TDS in every nanofilter indicates that unwanted solids were removed from the water and that the nanofilters were able to filter the water. The addition of nanofiber helps to improve the water filtration.

Figure 4.16 shows the average decrease in total dissolved solids for different layers of nanofiber measured for three different water samples: pond water, water jet cutter water, and tap water. Before filtration, the average TDS was found to be 470.6667 ppm, which was higher for

drinking purposes; after filtration, the TDS decreased and was found to be 244.66 ppm, 227.333 ppm, and 214.66 ppm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. It is clear from the graph in Figure 4.16 that the decrease of average TDS indicates that the nanofilters were able to filter the water and that the addition of nanofiber improved the water filtration.

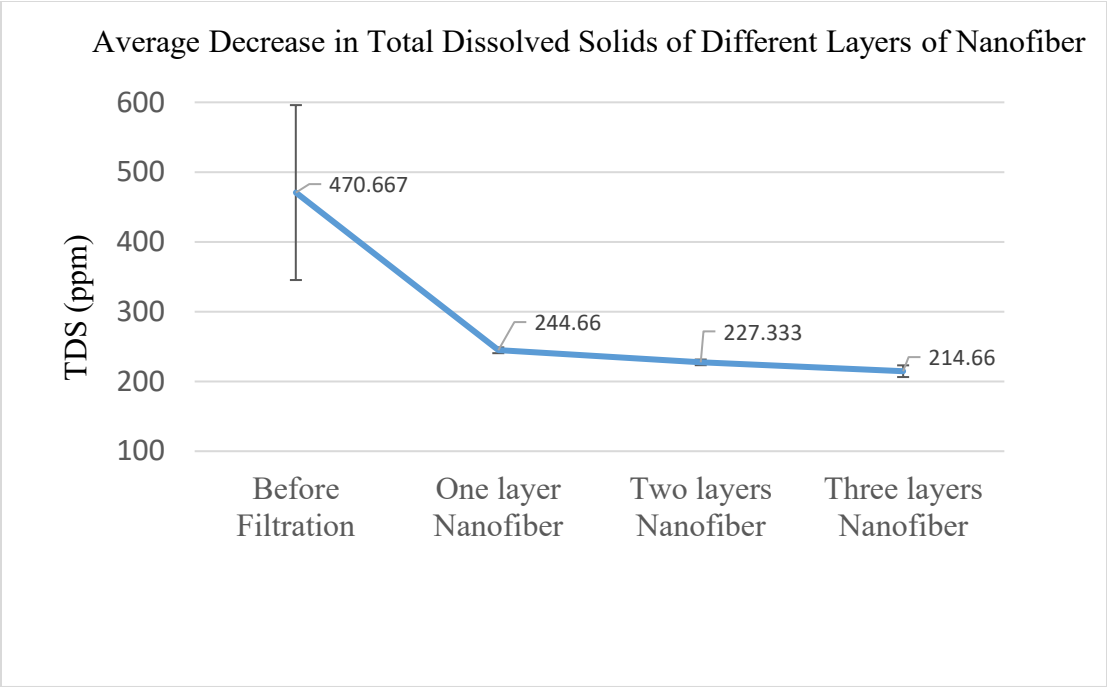


Figure 4.16. Average decrease in total dissolved solids in three different water samples before and after filtration.

Figure 4.17 shows the increase in total dissolved of solids for deionized water and carbon black deionized water samples before and after filtation with different nanofilters. Since deionized water lacks ions, the TDS was found to be 0 ppm before filtration, but after filtration, the TDS increased and was found to be 13 ppm, 16 ppm, and 18 ppm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. In the case of carbon black deionized water, the TDS was 5 ppm before filtration, but after filtration, the TDS increasaed to 15 ppm, 18 ppm, and 24 ppm for one layer of nanofiber, two layers of nanofiber, and three layers of

nanofiber, respectively. Even after filtration, both deionized water and carbon black deionized water had less TDS, but this was not sufficient for drinking purposes. Therefore, nanofiltration is not a suitable filtration method for deionized water or carbon black deionized water.

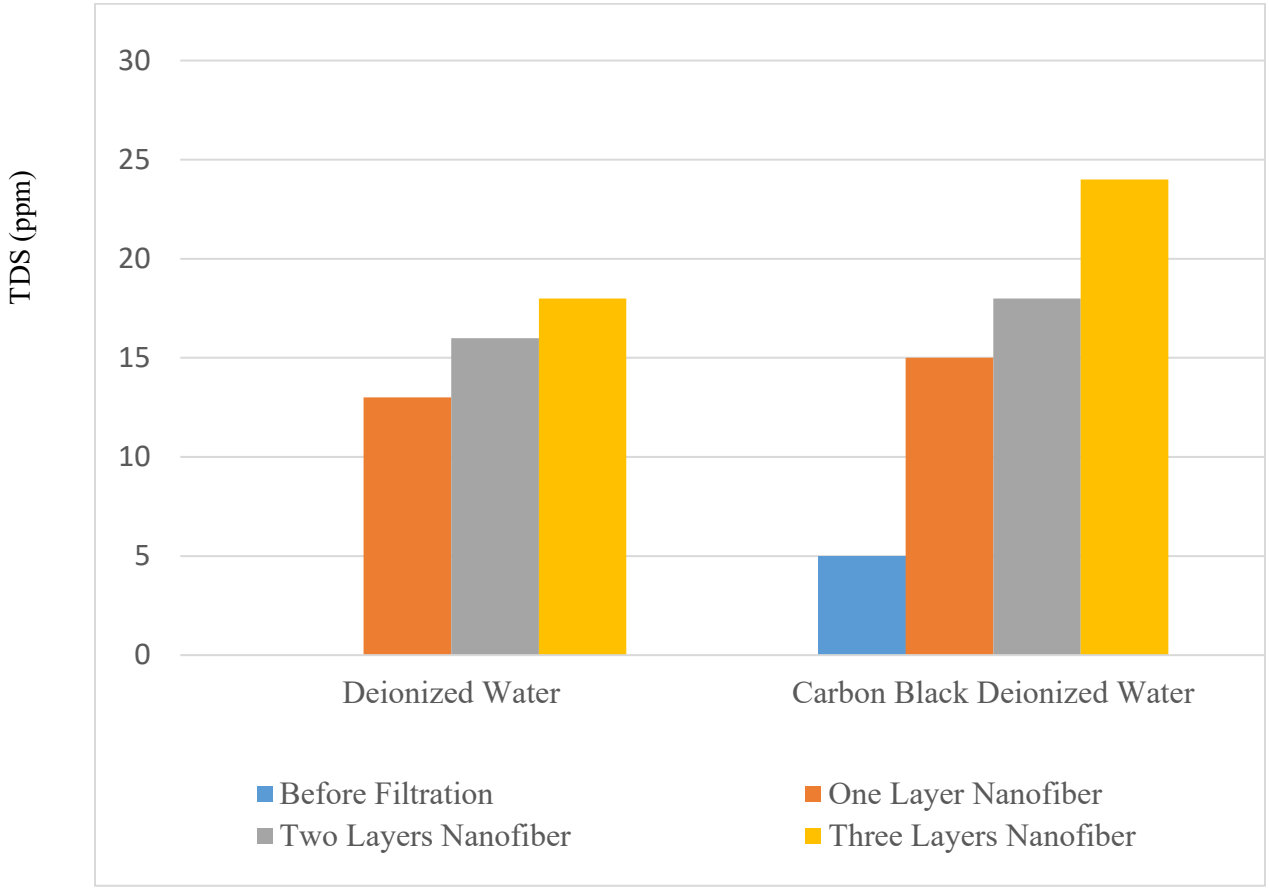


Figure 4.17. Increase in total dissolved solids of deionized water and carbon black deionized water before and after filtration with different nanofilters

Figure 4.18 shows the average increase in total dissolved solids before and after filtration with different layers of nanofiber for two different water samples: deionized water and carbon black deionized water. Before filtration, the average TDS was found to be 2.5 ppm, which was very low for drinking purposes, and after filtration, the TDS increased and was found to be 14 ppm, 17 ppm, and 21 ppm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. Even after filtration, the nanofilters were not able to improve the TDS of

deionized water and carbon black deionzed water. Therefore, the nanofiltration process is not suitable for deionzed and carbon black deionzed water.

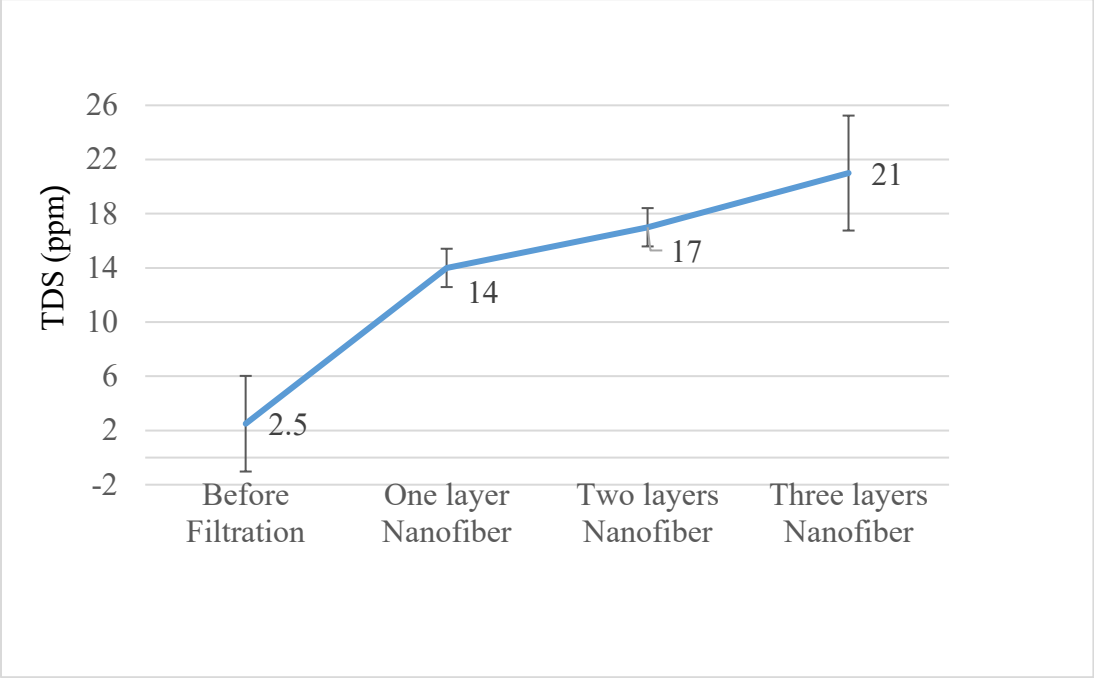


Figure 4.18. Average increase in total dissolved solids in deionized water and carbon black deionized water before and after filtration with different nanofilters

### 4.5.2 Turbidity

The turbidity of five different water samples before and after filtration was measured, and the average turbidity in each layer of filtration was compared. Figure 4.19 shows the turbidity of pond water, water jet cutter water, tap water, deionzed water, and carbon black deionized water before and after filtration. Before filtration, the turbidity of the water was 18 NTU, 64 NTU, 4.6 NTU, 0 NTU, and 17 NTU, respectively. First, different water samples were purified using one layer of nanofiltration system, where the turbidity decreased to 4.8 NTU for pond water, 4.7 NTU for water jet cutter water, 4.4 NTU for tap water, and 4.7 NTU for carbon black deionzed water, but increased to 1.4 NTU for deionzed water, due to the presence of activated charcoal inside the nanofilter. Further purification was done to observe the results, and water samples were then

filtered using two layers of nanofiber and three layers of nanofiber. In the case of two layers of nanofiber, turbidity decreased to 4.4 NTU, 4.4 NTU, 4.2 NTU, 1.1 NTU, and 4.5 NTU in pond water, water jet cutter water, tap water, deionzed water, and carbon black deionzed water, respectively, while in the case of three layers of nanofiber, there was a decrease in turbidity to 3.8 NTU, 4.1 NTU, 3.9 NTU, 0.9 NTU, and 4.1 NTU, respectively. The decrease in turbidity level in every nanofilter shows less cloudiness and haziness in the water, and it is clear that the nanofilters were able to filter the water. The addition of nanofiber helps to improve the water filtration.

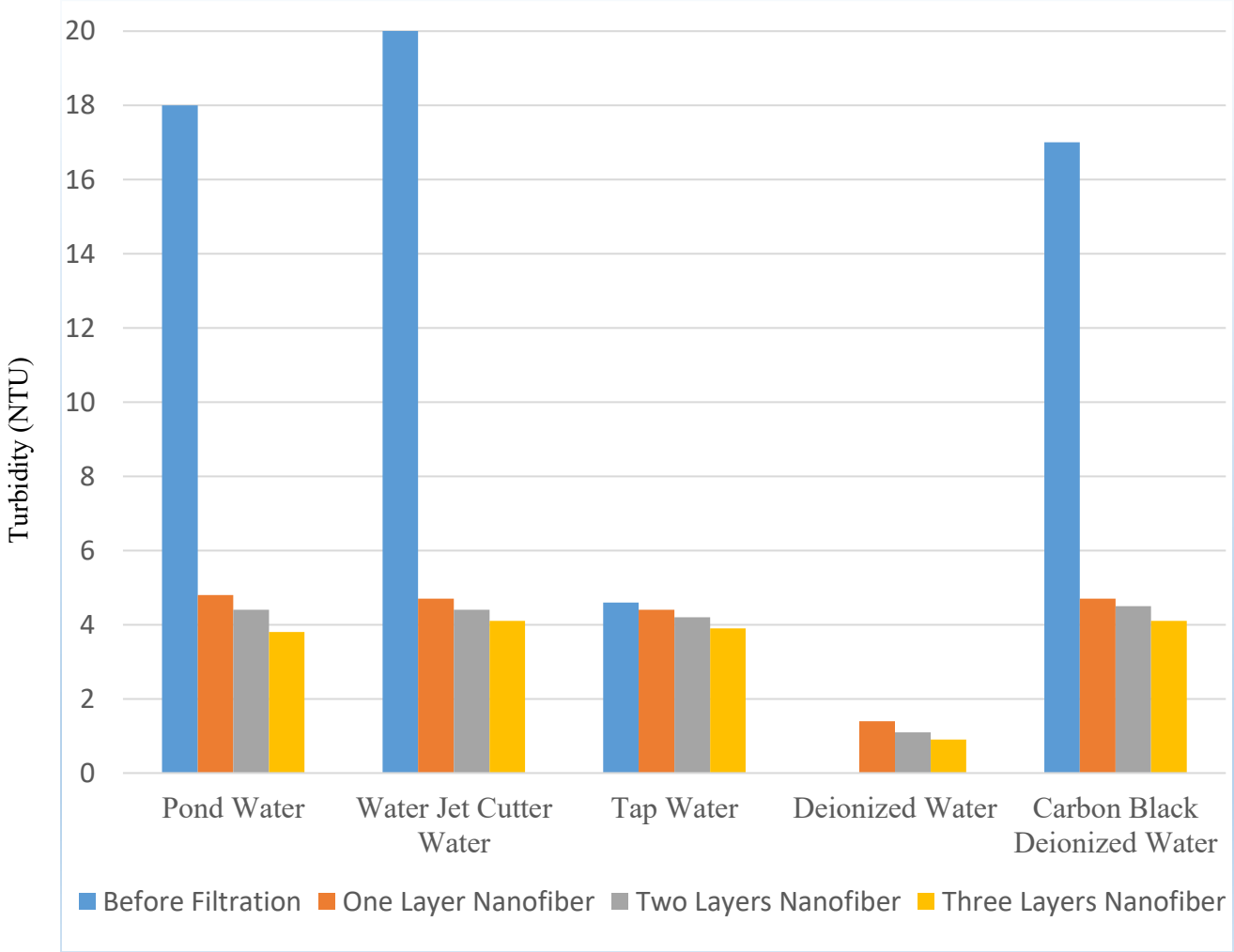


Figure 4.19. Turbidity of five different water samples before and after filtration

Figure 4.20 shows the average tubidity level using different layers of nanofiber on five different water samples: pond water, water jet cutter water, tap water, deionized water, and carbon black deionized water. Before filtration, the average turbidity was found to be 20.72 NTU, which was high for drinking purposes, but after filtration, the turbidity decreased and was found to be 4 NTU, 3.72 NTU, and 3.36 ppm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. It is clear from this graph that the decrease in average turbidity indicates that the nanofilters were able to filter the water and that the addition of nanofiber improved the water filtration.

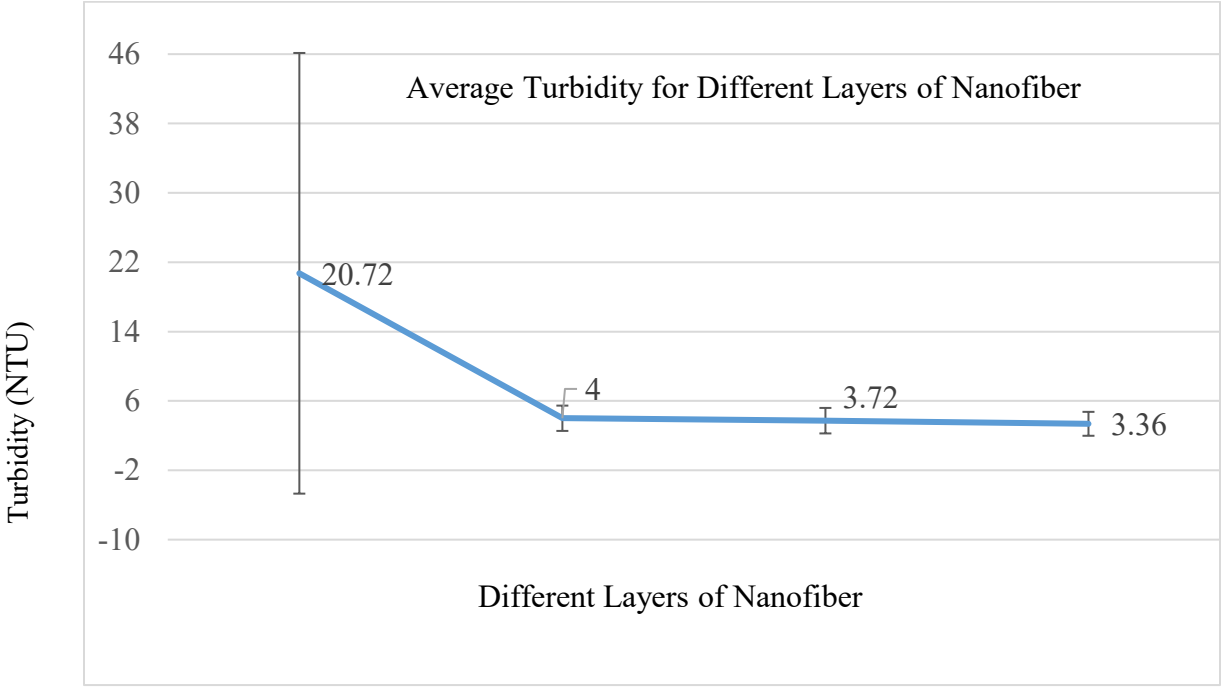


Figure 4.20. Average turbidity of five water samples for three nanofilters

### 4.5.3 Refractive Index

The refractive index is the measure of how much light can pass through a water sample. Contaminated water has many impurities; therefore, light cannot pass through it easily, and as a result of insufficient light, the refractive index of this low-quality water will be less. Figure 4.21

shows the refractive index of the five different water samples: pond water, water jet cutter water, tap water, deionzed water, and carbon black deionized water.

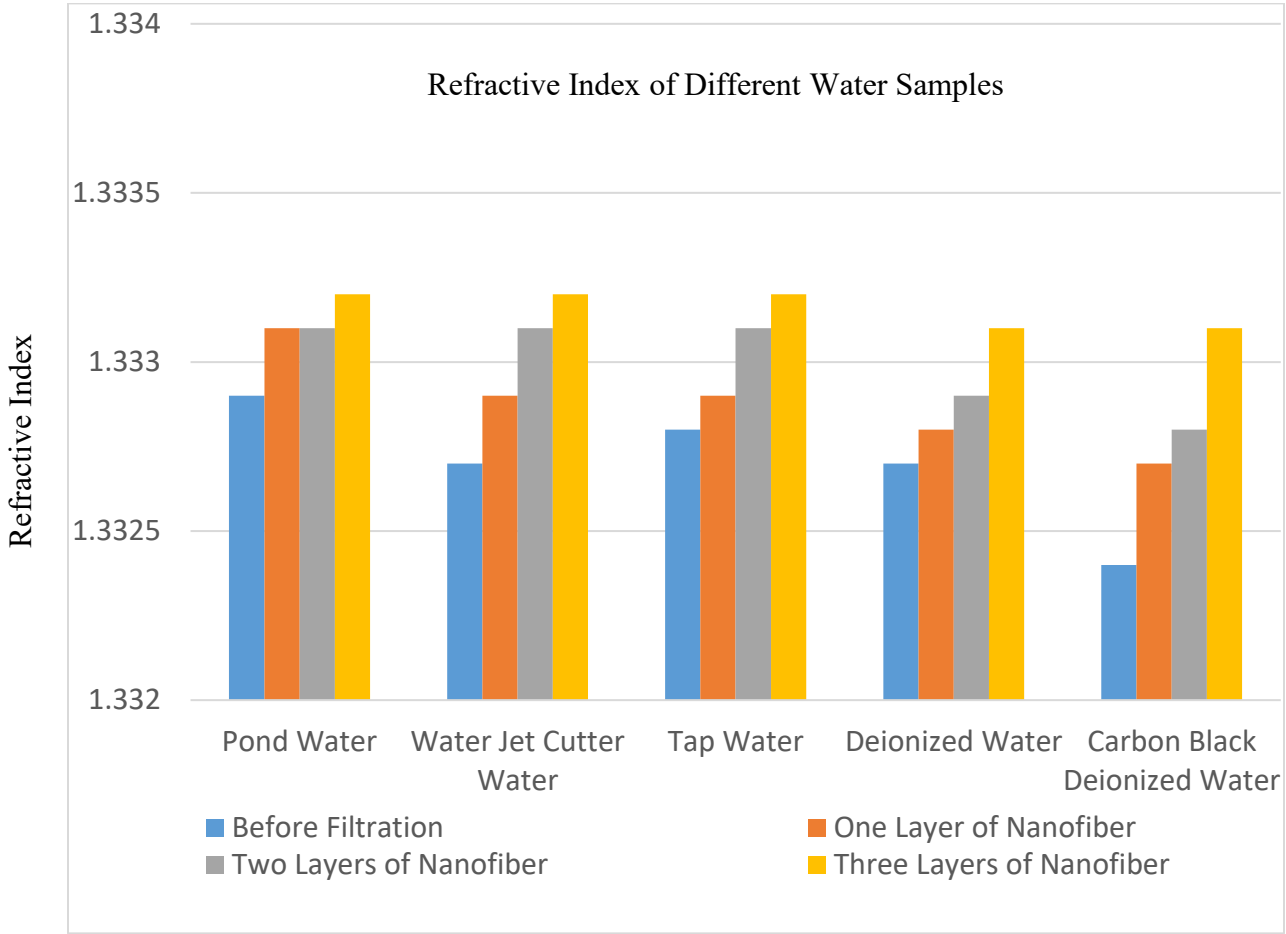


Figure 4.21. Refractive index of five different water samples before and after filtration

Before filtration, the refractive index of water was 1.3329, 1.3327, 1.3329, 1.3327, and 1.3324 for pond water, water jet cutter water, tap water, deionized water, and carbon black deionized water, respectively, all of which were low for drinking purposes. First, the different water samples were purified using one layer of nanofiber, where the refractive index increased to 1.3331 in pond water, 1.3329 NTU in water jet cutter water, and 1.3329 in tap water, which were

acceptable for drinking purposes, while the refractive index increased to 1.3328 in deionized water and 1.3327 in carbon black deionzed water, which were low for drinking purposes. Further purification was done using two layers of nanofiber and three layers of nanofiber. In the case of two layers of nanofiber, the refractive index increased to 1.3331, 1.3331, 1.3331, 1.3329, and 1.3328, for the five samples, respectively, while in the case of three layers of nanofiber, there was increase in refractive index to l.3332, 1.3332, 1.3332, 1.3331, and 1.3331, respectively. The increase in the refractive index shows the water quality improvement and clearly indicating that the nanofilters were able to filter the water. The addition of nanofiber helps to improve the water filtration.

Figure 4.22 shows the average refractive index for the three different layers of nanofiber measured for the five different water samples: pond water, water jet cutter water, tap water, deionized water, and carbon black deionized water. Before filtration, the average refractive index was found to be 1.3327, which is low for drinking purposes, and after filtration, the refractive index increased to 1.3329, 1.3330, and 1.3331 in the one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. It is clear from this graph that the increase in the average refractive index shows that the nanofilters are able to filter water and that the addition of nanofiber improved the water filtration.

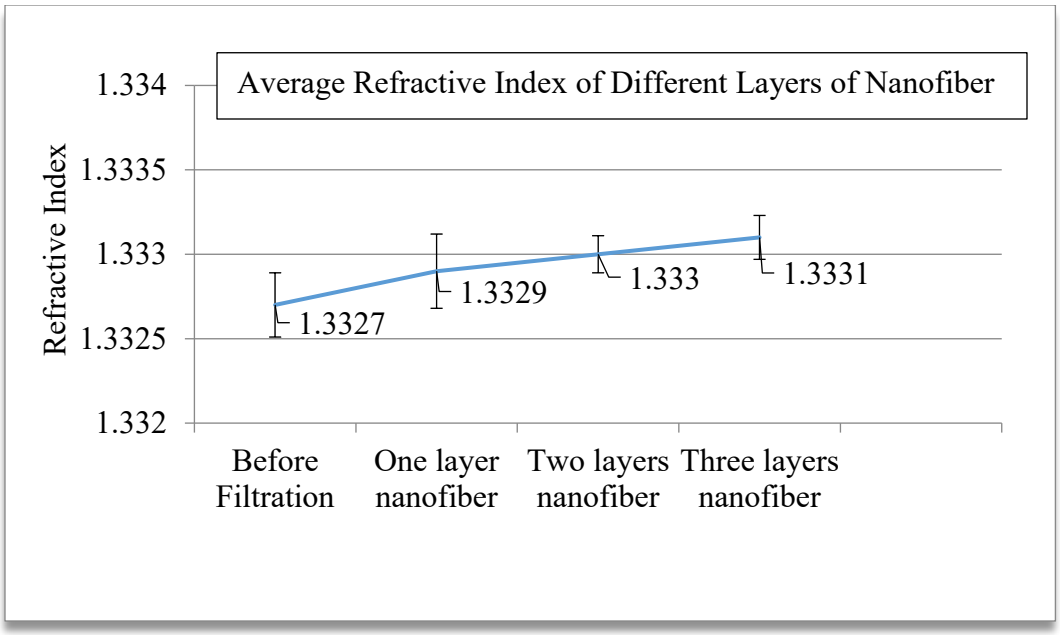


Figure 4.22. Average refractive index of five different water samples for three nanofilters

### 4.5.4 pH

The pH of Pond water, water sample from water jet cutter and tap water were high while the pH of deionized water and carbon black deionized water was low for drinking. After filtration, the pH decreased, resulting in impure water. Figure 4.23 shows the pH values of the five different water samples: pond water, water jet cutter water, tap water, deionzed water, and carbon black deionized water. Before filtration, the pH of the water was 8.7, 8.6, 8.2, 6.68, and 6.76, respectively, whereas after filtration, the pH values of pond water and water jet cutter water were values, and the pH of the deionized water and carbon black deionized water were low, which are not acceptable for drinking purposes.

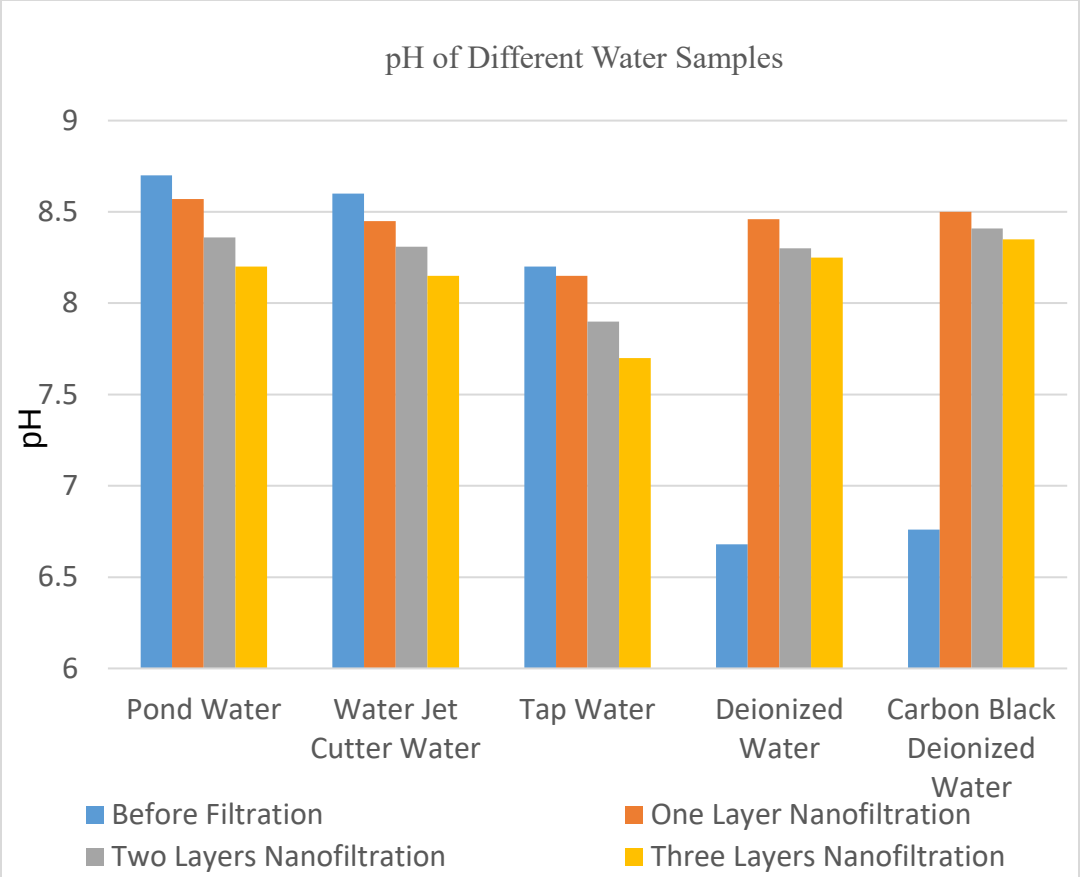


Figure 4.23. pH of five different water samples before and after filtration

First, different water samples were purified using the one-layer nanofiltration system, where the pH decreased to 8.57 for pond water, 8.45 for water jet cutter water, and 8.15 for tap water, which are acceptable for drinking purposes, while the pH increased to 8.46 for deionized water and 8.5 for carbon black deionzed water. Further purification was done using the two- and three-layer nanofiltration systems. In the case of two layers of nanofiber, the pH increased to 1.3331, 1.3331, 1.3331, 1.3329, and 1.3328, respectively, while in the case of three layers of nanofiber, the pH increased to 8.36, 8.31, 7.9, 8.3 and 8.41, respectively. This decrease in pH shows the improvement in water quality, making it clear that the nanofilters were able to filter the water and that the addition of nanofiber helps to improve the water filtration.

Figure 4.24 shows the average pH for different layers of nanofiber, which was measured among the five different water samples: pond water, water jet cutter water, tap water, deionized water, and carbon black deionized water. Before filtration, the average pH was found to be 7.79, and after filtration, the average pH increased to 8.43 in the one layer of nanofiber, and decreased to 8.26 and 8.13 in the two layers of nanofiber and three layers of nanofiber, respectively. It is clear from this graph that the decrease in average pH shows that nanofilters are able to filter water and that the addition of nanofiber improves water filtration.

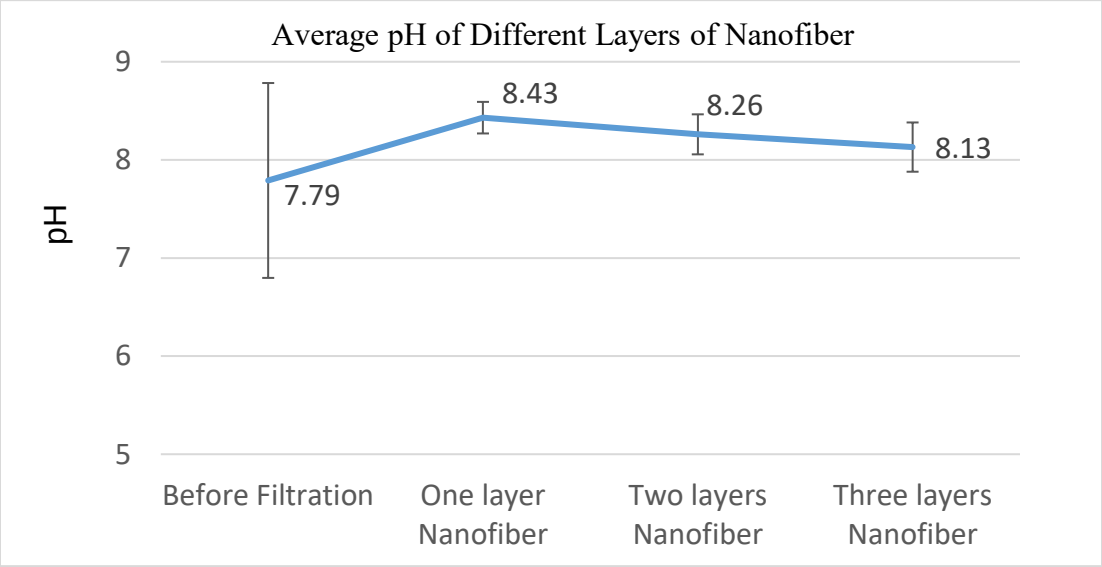


Figure 4.24. Average pH of five different water samples for three nanofilters

### 4.5.5 Electrical Conductivity

Pure water is a poor conductor of electricity. The electrical conductivity of the various water samples in this study were very high for drinking purposes. Figure 4.25 shows the EC for three waer samples—pond water, water jet cutter water, and tap water—before and after filtration. Before filtration, the EC of these samples was 1220 µs/cm, 870 µs/cm, and 734 µs/cm, respectively, which are not suitbale for drinking purposes.

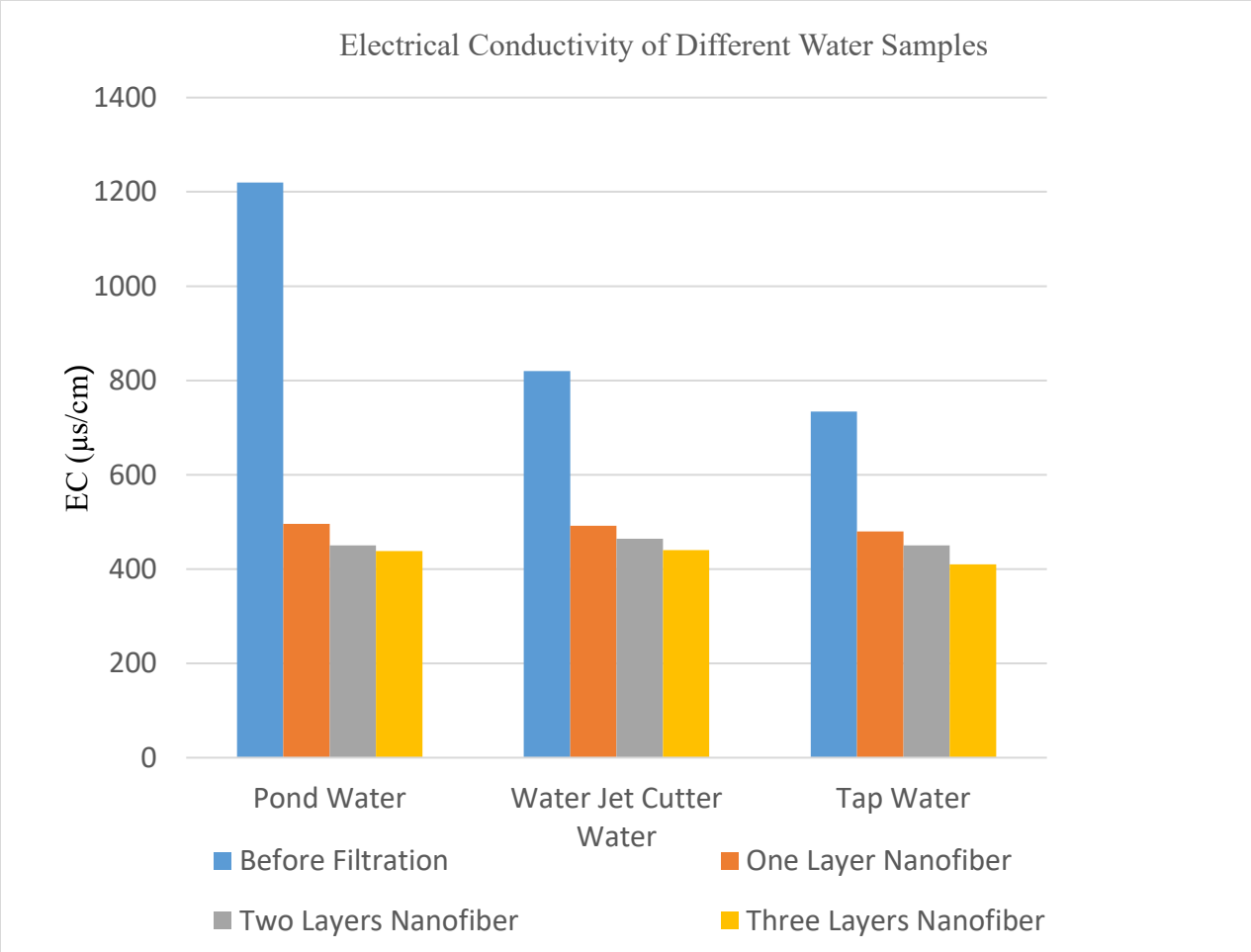


Figure 4.25. Electrical conductivity of three different water samples before and after filtration

First, different water samples were purified using the one-layer nanofiltration system, where the EC was reduced to 496 µs/cm, 492 µs/cm, and 480 µs/cm in pond water, water jet cutter water, and tap water, respectively, which are suitable for drinking purposes. Further purification was done using the two- and three-layer nanofilters. In the case of two layers of nanofiber, the EC decreased to 450 µs/cm, 464 µs/cm, and 450 µs/cm, respectively, while in the case of three layers of nanofiber, there was decrease in an eletrical conductivity to 438 µs/cm, 440 µs/cm, and 410 µs/cm, respectively. This decrease in EC in all three nanofilters shows that there was a removal of unwanted solids from the water. It is clear that the nanofilters were able to filter the water and that the addition of nanofiber helps to improve the water filtration.

Figure 4.26 shows the average electrical conductivity of three different water samples for different layers of nanofiber. Before filtration, the average EC was found to be 924.67 µs/cm, which was high for drinking purposes, and after filtration, the EC decresed to 489.33 µs/cm, 454.67 µs/cm, and 429.33 µs/cm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. It is clear from this graph that the decrease in average EC shows that the nanofilters were able to filter the water and that the addition of nanofiber improved the water filtration.

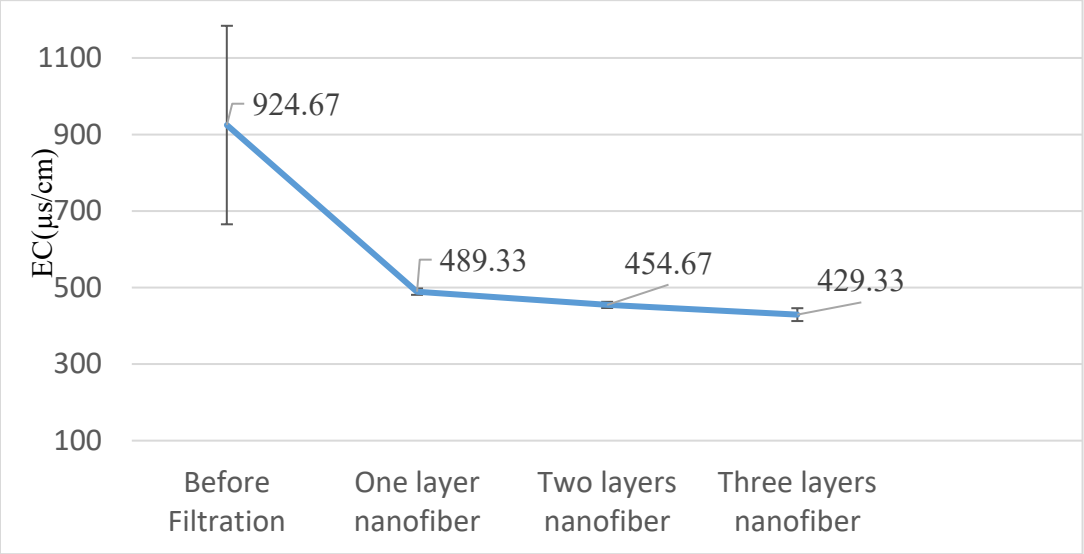


Figure 4.26. Average eletrical conductivity of three different water samples for three nanofilters

Figure 4.27 shows the electrical conductivity of the two different deionized water samples: deionized water and carbon black deionized water. Since deionized water lacks ions, its elextrical conductivty before filtration was found to be 0 µs/cm, but after filtration, the EC increased to 26 µs/cm, 32 µs/cm, and 36 µs/cm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. Carbon black deionized water before filtration had 10 µs/cm of EC, but after filtration, this increased to 30 µs/cm, 36 µs/cm, and 48 µs/cm for one layer of nanofilter, two layers of nanofilter, and three layers of nanofilter, respectively. Even after filtration, both deionized

water and carbon black deionized water had less EC, which was not sufficient for drinking purposes. Therefore, nanofiltration is not a suitable filtration method for deionized water and carbon black deionized water.

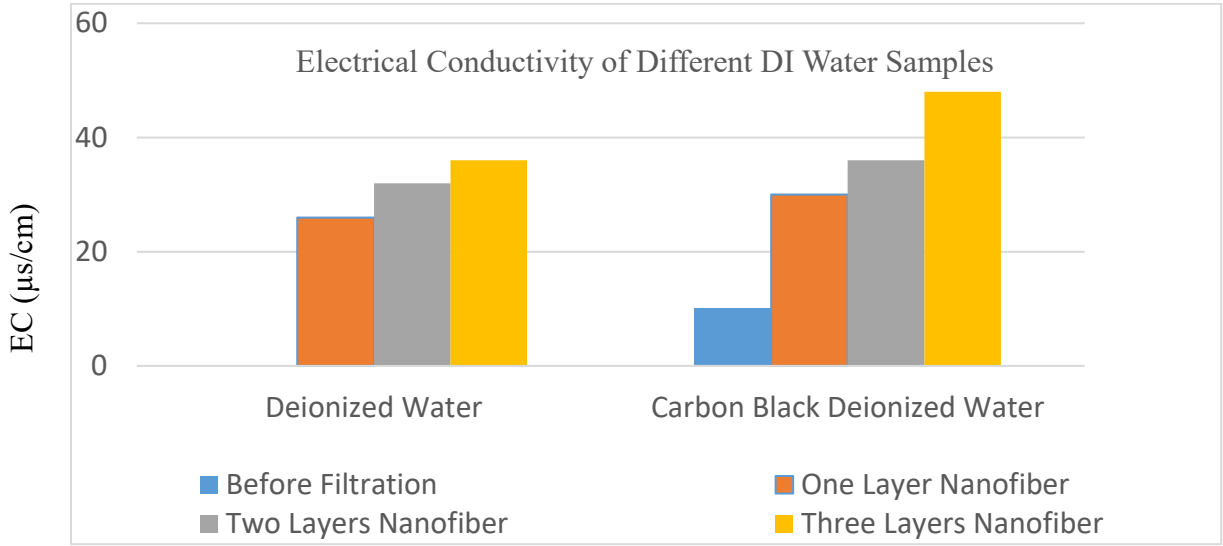


Figure 4.27. Electrical conductivity of different deionized water samples before and after filtration

Figure 4.28 shows the average electrical conductivty of the deionized water and carbon black deionized water for different layers of nanofiber. Before filtration, the average EC was found to be 5 µs/cm, which was very low for drinking purposes, and after filtration, the electrical conductivty increased to 28 µs/cm, 34 µs/cm, and 21 µs/cm for one layer of nanofiber, two layers of nanofiber, and three layers of nanofiber, respectively. Even after filtration, the nanofilters were not able to improve the EC of either of the deionzed waters. Therefore, it can be said that the nanofiltration process is not suitable for deionzed and carbon black deionzed water.

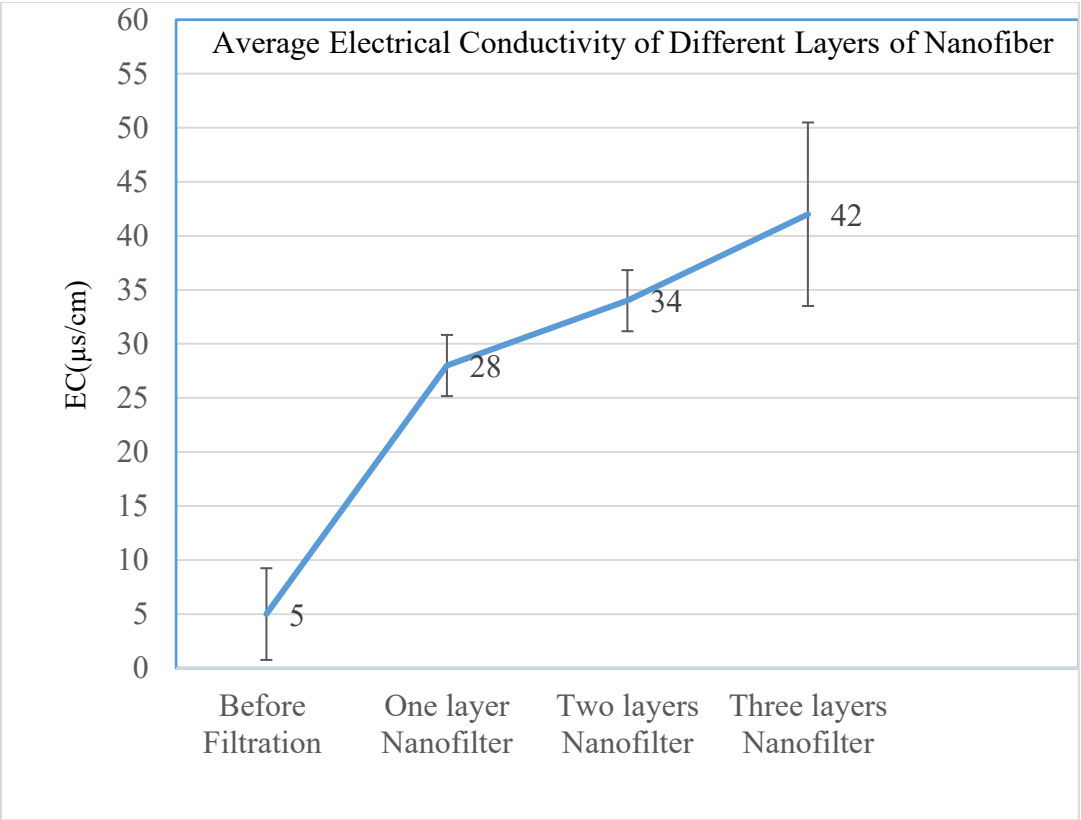


Figure 4.28. Average electrical conductivity of different deionized water samples for three nanofilters

## 4.6 Microfilter Test on Different Water Samples

Microfiltration involves the removal of suspended solids from water due to the small pore size of the filter. Unlike nanofiltration, microfilters remove unwanted particles ranging between 0.1 and 10 microns, including bacteria, but microfiltration cannot remove dissolved contaminants, unlike nanofiltration. Most portable filters employ microfilters for water filtration. Since the microfilter pore size of 0.1–10 µm is larger than the nanofilter pore size of 0.1 nm–0.001 µm, nanofiltration is preferred over microfiltration for water filtration. Figure 4.29 shows the larger-pore-size microfiber used in a microfilter, which is not as good as nanofiber. In this research, the main aim was to show that water quality was improved using a nanofilter, with a smaller poor size.

Figure 4.29. Microfiber used in microfilter

Table 4.6 shows different water parameters before and after microfiltration of different water samples. Here, the different water samples were filtered using microfilters instead of nanofilters. When pond water was filtered using a microfilter, the TDS, EC, pH, and turbidity quality decreased. Before microfiltration, the TDS was 610 ppm, but after microfiltration the TDS decreased to 390 ppm, but this was still high in comparison with nanofiltration results. Before microfiltration, the EC of pond water was 1220 µs/cm, but after microfiltration, the EC decreased to 780 µs/cm, which was still higher than the pond water filtered by a nanofilter. The turbidity and pH of pond water were 18 NTU and 8.7, respectively, before microfiltration, but following microfiltration, these values decreased to 5.2 NTU and 8.6, respectively. However, both values were still higher than pH and turbidity results after nanofiltration. It can be concluded that the use of a nanofilter is better than the use of a microfilter.

TABLE 4.6

DIFFERENT WATER PARAMETER FOR DIFFERENT WATER SAMPLES BEFORE AND AFTER MICROFILTRATION

| **Parameter** | **Pond Water** | | **Water Jet Cutter Water** | | **Tap Water** | |
|---|---|---|---|---|---|---|
| | Before Microfiltration | After Microfiltration | Before Microfiltration | After Microfiltration | Before Microfiltration | After Microfiltration |
| TDS (ppm) | 610 | 390 | 435 | 320 | 367 | 300 |
| EC | 1220 | 780 | 870 | 640 | 734 | 600 |
| Ph | 8.7 | 8.6 | 8.6 | 8.5 | 8.2 | 8.2 |
| Turbidity (NTU) | 18 | 5.2 | 64 | 6.2 | 4.6 | 4.5 |

In the case of water from the water jet cutter, the TDS, EC, pH, and turbidity were 320 ppm, 640 µs/cm, 8.5, and 6.2 NTU, respectively, after microfiltration. These water quality parameters decreased after using a microfilter; however, they were still higher than those using a nanofilter. Even in tap water, the water quality parameters decreased to 300 ppm of TDS, 600 µs/cm of EC, 8.2 of pH, and 4.5 NTU of turbidity after microfiltration. For each of these samples, the water quality improved after filtration with the help of a microfilter, but the quality of water was still better when a nanofilter was used. Therefore, it can be concluded that the nanofilter is better at filtering water than the microfilter.

# CHAPTER 5

# CONCLUSIONS

The main purpose of this research was to filter water by removing pathogens, arsenic, and other impurities by using nanofibers. Here, the application of nanofibers for water filtration was studied. The two most important requirements for water filtration are removing the bacteria and pathogens, and reducing the level of arsenic. First, nanofibers were prepared by the electrospinning process. The superhydrophilic property of nanofiber helps in water filtration. This property creates a type of surface that easily absorbs water and helps in water filtration. Nanofiber can be used for removing different contaminants such as viruses, algae, arsenic, and metal ions from the groundwater and surface water for drinking. The reuse of nanofiber is possible in water with less contaminants. However, for water with many contaminants, this is not feasible. Nanofiber can be used to lower the turbidity level of pond water, carbon black deionized water, and water jet cutter water, which can then make them acceptable for drinking. Also, nanofiber can be used to decrease the pH, TDS, and EC of both groundwater and surface water, also resulting in drinkable water.

The first stage of water nanofiltration can remove contaminants, while the second and third stages of nanofiltration will improve the quality of water**.** In many research studies, only one layer of nanofilter was used, while in this study, the number of layers used in the portable water filter was increased in order to increase the improvement of the water quality. Using only one layer of nanofiber in the filter had more impact on the nanofiber because the single-layer nanofilter does not last for multiple purposes, while using a filter with multiple layers of nanofibers not only increases the water quality, but the filter can be used repeatedly. The nanofiber was able to filter the pond water, water from the water jet cutter, and tap water, but it failed to purify the deionized water and carbon black deionized water because these two types of water lack minerals, and

nanofiber removes unwanted minerals from the water. Therefore, the reverse osmosis method is preferred for filtering carbon black deionized water because this process helps to add minerals to the water.

Many portable filters may be found on the market, which also help in improving the quality of water. Portable filters that can be bought on the market manly use a microfiltration process, which means that they cannot remove viruses, heavy chemicals, or other contaminates properly. The research here on nanofilters can greatly impact the field of water filtration because it shows that nanofiltration can remove some contaminates and pathogens from the water, thus making it safe for drinking.

# CHAPTER 6

# FUTURE WORK

The problem associated with the nanofiber in this research was about reusing the same fiber for multiple experiments, so future work could be done on improving the properties of nanofiber for using it multiple times. The research here employed polyacrylonitrile as the polymer for the nanofiber, so future work could employ other polymers than PAN.

Considerable research is being done on nanofiber and its application in water filtration. Future studies could be done as follows:

- Using different polymers and solvents.
- Using different voltage and flow rate of the polymer solution.
- Increasing the properties of nanofiber for reuse.
- Experimenting with larger-diameter and larger-length pipe in the nanofilter system.

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