Development of Nylon 6 Nanofiber Membrane for Removal of E. coli Bacteria from Drinking Water

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Abstract: **Due to increasing population, the activity of human which involved to contaminate the water also increased such as agriculture, industry, landfills, localized pollution and discharge of effluent into waterways. That's why water is contaminated with suspended particles, coliforms, toxic metals, and pesticides, which are very harmful to human health. According to the WHO organization report, about 50% people of Pakistan suffer from different diseases by using contaminated water and among 122 nations regarding water quality, Pakistan ranked on number 80. Herein, we fabricated the Nylon 6 nanofiber for efficient removal of bacteria from water. The bacterial efficiency of the Nylon 6 membrane and Ultra-fine UV filter were analyzed, resulting Bacteria removal efficiency of Nylon 6 nanofiber membrane and Ultra-fine UV filter were 99% and 82% respectively. The Nylon 6 nanofibers were characterized by SEM, FTIR, and XRD. Three different kinds of the membrane were fabricated in terms of different thickness 30, 40 and 60 micrometers. Membrane having 30 micrometer thickness is recommended due to better flow rate, economical and meet the prescribed limit of bacteria Set by WHO.**

***Keywords*: Nanofibers, Nylon 6, Water Filter, E. coli Bacteria, membrane**

I. INTRODUCTION

Electrospinning is the emerging technology for the manufacturing of the filtration membrane, by using the high electric field to spin the Polymer nanofiber with ranging from diameter 100 to 10 nanometers [1]. Charges are introduced in the polymeric solution by applying a high voltage (in Kilovolts) to the solution, as the resulting droplet is formed called the Taylor cone, and nanofiber were collected at collector in form of matt or membrane. Resultant membrane having unique property as compare to the commercial membrane, because the nanofiber membrane having a high surface to volume ratio, high porosity, smaller pore size, high degree of interconnected structure, lightweight and having good mechanical strength [3-6]. There are number of applications of nanofiber such as air filters [07], textile [08-10], sensors [11, 12], advance composite [13-15], photovoltaic cell [16], wound dressing [17, 18], scaffolds tissue engineering [19-23] and membrane for water treatment [24]. The discharge rate of water through membrane highly depends upon the morphology and properties of the membrane such as porosity, pore size, and its distribution, wettability, the pressure drops across the membrane and membrane thickness [26].

Contamination of water due to waterborne pathogens (E. coli) causes the number of diseases (i.e., diarrhea, gastrointestinal illness) [28]. According to the World Health Organization (WHO) currently, chlorination is widely used for disinfection of bacteria, despite it is an effective method to disinfection of bacteria but required an alternate easy and cheap method for disinfection of water and removal of pollutant [29]. The UV light is also used to disinfection the bacteria, this technology does not require any chemical reagents and does not form any hazardous by-product during the operation of UV light for water treatment [32]. However, its main drawback is many organisms including bacteria able to repair their damaged DNA in the presence and absence of Light [33]. This leads to a decrease in the efficiency of bacteria removal that's why water treated with UV light is unsafe due to reactivation of bacteria. Nanotechnology is a cheap, quick, free from any toxic chemical and environment-friendly green chemistry method as compare to convention technologies [30]. Convention methods are ineffective in provide adequate clean water due to increasing water demands, that's why there is a need to advance technologies to overcome this problem. Application of Nanotechnology in water treatment is best alternate to meet the shortage of freshwater [31].

In this content, we remove the bacteria from water by Physical method, in which we fabricate the Nylon 6 nanofiber membrane with different thickness by electrospinning technique. SEM, FT-IR and XRD test was required for the characterization of the membrane, and Turbidity meter and Incubation method is required for turbidity and bacterial test of water.

Experiment

Materials

Nylon-6 (weight average molecular weight of the polymer is 224.304 g/mole) which was purchased DuPont (U.S.A), Formic acid used as a solvent was purchased from Sigma Aldrich.

Electrospinning

The solution of Nylon 6 was prepared by dissolving 22% Nylon 6 polymer in formic acid, the solution kept on a magnetic stirrer for 24 hours under 300 rpm. The electrospinning process was performed at averagely 24° C and 45% relative humidity. For carrying out the process the solution was filled in plastic syringe, a tip of 0.6 mm was attached with syringe, one end of copper electrode was dipped in polymer solution, and another end of electrode connected to positive terminal of variable power supply and negative terminal was connected will aluminum foil, which was wrapped on cylinder called collector. The tip to collector distance measured was 12-15 cm and 22 kV was applied for electrospinning Nylon 6 polymer solution.

Characterization

The Morphology of the Samples was studied by using the field emission scanning electron microscope (S 4800, Hitachi Ltd. Japan) and the diameter of the nanofiber was measured through the Image J software. XRD report of the samples was carried by Riagaku RINT-2000 Diffractometer with the source of filtered CuKα Radiation with the diffraction angle of (2θ) from 10˚ to 70˚ at the scan rate of 4 degrees/min. Origin Pro 8.5 software was used to a made line graph of the XRD report and column chart of nanofiber diameter and its distribution up to 50 fibers.

Turbidity and bacterial test of water

The turbidity of water was measured through the Digital turbidity meter. the sample was taken before and after the filtrations. Surface water of the river Indus was used for a treatment purpose. initial turbidity of all sample was 50 NTU. The bacterial test of Domestic and Nylon 6 nanofiber membrane filtered water was determined by ASTM D5392-14 standard method.

Filtration process

Filtration process carried out by using ultra-fine UV light domestic water filter. which work on gravity and tape water pressure. This filter was modified by replacing UV light with Nylon 6 nanofiber membrane modified cartridge. Nylon 6 nanofiber membrane was wrapping on the commercial cartridge, then this cartridge replaced with the UV section of the domestic filter. Initially, the contaminates water passed through the first two ultra-fine cartridges of a filter to removes the turbidity and other heavy matter from water, the pore size of two cartridges was 10 and 5 micrometers respectively. Finally, the water was passed through the final or third cartridge, which was modified with the nanofiber membrane. The final cartridge removes the bacteria from water and only allows to passed bacteria-free water.

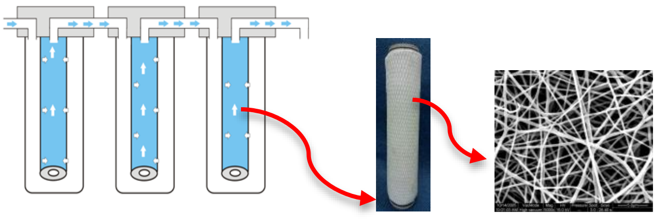

Fig: 1 show the water filtration process with Nylon 6 nanofiber membrane

II. RESULT AND DISCUSSION

Morphological of Nanofiber

The SEM image shown in figure 1 represents Nylon 6 nanofibers. It can be easily observed from the given SEM image that Nylon 6 nanofibers are regular, well oriented and free from any beads within the membrane. The nanofibers are fine, and its average diameter is 80 nanometers. The range of fiber diameter within the membrane is 75 to 300 nanometers, however, the fibers in larger diameter found in the membrane are very rare within the membrane. The maximum fibers within the membrane range 75 to 100 nanometers, that's why the size of membrane pores is in nanometers which are smaller than the bacteria size.

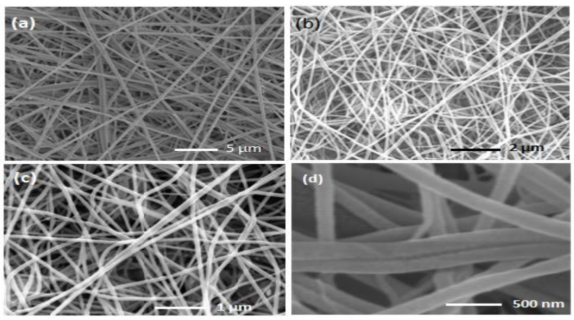

Fig 2: Show the SEM image of Nylon 6 nanofiber membrane at different magnified.
SEM image: (a) nanofiber at 5 μm, (b) nanofiber at 2 μm, (c) nanofiber at 1 at μm, (d) nanofiber at 500 nm

FT-IR

Different bonding in Nylon 6 polymer is characterized by the FT-IR spectra. due to different chemical bonding in the Nylon 6 polymer backbone, all three types of seconding bonding exist including Hydrogen bonding, Dipole-Dipole force, and London forces, that's it is strong and hydrophilic. Hydrogen-bonded NH stretching occurs at 3300 cm^{-1}, band at 3086 cm^{-1} is assigned to the NH Fermi resonance. The stretching of CH2 asymmetric and Symmetric occur at 2931cm^{-1} and 2859 cm^{-1} respectively. The Stretching of Amide I and Amide II occur at the bands of 1645 cm^{-1} and 1544 cm^{-1}respectively.

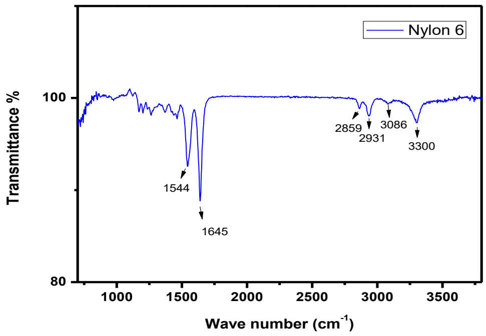

Fig.3 show the IR spectra od Pristine Nylon 6.

XRD report of pure Nylon 6

It was observed that a sharp peak ensures that material is crystalline. The narrow peak of pristine nylon 6 is achieved at 2θ=22. This narrow and highest peak occurs at the intensity of 1240 a.u. The maximum crystallinity occurs in the range 15 to 35 degrees at the 2θ. The intensity of the peaks afterward 35-degree decreases as the angle (degree) increase. The crystalline structure of nylon 6 plays a very important role in their strength that's why nylon 6 nanofiber can withstand the pressure of water.

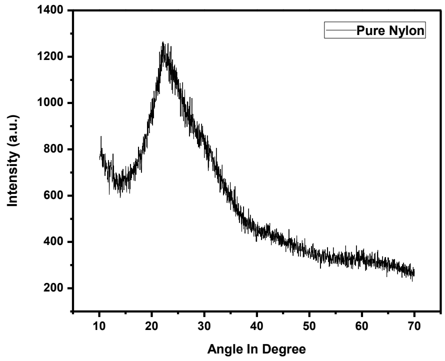

Fig.4 show the XRD report of pristine of Nylon 6 nanofibers.

Turbidity and bacterial removal result

We manufactured three kinds of Nylon 6 membranes in terms of different thickness including 30, 40 and 60 micrometers. The bacterial removal efficiency of the membrane was increased as the thickness of membrane increased. However, the maximum limit of turbidity in water is 5, which is prescribed by the WHO. The membrane having 30-micron thickness is enough to meet the WHO turbidity limit. The turbidity removal of ultra-filtration with UV light installed is more than the limit, which is prescribed by WHO. The bacterial removal efficiency of three membranes the same while the removal efficiency of Ultra-filtration with UV light is 80%, which is lower than the nanofiber membrane. By analyzing three different thicknesses and Ultra-filtration with UV, the membrane having a 30-micron thickness for efficient removal of turbidity and bacteria.

Table.1: show the turbidity of water in NTU after and before filtrations, treaded with different thickness.

Thickness of Membrane (microns)	Turbidity before Filtration (NTU)	Turbidity After Filtration (NTU)	Bacterial removal Efficiency (%)
30	50	5	99
40	50	5	99
60	50	4	99
Ultra-Filtration with UV light	50	7	80

III. CONCLUSION

Application of Nylon 6 Membrane is very promising in water treatment applications, due to excellent morphology, chemical resistance and bear high pressure of water. The turbidity and bacterial removal efficiency of the Nylon 6 nanofiber membrane are more than the Domestic water filter (ultra-filter with UV light installed). The turbidity of water after filtered by the Nylon 6 membrane is under the prescribed limit of WHO. However, this is not in case of Domestic filters. The bacterial removal efficiency of the Nylon 6 membrane is more than 99% which is higher than domestic filters. Among three different thickness Nylon 6 membrane, having 30 micrometers is more suitable due to economical as well as meet the prescribed limit of WHO.

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