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Sustainable air gap membrane distillation using recycled acrylic (RA) membranes: Application to Shatt Al-Arab water desalination

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Abstract

One of the research motivations in the MD field is to develop high-performance membranes by preparing hydrophobic membranes due to their high throughput and rejection. The current work focuses on the fabrication and performance evaluation of electrospun nanofiber membranes using recycled acrylic (Polymethyl Methacrylate) (RA) via air gap membrane distillation (AGMD). Recycling this material not only reduces plastic waste and pollution, but it also offers a low-cost alternative to virgin polymers, which aids in membrane fabrication. Scanning Electron Microscopy (SEM) confirmed a uniform, highly porous nanofibrous structure with interconnected pores in the prepared nanofiber membranes. Atomic Force Microscopy (AFM) revealed a rough surface morphology, while water contact angle measurements exceeding 121° indicated excellent hydrophobicity, critical for effective liquid-vapor separation. Fourier-transform infrared spectroscopy (FTIR) verified the preservation of key ester functional groups, confirming the chemical integrity of the RA. The assessments revealed that the electrospun nanofibers demonstrated considerable flexibility while preserving their structural and surface characteristics as evaluated through mechanical strength testing. The resulting membranes were utilized in a water desalination process employing an AGMD setup, tested under varying feed temperatures (45, 55, and 65°C) and flow rates (0.2, 0.3, and 0.4 L/min) to evaluate their impact on desalination efficiency. It was observed that increasing the feed temperature significantly boosted water flux; moreover, the feed flow rate notably improved permeate flux within AGMD systems, thereby enhancing mass and heat transfer capabilities. The highest permeate flux recorded was approximately 19 kg/m²·hr, achieved at a temperature of 65°C with a flow rate of 0.3 L/min and a salt rejection rate of 99.999%. Consequently, this study's results indicate that RA-based nanofiber membranes hold potential for sustainable and effective water desalination. Furthermore, AGMD proved to be highly efficient in salt removal from the Shatt al-Arab river and may serve as a viable solution for providing clean drinking water in southern Iraq.

Keywords: Desalination; Air gap membrane distillation (AGMD); Electrospinning system; Hydrophobic polymer; Nonwoven Nanofibers; Shatt al-Arab River.

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1- Introduction

Shatt al-Arab is one of the most important inland rivers in Iraq, possessing a strategic geographical location in terms of the economic and political. It is an important water resource for agricultural and industrial activities in the Basra governorate. Shatt al-Arab water quality is mainly affected by the quality of the water resource from the Tigris and Euphrates rivers [1], which has degraded and reduced over time due to low rainfall, high temperature that increases evaporation rate, and the construction of dams on the upper reaches of the riverine water reaches of the riverine water resources [2].

Consequently, these issues have led to elevated levels of salts and total dissolved solids (TDS) [3], adversely affecting the environmental conditions in Basra. As a result, the river's water has become largely unsuitable for drinking and agricultural purposes, impacting the local economy and ecosystem, and there is a need to establish an efficient method for desalination. Desalination is an important traditional process and a crucial conventional process for providing alternative sources of fresh water. The two main technologies are classified as either thermal or membrane-based processes [4]. Thermal processes have been generally overlooked for brackish water desalination because of the large energy requirement for the high heat of vaporization of liquid water. As a result, solving the problems of seawater desalination and sewage treatment cost-effectively and energy-efficiently has become the core of water shortage solutions [5].

Membrane processes play a significant role in water treatment in several countries due to the advantages membrane separation offers, which include the absence of expensive and inefficient heat in thermal technology [6]. Such researchers seek separation-effective methods in the desalination process. Nowadays, membrane distillation technologies (MD) are a novel and interesting technique, a potential and alternative method of water desalination.

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The benefits of MD desalination are: (a) its compatibility with high salinity brines, (b) ease of operation on low-quality temperature sources (<100°C), (c) 100% salt rejection, and (d) low fouling and depressurized operation (close to atmospheric operation pressure). However, the main drawbacks of these processes remain the relatively low permeate flux [7-9]. With these distinct advantages, Membrane Distillation (MD) processes have shown promising outcomes in seawater desalination, wastewater treatment, and various other applications. This success is primarily attributable to the driving force being independent of salinity [10] MD utilizes hydrophobic microporous membranes that are essential for preventing liquid feed from passing through the micropores while permitting only the transport of water vapor and volatiles. This selective permeability is facilitated by a difference in partial pressures across the membrane, which influences both the technological and economic viability of the MD process. Consequently, high-purity distillates can be produced, starting from a variety of aqueous waste streams, like effluents coming from the textile/agrifood [11], waters contaminated by heavy metals [12], sea and brackish waters [13].

The current interest in research on MD for desalination purposes stems from the diverse availability of membrane materials due to their high hydrophobicity, low wettability, small thickness, low tortuosity, low thermal conductivity, and good chemical stability at the operating temperature of membrane distillation [14, 15], such as polypropylene (PP) [16], Polyvinylidene Fluoride (PVDF) [17], and polytetrafluoroethylene (PTFE) [18]. Increasing demands for polymeric membranes sourced from fossil fuels inevitably lead to their end of life due to unforeseen fouling and defects caused by mechanical or chemical factors [19, 20]. Moreover, the use of these polymer materials in everyday products has created a significant challenge regarding their disposal after use. This situation highlights the urgent need for environmentally sustainable disposal methods that align with global principles of circular economy and sustainability [21, 22]. Consequently, leveraging the potential for recycling waste materials in membrane manufacturing can significantly lessen environmental impacts. This approach not only eliminates the necessity for new polymer production, thereby reducing associated environmental damage, but also mitigates waste-related issues through repurposing. Such material usage not only reduces plastic waste and pollution but also offers a cost-effective alternative to new polymers, enhancing membrane production efficiency. Examples of commonly generated waste include Polystyrene [23], Polyethylene terephthalate [24], tire rubber, keratin, cellulose, and its derivatives [25], among others.

Compared to alternative techniques for the preparation of membrane distillation (MD) membranes, electrospun nanofiber membranes (ENMs) have attracted significant interest in the MD process. This is largely due to their cost-efficiency and their emerging role as a viable option in recent years. ENMs are created using electrostatic forces to produce fine fibers from polymer melts or solutions. The electrospinning process streamlines fiber creation by utilizing a high-voltage power source that charges a fluid jet flowing through a capillary tube [26]. ENMs offer exceptional characteristics, including a high surface area-to-volume ratio, versatility in surface functionalities, inherently high porosity, fully interconnected pore structures, low hydraulic resistance, and the potential for scalable synthesis [27, 28]. Numerous studies have investigated and documented the creation of polymeric membranes via electrospinning techniques. A team of researchers designed a dual-layer membrane consisting of polyvinylidene fluoride and polymethyl methacrylate (PVDF-PMMA) intended for direct contact membrane distillation (DCMD). Both materials exhibit natural hydrophobic properties and were tested under various operational conditions within the DCMD setup. The research revealed that a membrane structure composed of 25 wt.% PVDF as the lower layer and 75 wt.% PMMA as the upper layer resulted in a notable increase in water permeate flux. This particular formulation of the membrane achieved a flux of 44.192 $kg/m^2 \cdot h$ and a salt rejection rate of 99.757% [29].

The current study is based on the use of the recycled acrylic (polymethyl methacrylate) (RA) in membrane fabricating, which is advantageous both in ecological and economic terms. The acrylic is a transparent thermoplastic used to make a lightweight alternative to glass. Because of its insolubility and mechanical integrity, it possesses a high potential for membrane applications. In addition, the use of recycled acrylic is much cheaper than sourcing new polymer and therefore emerges as a cost-effective and relatively green choice for membrane manufacturing. This study adds value towards closing the loop in a circular economy by utilizing post-consumer acrylic waste, and fulfills the worldwide demand for cost-effective and high-performance materials in water treatment.

The scope of this study is to investigate the fabrication of an electrospun nonwoven polymeric nanofiber membrane. The polymer used for making the membranes in this study was the recycled acrylic (RA). The fabricated RA-based membranes were characterized by different analysis techniques such as Scanning Electron Microscopy (SEM), Mechanical Properties evaluation, Water Contact Angle (WCA) measurements, Atomic Force Microscopy (AFM) and Fourier Transform Infrared Spectroscopy (FTIR). The membranes were then used for the desalination of water using the AGMD process with exploring the effect of feed temperature and flow rate in the desalination of Shatt Al-Arab water.

2- Materials and methods

2.1. Materials

Waste acrylic hard plastic, specifically, recycled acrylic (Polymethyl Methacrylate) (RA) is a synthetic resin recognized for its transparency and rigidity, which makes it a popular alternative to glass in windows and eyeglasses. Waste acrylic material was sourced from an advertising shop and is primarily used to prepare the RA powder as a base polymer for preparing the membranes in this work. For the synthesis of the electrospun membranes, the following chemicals were purchased: the organic solvents N, N-dimethylformamide (DMF) (density: 0.948 g/cm³) and Chloroform ($CHCl_3$) (density: 1.49 g/cm³) from Alfa- Aesar with a purity of 99.99% and were utilized to dissolve the prepared RA powder.

2.2. Nonwoven nanofiber membranes via electrospinning system

The membranes were fabricated using electrospinning technology, a well-known, versatile process for the fabrication of MD membranes with high porosity and excellent hydrophobicity. Its formation can be tailored because the porous structure can be adjusted to provide a high surface area and surface functionalities. In this study, the recycled acrylic (RA) powder was dissolved at a concentration of 15 wt.% in $CHCl_3$ first, then by the addition of the DMF solvent using a magnetic stirrer at 250 rpm at room temperature for 5 hr. The mixing process continued until the solution became clear and homogeneous. Subsequently, ensure there is complete facilitation of the removal of trapped air bubbles, aiding in the degassing process.

The electrospun membranes were fabricated by electrospinning using a lab-made device consisting of a syringe pump, a high-voltage power supply, and a rotating drum; further details can be found in our previous work [30]. The resulting homogeneous precursor solution was placed into a plastic syringe of 5 mL, which had a small inner diameter and a capillary metal gauge needle (21 × 11/2”). The polymeric solution was pumped at a feed rate of 2 mL/h and a tip-to-collector distance of 13 cm. The nozzle moved back and forth to obtain a membrane with a more even thickness of 13 × 30 cm. The electrospinning process was conducted at room temperature and with 20% relative humidity. The polymer solution was subjected to a very high electrostatic force (18 kV), resulting in the formation of a fine jet of polymer that deposits onto a collector. Then, the solvent evaporated, resulting in the formation of a mat of nonwoven nanofibers on the surface of the collector [31]. After electrospinning, the dried membranes were transferred and stored in clean plastic containers to prevent the membranes from contamination before testing and characterization [32].

2.3. Membrane characterization

A range of analytical techniques was employed to assess the chemical, physical, and surface characteristics of the synthesized membranes. The scanning electron microscope (SEM) is a well-established research tool used to visualize samples by scanning them with a focused electron beam. SEM (National Institutes of Health SEM, USA) images of the membrane were captured to offer critical insights into the surface topography and morphology of the developed RA-based membrane.

Atomic force microscopy (AFM) is a mechanical characterization technique utilized to produce high-resolution three-dimensional topographic images of solid surfaces by using (SPM AA300 Angstrom Advanced Inc., AFM, USA). The AFM images are instrumental in assessing surface roughness parameters and assist in determining the structure and pore size of the fibers in the resulting RA-based nonwoven nanofiber membranes.

The surface wettability of the membranes was evaluated via water contact angle (WCA) measurements using an optical contact angle meter (Theta Lite TL101, Biolin Scientific, USA). A droplet of distilled water was placed on the membrane surface, and its image was captured and automatically analyzed to calculate the contact angle. The chemical structure and functional groups of the membrane were analyzed using Fourier-transform infrared (FTIR) spectroscopy (Spectrum 1800, Shimadzu, Japan), which involves the passage of radiation through the sample. Some of the incident infrared radiation is absorbed by the sample, while some is transmitted. The transmitted signal reflects the spectral sensitivity of molecular absorption, a molecular fingerprint for the sample across the wavenumber range of 4000-600 cm^{-1}. The mechanical properties of membranes are an important material aspect for any practical application, such as reusability, handling, and anti-deformation capacity [33]. The assessment of the membranes' mechanical characteristics involved determining both the breaking strength and Young's modulus of the samples with a Dynamic Mechanical Analyzer (DMA) (AG-A10T, Shimadzu, Japan), which specimens measuring 10 cm in length and 1 cm in width were utilized. Young's modulus serves to quantify a material's elasticity and is defined as the ratio of stress to strain [34, 35]. All characterization measurements were performed at a laboratory temperature of 20°C.

2.4. Evaluation of the membrane performance in the air gap membrane distillation system

One of the four types of MD is Air Gap Membrane Distillation (AGMD), which is described in the schematic considered in Fig. 1. The feed solution was heated by the heater (water bath), and a pump circulated water through the top part of the membrane piece. The flow rate is regulated by a control valve and monitored by a pressure gauge. The wall of this channel consists of a micro-porous hydrophobic (non-wettable) membrane through which only water vapor can diffuse, and the liquid water is retained. Coolant flows through the bottom (chiller), managed by a control valve with a pressure gauge, and the generated permeate is collected in the middle chamber and gathered in a measuring cylinder. Both the feed solution and the coolant are pumped in counter-current flow in a closed-loop system within the membrane module. The membrane is situated between the feed and air gap compartments, and the temperature difference between the inner and the outer tubes creates a partial pressure gradient forcing the vapor to diffuse through the membrane and the air gap. The temperature of the inlet and outlet feed water and coolant was continuously monitored by four sensors installed at the feed water and coolant inlet and outlet of each membrane side. In the AGMD setup, the membrane module, featuring a 6 mm air gap, was designed and constructed from acrylic panels that are chemically resistant, have high heat transfer resistance, and are easy to fabricate. The chamber side in the AGMD configuration is 1.5 cm thick and 7 cm long and wide. AGMD measurements were performed for 3 hours under every comparison. In the AGMD process, the measurements of the collected volume of the permeate flux were determined by the continuous change in the volume of the permeate distilled water in the vessels. Permeate flux was used to assess the performance for each MD configuration, calculated by Eq. 1 [36]:

$$J = \frac{V \times \rho}{A \times t} \quad (1)$$

Where the permeate flux is represented in J (kg/m²·h), V is the freshwater volume (L), ρ is the water density (kg/L), t is the operational time (hour), and A is the area of the membrane and salt rejection (R %) as given in Eq. 2 [37]:

$$R\% = \frac{C_1 - C_2}{C_1} \times 100 \quad (2)$$

Where R is the salt retention, C_1 is the feed concentration, and C_2 is the concentration of the permeate flow.

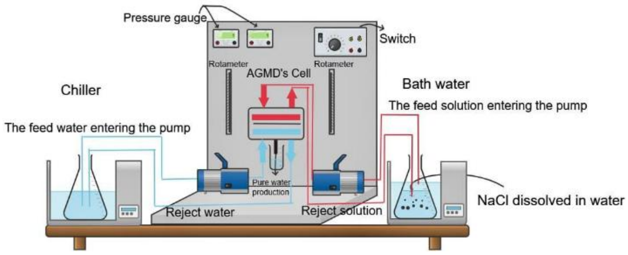


Fig. 1. The schematic diagram of the experimental rig of the AGMD process for the evaluation of the membrane performance

3- Results and discussion

3.1. Membrane characterizations

The morphology of the 15 wt.% RA-based electrospun nanofiber membranes was observed by SEM. As shown in Fig. 2, the average fiber size was about 1.12±0.28 µm, as determined by the measurement from 100 individual fibers measured from the SEM image by ImageJ. The diameter distribution reflected a uniform fiber formation in the range of 0.5–1.5 µm, which was relatively broad. Thus, the membrane had a smooth surface and uniform fiber diameter, demonstrating an absence of beads and surface defects, which showed good stability of the electrospinning process in the homogeneous fiber formation. Such fine fiber dimensions contribute to a high surface-area-to-volume ratio, which is beneficial for mass transfer in membrane distillation (MD) applications. It is anticipated that the coupled, fibrous network would maintain a significant level of hydrophobicity, essential to ensure liquid-vapor separation. Furthermore, the nanofibrous structure of the membrane permits efficient vapor permeation that is expected to enhance water flux without loss of high salt rejection. A beneficial effect of the fact that the fibers are randomly oriented is that a highly porous material is part of the resulting structure, and this is essential for enhancing vapor transport while keeping the thermal conductance and potential risk of pore wetting low.

In addition, the alignment of fibers within the membrane has a significant effect on the mechanical properties of electrospun nanofibers[38, 39]. The results of the mechanical properties showed a Young's modulus of 0.7367 MPa. The residual solvent makes a good adhesion between the fibers, leading to a high tensile strength of 1.30189 MPa, which is considered good for the nanofiber's membranes in previous works [40, 41].

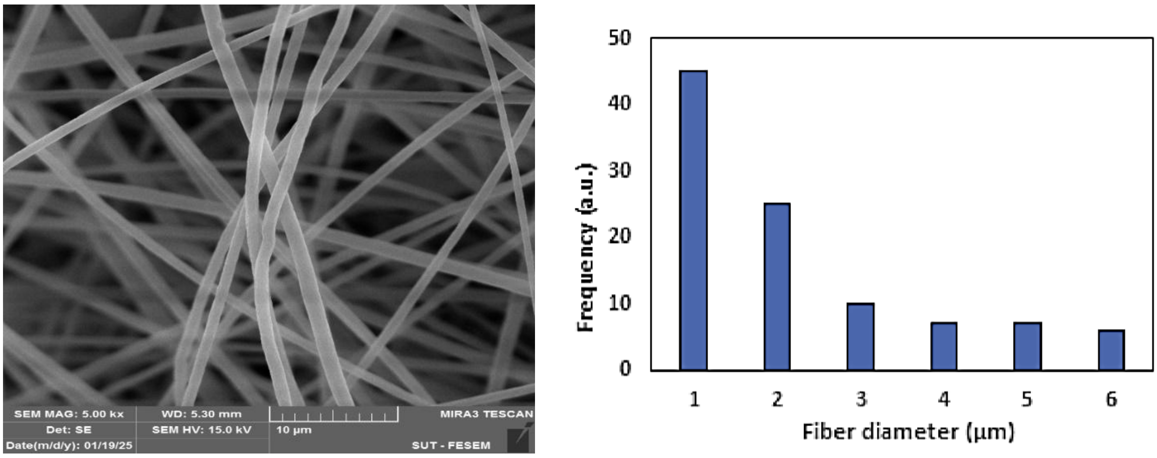
In addition, the AFM results revealed that the rough porous electrospun membrane was successfully prepared. The 2D and 3D images for the RA-based nanofiber membranes, as presented in Fig. 3, were employed to illustrate the roughness of the prepared electrospun nanofiber membranes. The RA-based membrane presented a mean value of surface roughness, and the membrane was found to be 132.9 nm with a mean diameter of 98.68 nm.

The random orientation of the nanofibers and resultant microscale topography contribute to facilitating the vapor transport effectively and reducing the possibility of pore wetting, which will render the hydrophobic membrane surface more hydrophobic. Membrane wettability, or hydrophobicity, representing the interactions between the liquid and membrane surface, is a crucial parameter for MD applications.

Here, fabricated electrospun membranes were analyzed with WCA and registered a water contact angle of 121.85°. This can be explained by the large roughness on the surface of the membrane produced by the electrospinning of nanofiber crossover, which also results in a decrease in the contact area between the water droplet and the membrane. This value is considered suitable for membrane distillation (MD) applications. Hydrophobic surfaces exhibit strong water-repellent properties, making it difficult for water to wet the surface. The chemical structures of the RA membranes prepared were analyzed by FTIR (Fig. 4). The peaks observed at 3024.38–3059.10 cm⁻¹ are attributed to alkenic C–H stretching vibrations [42]. While the strong absorptions in the 2924.09–2852.72 cm⁻¹ range correspond to C–H stretching of $–CH_3$ and $–CH_2–$ groups, consistent with the aliphatic backbone of RA. It is also seen that the peak at 1749.5 cm⁻¹, along with the broader range from 1664.57 to 1942.32 cm⁻¹, represents the C=O stretching vibrations of the ester groups and confirms the existence of the recycled acrylic material in the nanofiber membrane [43].

The bending vibrations of CH_2 and CH_3 groups are evident at 1450.47 and 1375.25 cm⁻¹, respectively. In the 1232.51–1001.06 cm⁻¹ region, multiple peaks correspond to C–O–C stretching vibrations of the ester moiety.

Furthermore, peaks in the 840–600 cm^{-1} region (including 754.17 and 698.30 cm^{-1}) are attributed to the out-of-plane bending of $–CH_2$ groups or side-chain vibration. The combination of these spectral attributes corroborates the successful preparation of RA-based nanofibers with ester functionalities preserved and the high chemical purity of our electrospun membrane, with no noticeable degradation or contamination signatures found.



(a) (b)

Fig. 2. The surface morphology of the prepared RA-based non-woven nanofiber membrane (a) SEM image. (b) The histogram of the fiber diameter distribution

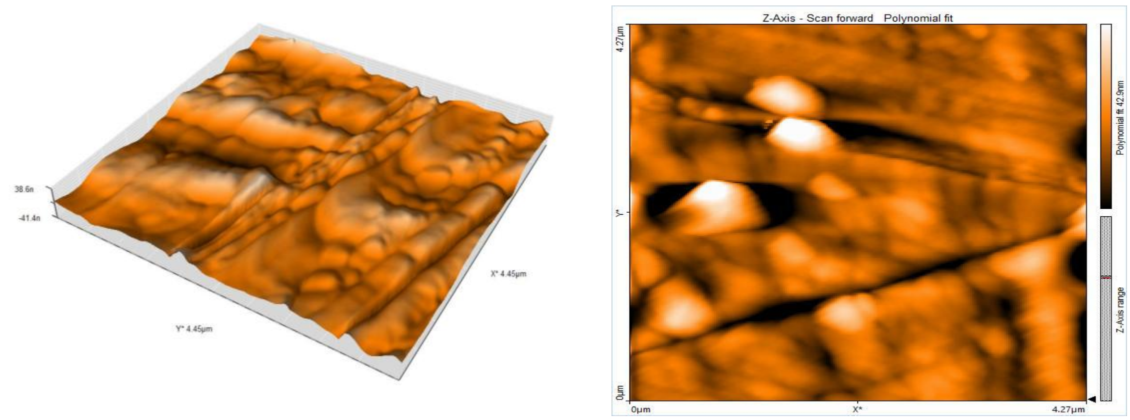


Fig. 3. Image of atomic force microscopy (AFM) of RA-based nanofiber membrane

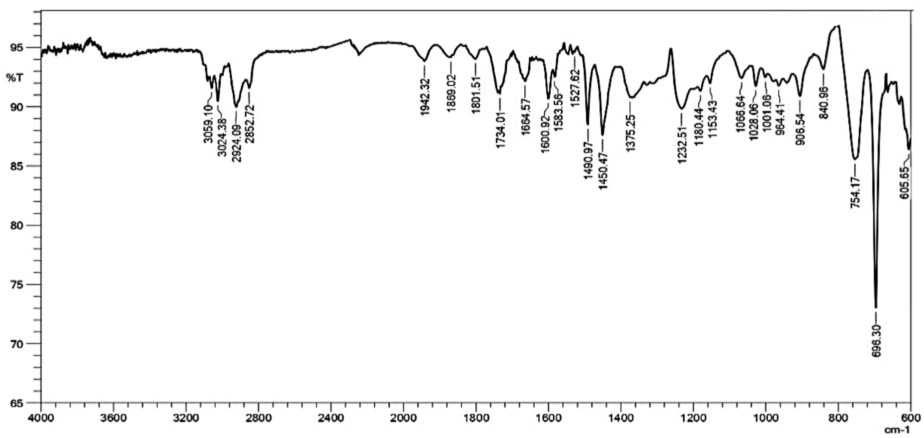


Fig. 4. The FTIR spectra of RA-based electrospun nanofiber membranes

3.2. Membrane performance test

To evaluate the potential of the fabricated membranes for Shatt Al-Arab River desalination, experiments were conducted using an Air Gap Membrane Distillation (AGMD) configuration. The study investigated the influence of key operational variables, including feed water temperature and feed flow rate, on permeate flux performance to identify optimal conditions for flux enhancement. The cold-side temperature and flow rate were maintained constant at 15°C and 0.3 L/min, respectively. The hot-side inlet temperature was varied across three levels: 45°C, 55°C, and 65°C. Additionally, hot-side flow rates were adjusted to 0.2, 0.3, and 0.4 L/min. The salt concentration of the feed solution (Shatt Al Arab water) was approximately 6000 mg/L, as shown in Table 1 for more details about properties, Shatt al-Arab River before distillation.

Table 1. Properties of the Shatt al-Arab River before distillation

Test Type	Result
Turbidity	28.90 NTU
pH	8.13
TDS	6000 mg/L
TSS	15 mg/L
Free Chlorine	0.01 mg/L
Magnesium	250 mg/L
Iron	3.34 mg/L

3.2.1. The influence of feed temperature

Feed temperature is a critical parameter for water recovery efficiency because MD systems operate with high sensitivity to feed temperature changes, especially on the hot side of the module. From Fig. 5, the feed temperature changed within the range of 45°C-65°C, and all other physical parameters were held constant: temperature coolant = 15°C, flow rate coolant = 0.3 L/min, a membrane thickness of 300 µm and feed rate = 0.3 L/min, while salinity for the test in Shatt Al-Arab was kept at 6000 mg/L. As can be seen, an increase in feed temperature can lead to a significant increase in distillate flux. It is anticipated that when the temperatures are raised much higher, potentially giving rise to significant exponential increases in the saturated vapor pressure of volatile species, the driving force of vapor permeation through the membrane would be increased as well.

According to Antoine's equation, the vapor pressure of a liquid depends exponentially on the temperature, which is the key force for the mass transfer in the MD process [43]. The highest flux was reached at 19.04 kg/m²h at 65°C; therefore, the optimal operational temperature for this study was chosen to be 65°C due to the commercial feasibility of this temperature in commercial desalination systems. The temperature of 65°C offered an optimal balance between performance and energy, enabling high water recovery and yet moderate thermal energy requirements, indicating its potential for efficient brine processing using AGMD. The membrane exhibited good performance in desalting, with a slight maximum in salt rejection of approximately 99.999%.

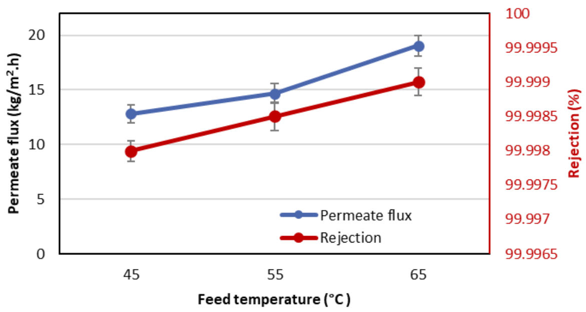


Fig. 5. The impact of feed temperature on the permeate flux and salt rejection of RA- based membrane using the AGMD configuration at 0.3 L/min

3.2.2. The influence of feed flow rate

Feed flow rate is a critical parameter in heat and mass transfer in membrane modules that affects membrane distillation (MD) performance. The experiments were performed at a temperature of 55 °C, a membrane thickness of 300 µm and the salinity of the feed in the case of Shatt Al-Arab was 6000 mg/L. Additionally, the feed flow rate was varied at both 0.2–0.4 L/min to determine the effect of flow rate on the AGMD plant. As shown in Fig. 6, the distillate flux almost linearly increased with the increasing speed, which enhanced the efficiency of AGMD until the permeate flux reached 17.97 kg/m²h. This improvement is the result of the additional turbulence developed in the flow channel, which in turn favors better mixing and mass transfer across the RA-based membrane. The increase in the Reynolds number resulting from the increase in flow rates affects the shortening of the thickness of the hydrodynamic boundary layer and subsequently leads to a significant improvement in the heat transfer coefficient with decreasing temperature polarization impact on the feed side [44]. Crucially, at feed flow rate ranges of 11.3 to 17.97 kg/m²h, the prepared membranes exhibited very good separation performance, with the extent of salt rejection ranging from 99.9981% to 99.999% throughout the tested flow rates.

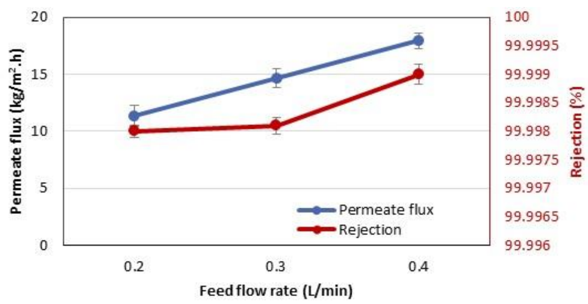


Fig. 6. The impact of feed flow rate on the permeate flux and salt rejection of RA-based membrane using the AGMD configuration at 55°C

However, a much higher feed flow rate or approximately, was employed in our study (as shown in Table 2); the RA-based membrane demonstrates competitive AGMD performance in an air gap thickness of 6 mm compared to other previously reported membranes, owing to its highly porous nanofibrous structure with interconnected pores that facilitate vapor transport. Additionally, water contact angle measurements exceeding 121° indicate excellent hydrophobicity, which is essential for effective liquid–vapor separation and confirms the important rule that RA-based nanofiber membranes are environmentally sustainable and also highly effective for cost-effective (economical), high-salinity brine desalination in AGMD. The study examined a high-water flux of 22.9 L/m².h and an almost complete salt removal rate using a PVDF-HFP/graphene nanofibrous membrane within a 3 mm air gap. This highlights the promising potential of MD-based desalination and water treatment, which can be attributed to the remarkable inherent hydrophobicity of the PVDF-HFP polymer, evidenced by a WCA value of 142.3° for the unaltered membrane, along with its notable porosity of 88.7% [45] .Compared to another membrane, RA material is more inexpensive and practical for further modification or grafting because of the available surface functional groups.

Table 2. Comparison with other studies of membrane researchers' operating conditions and permeate flux in AGMD

Membrane name	Temp. of feed (°C)	Flow rate of feed (L/min)	Conc. of feed (g/L)	Air gap thickness (mm)	Time of exp. (h)	Permeate flux (kg/m²·h)	Salt Rejection (%)	Ref.
PVDF-co-HEP+graphene	40	0.2	35	3	60	22.9	~100	[45]
PVDF/GO-APTS	40	0.5	3.5	2	15	10.7	~100	[46]
PVDF	40	0.35	60	2	600	4.2	99.9	[47]
FGO-4/PVDF	40-60	0.16	35	4	8	5.33-21.43	99.9	[48]
Recycled Acrylic RA	45-65	0.2-0.4	Shatt Al-Arab River	6	24	11.3-19.04	99.999	Present work

4- Conclusion

A study of the Air Gap Membrane Distillation (AGMD) proceedings for the desalination of Shatt al-Arab water in (Basra, Iraq) was conducted by the successful fabrication of electrospun nanofiber membranes using recycled acrylic (RA) as a sustainable polymer source. The membranes exhibited favorable morphological and physicochemical characteristics, including a uniform and highly porous fiber network with a diameter distribution that reflected a uniform fiber formation in the range of 0.5–1.5 µm, notable surface roughness can be seen 132.9 nm, and strong hydrophobicity, with water contact angles exceeding 121°. FTIR analysis confirmed the preservation of functional groups, indicating good chemical integrity and thermal stability and Mechanical strength assessments demonstrated that the electrospun nanofibers displayed notable flexibility while preserving their structural and surface characteristics. The membranes were evaluated in a custom-designed AGMD system under a range of operating conditions, including feed temperatures between 45 and 65 °C, flow rates of 0.2 to 0.4 L/min, salt concentrations from 6000 mg/L, it was found that the best permeate flux obtained was approximately 19.04 kg/m².h,, which was obtained at a temperature of 65°C and a flow of 0.3 L/min; the rejection of salt changed to 99.999%. Performance analysis revealed that increases in feed temperature and flow rate enhanced flux, primarily by increasing vapor pressure and mitigating temperature polarization, underscoring their reliability. Overall, the findings highlight the potential of RA-based nanofiber membranes as an effective and environmentally responsible option for desalinating the Shatt Al-Arab River using AGMD. This work supports the broader goal of developing sustainable, cost-effective membrane materials for future water treatment technologies and selectivity even under challenging conditions.

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التحلية المستدامة بطريقة التقطير الغشائي بالفجوة الهوائية باستخدام أغشية الأكريليك المعاد تدويره :(RA) تطبيق على تحلية مياه شط العرب

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الخلاصة

أُجريت دراسة لعمليات التقطير الغشائي بطريقة الفجوة الهوائية (AGMD) لتحلية مياه شط العرب في محافظة البصرة، العراق، من خلال تصنيع ناجح لأغشية نانوية من الألياف المغزولة كهربائيًا، باستخدام الأكريليك المُعاد تدويره كمصدر مستدام للبوليمر. أظهرت الأغشية خصائص مورفولوجية وفيزيائية–كيميائية ملائمة، بما في ذلك شبكة ألياف موحدة وعالية المسامية، مع توزيع منتظم لأقطار الألياف ضمن من نطاق يتراوح بين (٠،٥) و(١،٥) ميكرومتر، بالإضافة إلى خشونة سطحية ملحوظة بلغت (١٣٢،٩) نانومتر، وكراهية عالية للماء بزوايا تلامس تجاوزت (١٢١°) درجة. أكد تحليل FTIR الحفاظ على المجموعات الوظيفية، مما يشير إلى سلامة كيميائية جيدة واستقرار حراري ملحوظ. وأشارت التقييمات إلى أن الألياف النانوية المصنوعة بالغزل الكهربائي أظهرت مرونة كبيرة مع الحفاظ على خصائصها البنيوية والسطحية من خلال اختبار القوة الميكانيكية. تم تقييم الأغشية ضمن نظام AGMD مُصمم خصيصًا، وتحت مجموعة من ظروف التشغيل، شملت درجات حرارة تغذية تتراوح بين (٤٥) و(٦٥) درجة مئوية، ومعدلات تدفق بين (٠،٢) و(٠،٤) لتر/دقيقة، وتركيزات ملحية بلغت (٦٠٠٠) ملغم/لتر. وقد بلغ أعلى تدفق نفاذ تم تحقيقه نحو (١٩،٠٤) كغم/م^{٢}ساعة ، عند درجة حرارة (٦٥) درجة مئوية ومعدل تدفق (٠،٣) لتر/دقيقة، مع نسبة رفض للأملاح وصلت إلى ٩٩،٩٩٩٪. كشف تحليل الأداء أن زيادة درجة حرارة التغذية ومعدل التدفق ساهمتا في تعزيز التدفق بشكل ملحوظ، وذلك بشكل رئيسي من خلال زيادة ضغط البخار وتقليل تأثير استقطاب درجة الحرارة، مما يعكس موثوقية أداء النظام. بصورة عامة، تُبرز النتائج الإمكانات الواعدة لأغشية الألياف النانوية القائمة على الأكريليك المعاد تدويره كخيار فعّال وصديق للبيئة لتحلية مياه نهر شط العرب باستخدام تقنية AGMD، بما يدعم التوجّه نحو تطوير مواد غشائية مستدامة وذات كفاءة اقتصادية عالية لتقنيات معالجة المياه المستقبلية، حتى في ظل ظروف تشغيل صعبة.

الكلمات الدالة: تحلية المياه، التقطير الغشائي بفجوة هوائية (AGMD)، نظام الغزل الكهربائي، البوليمر الكاره للماء، الألياف النانوية غير المنسوجة، نهر شط العرب.