

WATER TREATMENT PERFORMANCE: APPLICATION OF ELECTROSPUN NANOFIBERS

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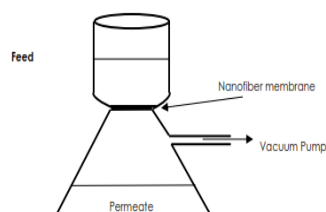
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Graphical abstract



Abstract

The aim of this study was to evaluate the use of nanofiber microfiltration membranes, spun by an innovative electrospinning technique, in water filtration applications. This study bridges between developments in electrospinning techniques for the production of flat sheet membranes and the application of these membranes in water filtration. The functionalized or non-functionalized for the removal of pathogens was investigated, in term of culture mechanism of bacteria spot in the waste water. Physical properties such as clean water permeability (CWP) and strength were also examined. The test showed that the electrospun membranes can be used for water filtration applications.

Keywords: Electrospinning, nanofiber, microfiltration, pathogen removal

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1.0 INTRODUCTION

The research and development of nanofibers have gained much interest in recent years due to the heightened awareness of its potential in medical and engineering applications. A number of processing techniques such as drawing, template synthesis, phase separation, self-assembly and electrospinning have been used to prepare polymer nanofibers in recent years. Among the most successful methods for producing nanofibers is the electrospinning process [1]. Electrospinning is a process that produces continuous ultrafine polymer fibers through the action of an external electric field imposed on a polymer solution or melt. Recently, polymer nanofibers have been attractive materials for a wide range of application because of their large surface area to volume ratio and

the unique nanometer scale architecture built by them (Figure 1). One of the possible applications of the nanofibers is water filtration. For this application a nanofiber flat sheet membrane can be produced that can be used as water filtration membrane. More specifically, this can be used in microfiltration. Nanofibers due to their higher porosities and interconnected pore structures offer a higher permeability to water filtration over conventional materials being used [2].

Microfiltration membranes have pore sizes between 0.1 and 10 μm and pressure (TMP) between 0.01 and 0.2 bar is used. With these membranes it is possible to retain suspended solids and depending on the pore size even microorganisms such as bacteria, yeast and fungi. Earlier studies have indicated that in case of a 0.45 μm pore size a log 2–log 4 bacteria reduction

could be obtained [3,4]. As the membrane, which is subject of this study, has a nominal pore size of 0.2 to 0.4 μm it seems very interesting to evaluate its bacteria removal capacity. Further, the added value of silver functionalized membranes to pathogen removal was studied. These tests were performed in a flow through system as few studies have been carried out so far to test the filtration performance and disinfection efficiency of the silver impregnated nanofiber membranes [2]. In this research, the fouling characteristics and physical properties such as strength

and thickness are very important parameters. These parameters are also the subjects of this study.

This study aims at assessing the possible use of electrospun nanofibers membrane in water filtration in two different areas: first, membranes for pathogen removal, to be applied as a membrane for antibacterial; and second, strength functional membranes; to be applied as stand-alone microfiltration unit.

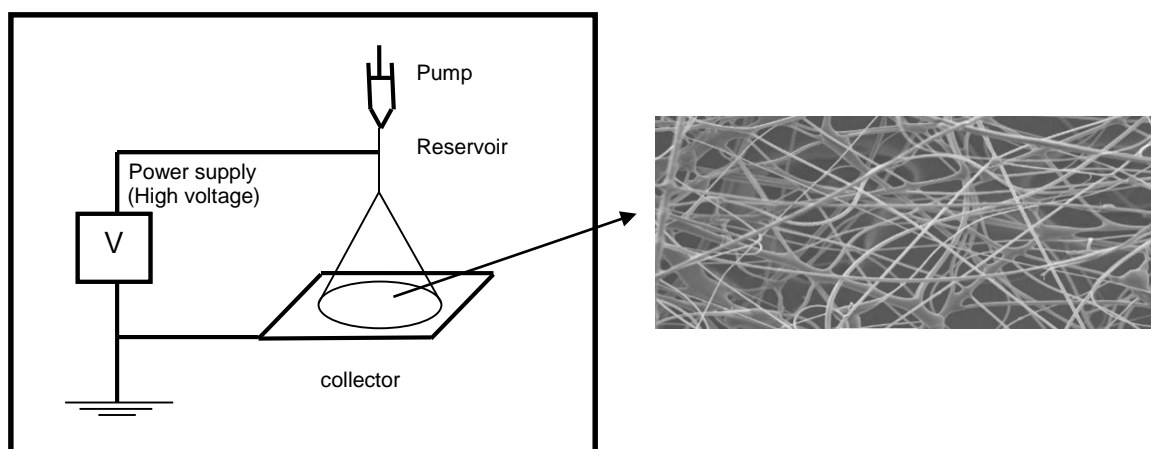


Figure 1 Electrospinning principle and resulting of nanofibre mat (SEM picture)

2.0 EXPERIMENTAL

2.1 Materials and Dope Preparation

Polyacrylonitrile (PAN) powder, Polyethersulfone (PES) powder and Polyvinylidene fluoride (PVDF) powder, N, N-dimethylformamide (DMF) and acrylamide (AM) were obtained from Aldrich Chemicals and were used without further purification. Dope solutions were prepared by dispersing predetermined amount of silica nanoparticles (1 wt.% to solution) and silver nanoparticles (1 wt.% to solution) into 18 wt.% solution (PAN/ PES/PVDF) in DMF. The mixture was mechanically stirred for at least 24 h at 60 °C in order to obtain homogeneous dispersed solutions [5].

2.2 Membrane Production Process

For the preparation of nanofibers mat, a 100 mL reservoir was used to hold the electrospinning solution. The experimental set-up to electrospin nanofibers is shown schematically in Figure 1, together with the picture of nanofibers mat. The solutions prepared were pumped at a constant rate of 2 mL/h with the help of a metering pump through a stainless steel needle of inner diameter 0.8 mm. A drum of 15 cm diameter, connected to a variable speed motor, was used to collect the nanofibers. A high DC voltage was applied to the needle with the help of high voltage regulated DC power supply (Model ES 30P-5W, Gamma High

Voltage Research, Ormond Beach, FL, USA). The applied voltage was set at 21 kV and distance between the tip of the needle and the surface of the drum at 10 cm. The collecting drum was grounded so as to generate the desirable electric field strength between the tip of the spinneret and the collector surface. Polyacrylonitrile (PAN), Polyethersulfone (PES) and Polyvinylidene fluoride (PVDF), supplied by Sigma-Aldrich, proved to be suitable for electrospinning because they can be electrospun under steady state conditions. This production process resulted in a flat sheet non-woven nanofiber membrane with a mean pore size of 0.4 μm (as measured with a bubble point test [6]), a fiber diameter between 50 and 100 nm and a thickness of 120 μm . The nanofibrous mat was carefully removed from the collector, and the residual solvent associated with the nanofiber mat was removed by keeping the mat in an oven for at least 2 days at 40 °C. The dried electrospun mats were stored in desiccators.

2.3 Removal of Pathogens

2.3.1 Culture Mechanism of Bacterial Spot

To evaluate the removal of pathogens by filtration, different water samples were taken, namely, wastewater from a general hospital (Palembang), water from a local pond (Inderalaya Pond) and water from local river (Inderalaya). Compositions of the water

are summarized in Table 1. Before filtered by using nanofibers mats, the sample water has checked for the content of e. coli. The cultural microorganisms were identified by inoculation in nutrient agar (NA) culture medium. The water samples were added by swapping method into nutrient agar medium in petri dish. Then,

the samples were left for 24 h at room temperature. After leaving, the bacteria spots were identified in the nutrient agar medium of all three water samples. The water samples were then filtered by nanofibers membrane by the filtration system illustrated in Figure. 2.

Table 1 Composition of wastewater

| Constituent, unit | Influent (hospital) (a) | Influent (pond) (b) | Influent (river) (c) | National primary discharged standard (P.U. (A) 434, Standard B, Desember 10, 2009) |
|-------------------|-------------------------|---------------------|----------------------|--|
| E. coli, spot/l | 3 | 8 | 6 | 0 |

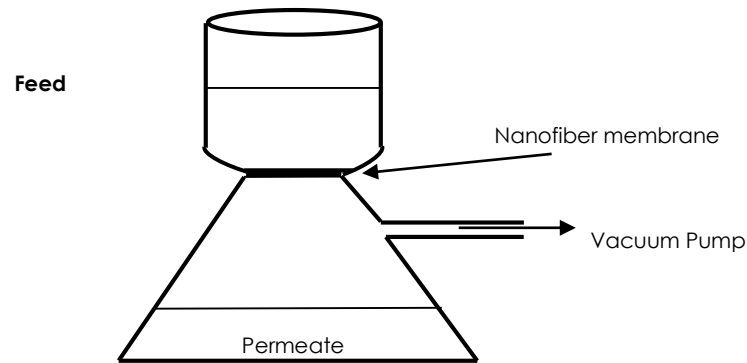


Figure 2 Filtration system illustrated

2.3.2 Antibacterial Activity

The technique was adopted from Zodrow *et al.* by using vacuum filtration cell [13]. The membrane used in the filtration was put in medium to investigate the inhibition of bacteria growth at 37 °C for 24 h. Considering the membranes were sterilized before filtration, the growth of E. coli must come from the filtration process.

2.4 Evaluation of the Physical Characteristics

2.4.1 Clean Water Permeability

Clean water permeability (CWP) with used the water permeation system represents the maximum flux achievable dependent on the state of the membrane. It can be determined by measuring the flux at different trans membrane pressures (TMP). The slope of the resulting curve is considered as the CWP [6]. The CWP test was performed at 25 °C.

2.4.2 Tensile Strength Test

A tension testing machine ((LRx2.5 KN LLYOD Instrument with a load cell of 1 N, accordance with ASTM D 3379) was used to examine the tensile strength of the nanofiber membrane. A specific test strip (5 cm) was stretched at a pulling speed of 50 mm/min until rupture. This resulted in the maximum tensile strain. The tensile strength test was performed at ambient temperature. Tensile stress was calculated as follow: $\sigma = P/A$, where P is the maximum load and A is the cross-sectional area.

3.0 RESULTS AND DISCUSSION

3.1 Removal of Pathogens

3.1.1 Culture Mechanism of Bacteria Spot

Figure 3 illustrates the amount of bacteria spot in the water samples. The water sample has the largest bacteria number of spots among all water samples. Hence, pond water was used for the ring-test.

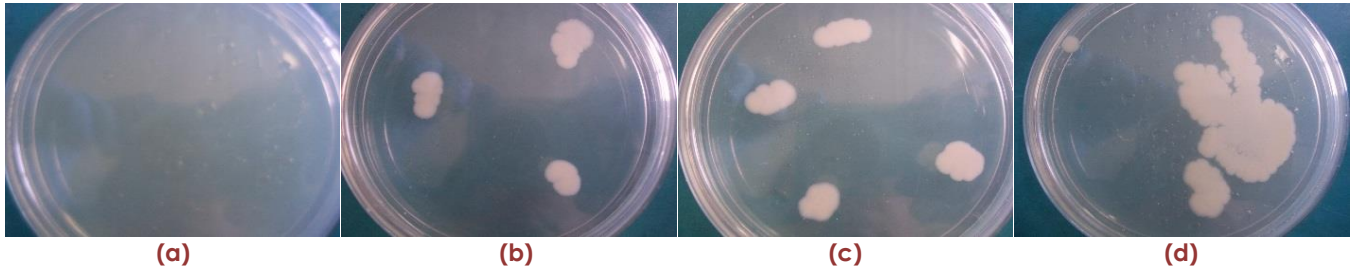


Figure 3 Illustration of nanofiber membrane filtration set up for stand-alone application Content of *E.coli*; (a) control *E. coli* (b) water from hospital (c) water from river (d) water from pond

3.1.2 Antibacterial Activity

The results of the antibacterial activity are shown in Figure 4. Each membrane displayed the large inhibition ring (diameter increment around 8%). Silver is believed to act as an antibacterial agent either upon contact to the bacteria or as released ion in the media [10]. For silver ion, as studied by Kumar and Munstedt, the release system is controlled by the rate of water diffusion in the composite [11]. As for silver particles, the ability to inhibit bacterial activity is depending on the particle size which corresponds to surface-to-volume

ratio in which the smaller particle with larger surface area will lead to more bactericidal effect [12].

The results of antibacterial activity shown in Figure 4 are in agreement with the results reported by Kumar and Munstedt and Basri *et al.* in which silver containing polymer (PES, PAN and PVDF) exhibited better antibacterial activity due to content of silver ion released from the system. Thus we could conclude that the silver nanoparticles had a good retention on the membrane, indicating the successful application of the silver nanoparticles on the nanofiber membrane.

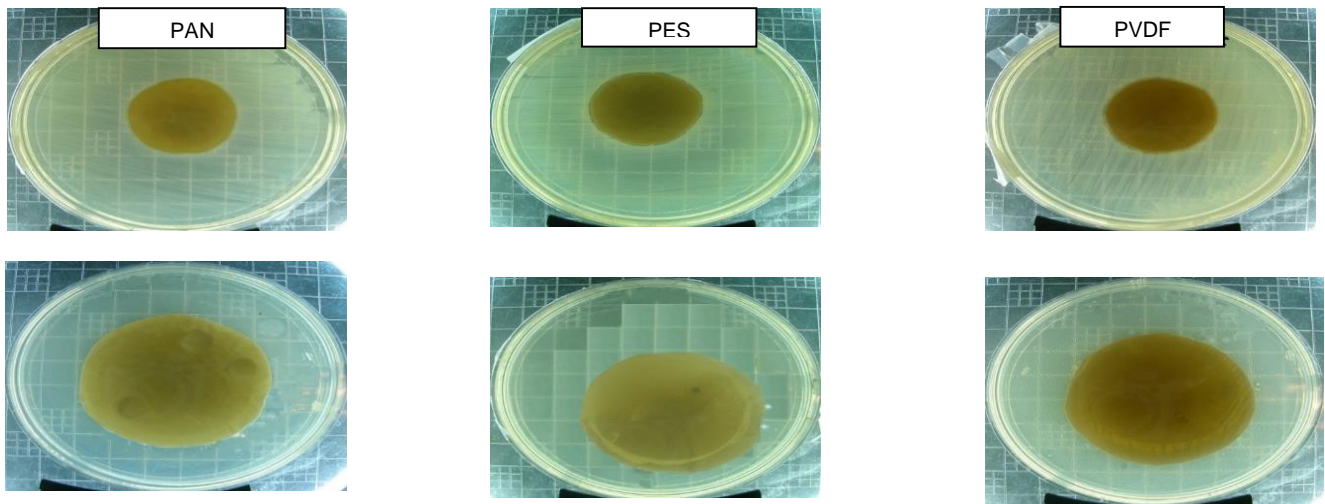


Figure 4 Antibacterial activity

3.2 Physical Characteristics of the Nanofiber Membrane

3.2.1 Clean Water Permeability (CWP)

The CWP are given in Table 2 for different nanofiber membranes. The values are high enough to treat large volumes of water in absence of particles that could obstruct the nanofiber membrane. Further this high CWP indicates that nanofiber membranes could be energy saving [14].

Table 2 Comparison of CWP-value

| Membrane type | CWP (l/m ² .h.bar) |
|-------------------------|-------------------------------|
| Polyethyl Sulfone | 2134 |
| Polyacrylonitrile | 1982 |
| Polyvinylidene fluoride | 2001 |

3.2.2 Tensile Strength Test

The results showed that the strength of the membrane was independent of the direction in dry condition. Also it could be concluded that in wet condition of the

membrane, it is stronger lengthwise. The results of all nanofibers are listed in Table 3. These values show that the strength of nanofibres membranes is satisfying [7]. Meanwhile, PAN membranes were more brittle than PES and PVDF membranes and difficult to install in the water permeation system.

Table 3 The tensile strength of PES, PAN and PVDF

| Membrane type | Tensile test (KPa) |
|-------------------------|--------------------|
| Polyethyl Sulfone | 986 |
| Polyacrylonitrile | 1065 |
| Polyvinylidene fluoride | 902 |

4.0 CONCLUSION

The nanofiber membrane was tested in a stand-alone application wastewater. The challenge with this waste water treatment was to removal unuseful organic in the water. The following results were obtained when The Clean Water Permeability (CWP) gave an idea of the fouling on the membrane. The values showed a very high CWP-value this could be useful to treat large volumes of water in absence of particles that could obstruct the nanofiber membrane. Further this high CWP indicates that nanofiber membranes could be energy saving.

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