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Research Article

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Improving Water Flux Using Agave Reinforcement in Polymeric Membranes

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Abstract

When it comes to water on earth, the phrase “Water, water, everywhere” is true. Only 3% of the water available on earth’s surface is potable. Climate change, global warming, and the increase in population are reducing freshwater availability day by day. Desalination and filtration can be improved to reduce these challenges. Every human being has a fundamental right to get clean water. The creation of low-cost water filtering methods can accomplish this. In contrast to commonly utilised membranes made of carbon nanotubes, low-cost membranes created in this work have improved water permeability. The polysulfone (PSF) base material, N-Methyl-2 Pyrrolidone (NMP) solvent, polyvinyl pyrrolidone (PVP) pore former, and a few additional powders were used to create the composite membranes. The key factor in water filtration using membrane technology is the membrane’s pore size. Mango leaves, date palm leaves, maize fibers, coconut coir, and coconut coir ash have all been employed as naturally occurring fibers in membranes. A medicinal plant called agave was used as an adjuvant in this experiment. Three dope solutions were created, containing 0.05%, 0.1%, and 0.15% weight of agave powders. These amounts were proportional to the total volume of the dope solution. At room temperature and a pressure of 2 bar, the membrane’s water permeability was examined. The membrane with the highest water permeability contained 0.15 wt.% of additive powder. This membrane had a water permeability of 743.38 LMH. To assess the pore size, scanning electron microscopy (SEM) was employed. The study demonstrates the potential of low-cost composite membranes with enhanced water permeability, offering promising prospects for more efficient and affordable water filtration methods to alleviate the escalating global water crisis.

Keywords

Composite membrane, Scanning electron microscopy, Natural material, Water permeability, Pore size

Introduction

Water scarcity is increasing all around the globe. People are struggling for the quantity as well as the good quality of water in the water stresses regions. A survey has shown that, around the globe women and children spend around 200 million hours per day collecting water for their families [1]. Around 71% of earth’s surface is covered with the water, but only 3% of it is water that can be consumed by human and animals. Most of the water available is saline water which cannot be used directly for household or agricultural use. This problem can be solved by using modern, scalable, and affordable filtration and desalination techniques. Membrane technology can be used for different characteristic separation processes. The popularity of membrane technology is increasing as it consumes less energy. The challenges with membrane technology are the cost of additive materials used and the membrane fouling associated with it. This leads to an increase in the cost of final filtration system. This problem can be tackled by using naturally occurring materials like coconut coir, bagasse, and dried leaves. Using natural materials for membrane synthesis reduces the cost of membrane drastically (Figure 1).

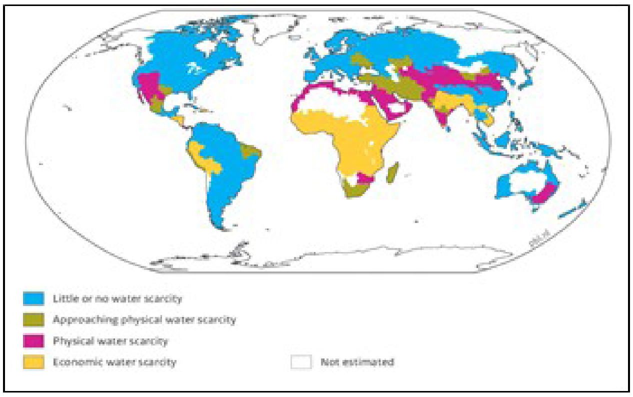

Figure 1: Water scarcity around the globe [2].

Literature review

Literature review of last 10 years has been done. It was found that, many researchers have used polymeric membranes for the filtration process. Some of them have used nano particles such as Carbon nanotubes (CNTs) and some metal oxides as an additive in the polymeric membrane. Water permeability is the significant parameter considered to check the performance of a polymeric membrane.

The synthesis and characterization of PSF based membranes were done by many researchers. In one such work nanoparticles of multi-walled CNTs and iron oxide coated with oleic acid were saturated on the polymeric host matrix. To check the performance of membranes some of the parameters observed were water permeability of the membrane and the amount of solute rejected. It was seen that the permeability of the PSF membrane increased three times at a 0.1% loading of multi-walled CNTs. The selectivity of rejections is also not compromised. The membrane microstructure was studied with the help of Small Angle Neutron Scattering and it was observed that pore size and water permeability have quite a good relationship [3].

Another work that was carried out to study opportunities for membrane technologies, revolution and development in membrane materials reported the highest quantity of wastewater is generated in oil and gas industries and this can be recycled. The recycled water quality depends on the membrane process used, such as microfiltration, ultrafiltration, and nanofiltration. These processes can be used as a single filtration process, or it can be combined with other processes to get enhanced results. It is seen that, the hybrid integration of processes has been capable of removing considerable number of suspended particles, macromolecules, and oil in pre-treatment itself. Membrane fouling is the biggest challenge in membrane processes. As the life of membrane improves the cost of capital and cost of operation reduces. It has been seen that the membrane modification is the best option to reduce membrane fouling. Chemical structure and morphology of membrane affects the membrane fouling. Low fouling of membrane is seen for the membranes having high hydrophilicity, high surface smoothness and negative surface charge [4].

Another study done by using PSF as a base polymer and NMP as a solvent with different molecular weights of PVP added studied the morphology and water permeability of PSF membranes. Field emission scanning electron microscope and atomic force microscopy were used to analyze the surface structure and morphology of membranes. The number of pores, size of pore, and pore area for all the membranes were calculated with the method of liquid displacement porosimetry. The compaction factor and water flux were calculated for all the membranes. Results have shown that, there was a strong inter relationship of parameters of morphology and the flux performance of the membranes with the molecular weight of PVP. As the molecular weight of PVP increases at the constant molecular weight of polyacrylic acid, the number of pore and pore area increases. All the resulting parameters were compared and concluded with the fact that addition of small amount of polyacrylic acid in PSF/PVP/NMP casting solution can be better than addition of PVP alone. The water permeability increased from 44.4 LMH to 76.6 LMH for plain and 4 wt.% copolymer containing PSF membrane, respectively. Similarly, contact angle of water was also found to be reduced from 76.25° to 61.65°.

Amino alcohol plasticizers were used to develop polysulfonic membranes with improved hydrophilicity. The reaction between polyethylene glycol and isatoic anhydride gives rise to amino alcohol plasticizers. Different molecular weight of polyethylene glycol and isatoic anhydride (molecular weight 163 Da) had been used for preparing the amino alcohol plasticizers. Asymmetric membranes were fabricated by blending these plasticizers in membrane casting solution. Formation of amino alcohol plasticizer was confirmed by Fourier transform infrared and nuclear magnetic resonance spectra of amino alcohol plasticizer. Characterization of membranes was done in terms of hydraulic permeability and hydrophilicity. The water permeability was found to be increased from 29.3 LMH to 110.1 LMH [5].

Different membrane operations can be utilized for water treatment and reuse such as membrane bioreactor, forward osmosis, and membrane distillation. Forward osmosis can also be combined with membrane distillation for re-concentrating the draw solution and producing freshwater. Biofouling can be minimized by implementing quorum quenching [6].

Another work carried out to study metal organic frameworks (MOFs)-boosted filtration membrane technology has reported the parameters like water permeability, membrane fouling and selectivity for the particles rejected to check the performance of such membranes. In the study researchers found that MOF mediated membranes had high water permeability, antifouling properties, and also the membranes were adsorptive in nature. The MOF membranes had high control on the pore size. It was suggested that for practical applications the MOF powders should be integrated with polymeric filtration membranes [7].

Developments and challenges for reverse osmosis membrane technology were reported in a research work wherein the working of the reverse osmosis plant inclusive of the pre- and post-treatment procedures had been studied. It was found that the use of functional materials like vertically aligned CNTs, aquaporins, lyotropic liquid crystals had enabled the highest permeation rates achieved to date. Membrane configuration was found to play a vital role. The integration of reverse osmosis with ultrafiltration and microfiltration increased the productivity [8].

Hydrate gel membrane technology for filtration of mine tailings had been reported. The study was carried out to collect and filtrate the water obtained from the mine tailing. The parameters observed were filtration rate, turbidity of the liquid, residue thickness and the moisture content of final residue. This filtration performance was compared with the other techniques used to filter the same water. It was found that the turbidity of water after filtration by gel membrane technology was much lower than the other techniques used. The amount of water flux was little lower than the amount of water filtered by other methods. The pressure required for the filtration process was very less sometimes no pressure was required [9].

A novel sulfonated polyether ketone polymer with high hydrophilic nature prepared as a thin film composite membrane gave high performance. This material was specially designed to enhance the performance of the membrane for desalination with forward osmosis. M-Phenylenediamine and 1,3,5-trimesoyl chloride were used as the monomers. The reaction of interfacial polymerization caused the formation a layer of a thin aromatic polyamide. It was observed that the blending of sulfonated polyether ketone in the PSF gives rise to fully sponge like structure with higher hydrophilicity. The thin film composite membrane used in forward osmosis had 50% weight of sulfonated polyether ketone had given highest permeability of water i.e., 50 LMH against deionized water. It had shown water flux as 22 LMH against 3.5 wt.% sodium chloride model solution [10].

Methodology

The membrane material varies according to the applications. There are various characteristic processes available which can be performed by using membrane technology, such as ultrafiltration, microfiltration, and reverse osmosis. Selection of processes depends on the size of particles to be removed. The pore size of membrane is responsible for the removal of unwanted particles. Reverse osmosis and nanofiltration can be considered as a borderline case between the porous and non-porous dense membranes. The membrane material should have good thermal, chemical, and mechanical properties. The most widely used membrane materials are hydrophilic materials. The adsorption capacity of hydrophilic materials is less; hence the chances of membrane fouling reduce. There are few steps followed for the preparation of composite membrane. It includes preparation of fine powders of additive materials, formation of dopes followed by casting of membrane.

Agave powder preparation

450 g of agave fibers were collected and dried at 70 °C for a month, in an oven. The powder was prepared by grinding and sieving of the dried agave leaves (Figure 2).

Figure 2: Agave fibers and their fine powders.

Dope solution for composite membrane

NMP was used as a solvent to prepare the dope solution. The amount added was 37.35 ml i.e., the 75% weight of the entire dope solution. The quantity of additives taken was 0.025 g, 0.05 g, and 0.075 g of powders i.e., 0.05 wt.%, 0.1 wt.%, and 0.15 wt.%, respectively, and added it to NMP solution. The solution was sonicated for 15 min to ensure dispersion and dissolution. 3.6 g of PVP and 9 g of PSF beads were added in the sonicated solution. Screw capped bottles were kept in a shaker for 5 days until all the polymer beads got dissolved and a homogeneous solution was obtained (Figure 3).

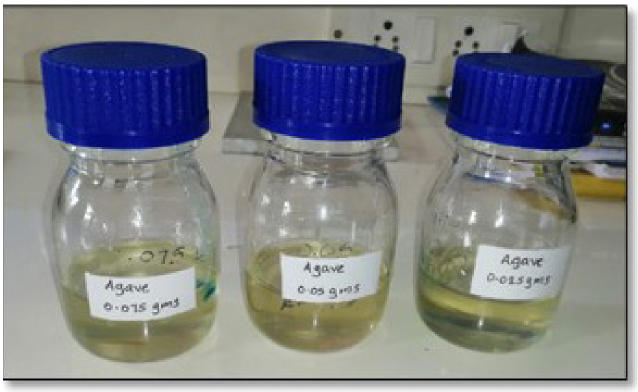

Figure 3: Final dope solutions.

Membrane casting

The membranes were prepared from the polymer dope solution, which was a solution of two polymers (basic polymer and a pore former) in a suitable solvent, using a method known as "phase inversion" method. The synthesis of membrane involves pouring of above solution (referred to as dope) on the casting plate, allowing the plate to pass underneath a casting blade and then submerging the plate in water tank. The polymer solution precipitates in form of a thin polymer sheet (Figure 4).

Membrane casting setup was used for the preparation of membranes, manually. The setup consists of a railing, blade, and the glass plate. After membrane casting, membranes were kept in a container filled with water for 1 - 2 days so that

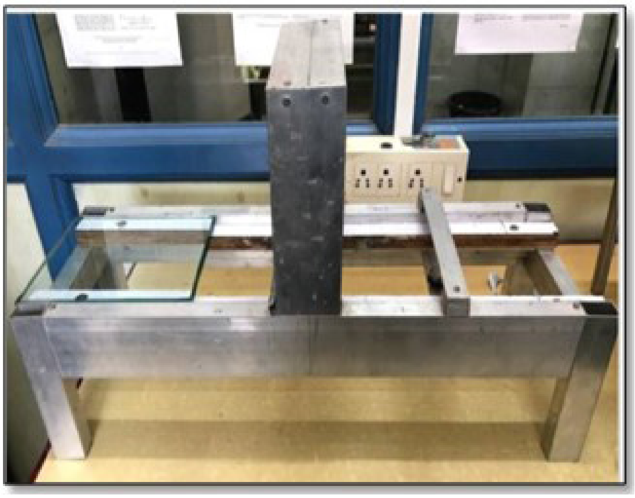

Figure 4: Tabletop membrane casting machine.

solvent and pore former get completely dissolved in water due to which void spaces known as pores gets formed on the membrane.

Membrane testing

Synthesized membranes were tested for the water permeability. For the same purpose membranes were cut into the circular shape with the use of stainless-steel stencil. The water permeability is the main parameter considered to check the performance of the membrane. The water filtration test setup is used for testing the water permeability of membrane (Figure 5).

Figure 5: Water filtration setup.

Conductivity, total dissolved solids (TDS), and pH test

The conductivity of water samples was checked before and after ultrafiltration test with the help of digital conductivity meter. After that the TDS value were calculated by using equation 1.

$$\text{TDS} = \text{Correlation Factor} \times \text{Conductivity} \tag{1}$$

Where 'Correlation Factor' is taken as 0.67 (Range is 0.55 to 0.8).

The pH value was measured with the help of digital pH meter.

Porosity test

Porosity plays an important role in the water permeability. To check the pore size and the porosity of an agave membrane SEM was used. Energy dispersive X-ray (EDX) spectroscopy gave the composition of the membranes.

Results and Discussion

Observations and calculations

The water permeability of all the prepared membranes were as checked. Table 1 shows the permeability results of all the compositions made.

Table 1: Observation table of ultrafiltration test naturally occurring material.

Agave fiber					
Wt.% of additive	Water permeability (ml)				Average
0.0 (Pure PSF)	34	32	29	27	30.5
0.05	42	34	30	28	33.5
0.1	76	68	62	58	66
0.15	86	76	70	64	74

Observations for ultrafiltration test

The above observations show that the water permeability of the membrane with 0.15 wt.% of date palm powder is the highest. Agave additions did help in improving the permeability of water.

Calculation for water permeability in LMH

The water permeability in LMH is calculated by equation 2. Permeation flux of membrane (F) is:

$$F = \frac{v}{S_t} \tag{2}$$

Where 'F' is Permeable flux of membrane (L/m^2/h), 'V' is Volume flow rate of permeate (L), 'S' is active area of membrane (m^2), 't' is Time (h).

Diameter of active area of membrane (D) = 0.039 m.

Area of membrane (S):

$S = \pi \times r^2 = 3.14 \times (0.0195)^2 = 0.00119$ m^2

Permeable flux of membrane (0.015 wt. of agave fiber powder as an additive) from equation 2:

F = 0.074/0.00119 x 0.08333 (Time 't' = 5 min)

F = 746.24 LMH

Observations and calculations for conductivity, TDS, and pH

The conductivity of tap water is 144.5 MHOS/cm, TDS value for tap water is 96.81 mg/L, and

pH of tap water is 7.66 (Table 2).

SEM and EDX observations

A SEM image of membranes developed with 0.15% agave powder added revealed clear, round pores evenly distributed throughout the surface of the sample. In addition to the open pores, subsurface pores were also visible. Approximately one micrometer was the size of the pores that were open to the surface (Figure 6).

Table 2: Observation table for conductivity, TDS, and pH.

Agave fiber			
Wt.% of additive	Conductivity (MHOS/cm)	TDS (mg/L)	pH
0.05	150	100.5	7.76
0.1	127	85.09	7.7
0.15	121.4	81.33	7.83

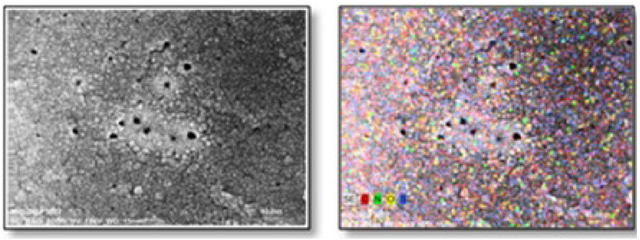

Figure 6: SEM image and EDX spectra of membrane with 0.15 wt. of agave powder.

Conductivity, TDS, and pH

According to the observations it was seen that, conductivity of membrane having 0.075 g of agave fiber powder as an additive was least i.e., 121.4 MHOS/cm. It shows that the amount of TDS in the water was also the least i.e.,81.33 mg/L. There was no promising change in the pH value of water sample after filtration (Table 3).

Composition of membrane and pore size

According to the observations, 0.15 wt.% of agave powder membrane is a composition of 73.25 wt.% of carbon, 13.57 wt.% of oxygen, 9.13 wt.% of sulfur and 4.05 wt.% of nitrogen. A homogenous composition was found in the membrane and no regions of segregation were observed. The pores were isolated and rounded and their size was found to be approximately 4 nm.

Conclusions

- It has been observed that water permeability of membrane increased by adding natural ingredients like agave fiber as compared to pure PSF membrane in ultrafiltration at a pressure of 2 bar.
- After going through the result of ultrafiltration, it was noticed that membrane with PSF + agave powder (0.15 wt.%) had highest permeability i.e., 746.24 LMH.
- The conductivity value for date palm membrane with 0.075 g of additive was 121.4 MHOS/cm and a TDS value was 81.33 mg/L.
- The membrane has the potential to remove bacteria, since the average size of bacteria to be removed from water is 0.5 to 3 μm and average pore size of membrane is 4 nm.

Table 3: Result of water permeability studies for ultrafiltration.

Membranes	Additives	Water permeability (LMH) measured at 2 bar for 5 min
Pure PSF	Nil	305.86
PSF + Additive (0.15wt.%)	Agave fiber powder (0.075 g)	746.24

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Conflict of Interest

None.

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