

Research Article

A Novel Antifouling RO Polyamide/Myrrh Membrane for Waste Water Purification

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In the present work, desalination of real samples from Dumat Al-Jandal Lake water (located in Jouf region) was carried out via reverse osmosis (RO) technique. The growth of bacteria on the surface of RO membrane is an essential issue of this method. It creates defects in membrane properties as salt rejection and preparation. Many approaches have been proposed to prevent the growth of bacteria on membrane. The addition of some materials such as natural products was one of those approaches. In this work, myrrh was chosen because it is well known as an antibacterial natural product. Unmodified RO membrane was prepared in the lab using interfacial polymerization between trimesoyl chloride (TMC, 0.1 M) and m-phenylenediamine (MPD, 0.3 M). The characterization was obtained by using infrared (IR) and scanning electron microscopy (SEM). The properties of RO membrane as water flux and salt rejection were determined using lake water. The obtained results were 25 and 65% for water flux and salt rejection, respectively. In respect of modified RO membrane, myrrh solution with different concentrations was prepared and mixed with membrane materials. The modified membrane was characterized with IR and SEM. Water flux and salt rejection were determined obtaining results of 42 and 41% for water flux and salt rejection, respectively. The resistance of bacterial growth was tested for both modified and unmodified membranes, showing that the modified membrane presented high resistance of bacterial growth in contrast to the unmodified one.

1. Introduction

Osmosis is the natural passage of solvent particles over a selectively permeable membrane from a low-solute-concentrated solution to a high-solute-concentrated solution in a manner that seems to equalize the solute concentrations on both sides [1–4]. It might also refer to a physical process in which any solvent flows through a selectively permeable barrier (permeable to the solvent but not to the solute) that separates two solutions of varying concentrations [5–7]. Osmotic pressure is the external pressure that must be applied to prevent any net passage of solvent across the membrane. Osmotic pressure is a colligative feature, which means it is governed by the molar concentration of the sol-

ute rather by its identity [8]. Osmosis is an essential process in biological systems because biological membranes are semipermeable. These membranes are impermeable to large and polar molecules like ions, proteins, and polysaccharides, while nonpolar or hydrophobic molecules like lipids as well as tiny molecules like oxygen, carbon dioxide, nitrogen, and nitric oxide are permeable [9]. Solubility, charge, and chemistry, as well as the size of the solute, all impact permeability [10]. Water molecules can diffuse through the phospholipid bilayer of the plasma membrane, tonoplast membrane (vacuole), or protoplast membrane via aquaporins (small transmembrane proteins similar to those responsible for facilitated diffusion and ion channels). The most common technique for moving water in and out of cells is osmosis.

The turgor pressure of a cell is mostly maintained by osmosis across the cell membrane between the cell interior and its generally hypotonic surroundings.

Reverse osmosis (RO) is a water purification technology that uses a partly permeable membrane to extract ions, undesirable compounds, and bigger particles from drinking water. In reverse osmosis, a colligative property caused by chemical potential fluctuations in the solvent, a thermodynamic parameter, is employed to resolve osmotic pressure [11]. Reverse osmosis can remove a wide spectrum of dissolved and suspended chemical species as well as biological species (most notably bacteria) from water and is employed in both industrial operations and the manufacture of drinkable water [12]. As a consequence, the solute is confined on the membrane's pressured side while the pure solvent passes through. To be "selective," this membrane should prevent big molecules or ions from passing through the pores (holes), but smaller components of the solution (such as solvent molecules, i.e., water) should be permitted to flow freely [13].

Medeiros et al. [14] synthesized hybrid polyamide6 (PA6)/montmorillonite (MMT)/porogenic agent membranes (CaCl_2). X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FT-IR), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), porosimetry by mercury interference (PMI), flux measurements, and rejection were used to characterize the hybrid membranes with CaCl_2 . The hybrid membranes with CaCl_2 have an exfoliated and/or partially exfoliated composition, as revealed by X-ray diffraction. When FT-IR and DSC of hybrid membranes with CaCl_2 were compared to PA6 membrane, the spectra and crystalline melting temperature remained virtually unchanged. The addition of MMT and CaCl_2 to the PA6 membrane resulted in an increase in the number of pores on the surface and cross section of these membranes.

Using simple strategy of interfacial polymerization with the addition of free radicals, a novel aromatic polyamide (PA) RO membrane with nanoscale water channels and hydrophilic molecular skin surface, close to those of biomimetic neural networks, was realized for textile waste water treatment, Liu et al. [15]. Irradiation triggered the formation of a polyimide-hydrophilic polyolefin interpenetrating network structure as the functional layer and a molecular brush as the hydrophilic surface layer from diallyl dimethyl ammonium chloride spread within and on the surface of the PA functional layer.

The use of a porous carbon nitride (C_3N_4) nanoparticle to boost the water flux and salt rejection of state-of-the-art polyamide (PA) thin film composite (TFC) membranes is described by Zhou et al. [16]. The organic-organic covalent bonds endowed C_3N_4 with a high level of compatibility with the PA substrate, which influenced the interfacial polymerization customization positively (IP). Using the positive effects of C_3N_4 , a more hydrophilic, more crumpled thin film nanocomposite (TFN) membrane with a larger surface area was formed, as well as an increased cross-linking degree of the PA layer. Furthermore, the uniform porous structure of the C_3N_4 embedded in the PA layer's "ridge" parts may

have created additional water channels. All of these factors combined resulted in the best performance for seawater desalination of any PA-TFC membrane ever recorded. The optimized TFN membrane has a 2.1-fold higher water permeance than the pristine PA-TFC membrane, and its NaCl rejection has improved to 99.5 percent from 98.0 percent. The method showed promise in improving the efficiency of current PA-TFC membranes in seawater desalination.

Mohd Yusof et al. [17] investigated the synthesis and efficiency of a polyamide forward osmosis (FO) membrane for the removal of humic acid (HA). At different reaction times, three polyamide membranes were synthesized by reacting m-phenylenediamine and trimesoyl chloride (10, 30, and 60 s). In one hour, water flux, reverse salt diffusion, and HA removal were measured using five different concentrations of sodium chloride draw solutions and 15 mg/l of HA solution as feed solution. Conductivity and a UV-vis spectrometer were used to test reverse salt diffusion and HA elimination, respectively.

Al Zoubi et al. [18] conducted research. Materials that are chemically stable and antibacterial are ideal for bone restoration and packaging. Because of their low cost, simplicity, and excellent mechanical properties, cross-linked polymer-inorganic materials have gotten a lot of attention in this area.

Fabricating hybrid organic-inorganic films with regulated electrochemical, photocorrosion, and antibacterial efficiency that are stable in aggressive solutions and solvents has proven difficult. To fabricate contact active antibacterial membranes, Zhai et al. [19] studied thin film composite polyamide (PA) membranes modified by polyethyleneimine (PEI) and 2,6-diaminopyridine (DAP) by sequential interfacial polymerization. Improved hydrophilicity and zeta potential have been observed in the modified membranes. The membrane flux rises from 35.7 to 46.7 and 50.01 m² h⁻¹, respectively, when PEI and DAP are tethered to the PA membranes. Furthermore, the salt rejection rate rises from 96.6% to 98.0% and 98.8%, respectively. The PAPEI membranes outperform PADAP in terms of antibacterial efficiency, with a bacterial killing ratio of over 96.7% for both *Escherichia coli* (*E. coli*) and *Staphylococcus aureus* (*S. aureus*), compared to 13.3% for *E. coli* and 8.4% for *S. aureus* for a commercial LC LE4040 membrane.

An innovative approach to restrain bacterial adhesion and growth on membranes is critical to prevent membrane efficiency degrading due to biofouling, studied by Zhang et al. [20]. In this study, interfacial polymerization was used to incorporate nanofillers of p-aminophenol-modified graphene oxide (mGO) into the polyamide skin layer, resulting in a sequence of thin film nanocomposite (TFN) reverse osmosis (RO) membranes. This research shows how to make TFN RO membranes with good separation efficiency and attractive antibacterial properties in a simple way.

Microorganisms are the most numerous biopollutants in the world. The changing distribution of biopollutant units in water over time [21], as well as the presence of numerous microorganisms in water, has been linked to human health risks [22, 23]. Many studies [24] have recorded the use of medicinal plants in traditional medicines. Medicinal plants, which are an important part of agriculture, are one of the

primary sources of active chemicals used in pharmaceutical manufacturing [25]. Medicinal plant products have proven to be important in the identification of efficient antimicrobial agents [26, 27]. The use of herbaceous plants, which are not harmful to human health or the environment, in place of chemical fungicides is a potentially effective alternative strategy [28, 29]. Several plant stem, roots, bark, flowers, and leaves have been found to have antibacterial characteristics [30, 31]. Myrrh (*Commiphora molmol*) is a yellow oleo-gum resinous secretion with medicinal properties that has been used for centuries in the Arabian and North African regions to treat a wide range of clinical symptoms including ulcerative colitis, fever, gall bladder ailments, skin infections, dysmenorrhea, amenorrhea, tumors, chest ailments, and burns [32–35]. It is formed of exudates produced by the stems of plants from the genus *Commiphora*, family *Burseraceae* [36, 37].

In the present work, a novel polymer composite consists of polyamide loaded with myrrh was fabricated for use in desalination of Dumat Al-Jandal Lake water. All samples were collected from Dumat Al-Jandal Lake, (N 29° 49' 5.5272", E 39° 52' 5.5128"), Al-Jouf region, Saudi Arabia. Collections were made in March 2021.

2. Experimental

2.1. Materials and Instruments. Toluene (98%), benzene-1,3,5-tricarboxyl acid chloride (trimesoyl chloride, TMC), and m-phenylenediamine (MPD) were purchased from Sigma-Aldrich. Polysulfone (PSF) membranes supported by polyester layer were purchased from GE. n-Hexane (96%) was purchased from Scharlau. Methanol was purchased from Merk. Sodium dodecyl sulphate (SDS) was purchased from BDH while Campor-10-sulfonic acid (CSA) was purchased from Fluka. Isopropanol (IP) was purchased from Vetec. For SEM photodetection, Thermo Scientific Quattro S was employed. For the FT-IR measurements, a SHIMADZU IRTracer-100 spectrophotometer was used.

2.2. Methods

2.2.1. Salt Rejection. The calculation of salt rejection (R) was performed by measuring the conductivity of the permeate which was converted to concentration (ppm) using a calibration curve. The calibration curve was obtained by measuring the conductivity three times for eight different concentrations of sodium chloride solution which includes the blank solution (0, 5, 10, 20, 40, 60, 80, and 100 ppm). The average conductivity of these solutions versus the concentration is shown in Figure 1.

The obtained result resented in Figure 1 shows that the ability-modified membrane to reject the salt molecules to permeate the membrane was conserved.

2.2.2. Sample Collection. Water samples were collected from Dawmat Al-Jandal Lake, Dawmat Al-Jandal City, Al Jouf, Saudi Arabia, during March 2021. Water was collected from a depth of 30 cm of the lake in a 500 ml bottle of commercial

mineral water after it was opened and discarding the water next to the lake and then filled directly.

2.2.3. Isolation of Fungi. Fungi were isolated using Potato Dextrose Agar (PDA) medium that was added with rose bengal (0.001 gm) prior to sterilization in the autoclave [38]. To isolate the fungi, add 1 ml of diluted collected lake water (1/3; v/v) in a sterile petri dish and add 15 ml warm PDA (prior to the solidification) medium and leave in the isolation compartment until it hardens in sterile conditions. Incubation was then done in an incubator adjusted to 27°C in the dark until sufficient growth of the fungal colony appeared.

Colonies formed by the isolation of fungi from Dawmat Al-Jandal Lake were purified using PDA medium without rose bengal. Inocula were taken from fungal colony, or a small piece of mycelium growth, and placed in the middle of PDA disc which is incubated at 27°C in the dark until growth of the mycelium appeared. Genera and species of isolated filamentous fungi were identified on the basis of macroscopic (colonial morphology, color, texture, shape, and appearance of morphology) and microscopic characteristics (septation in mycelium, presence of specific reproductive structures, shape, and structure of conidia) [39].

2.2.4. Isolation of Bacteria. Nutrient agar (NA) medium was used to isolate bacteria spp. from Dawmat Al-Jandal Lake water sample which was diluted (1:3; v/v) and inoculated into nutrient agar media followed by 24–48 h incubation at 35°C. Isolated bacteria were identified and purified for subsequent operations.

2.2.5. Thin Layer of Polyamide Perpetration. Polyamide membranes were prepared using the interfacial polymerization process; the polyamide layer was formed on the top surface of the supporting layer (PSf). The porous PSf was saturated with MPD aqueous solution+myrrh (0.1%Wt/V) (aqueous phase) and then was covered with TMC in an organic solution (organic phase) in Figure 2.

At the interface between the aqueous and organic solutions, the reaction of aqueous phase and organic phase resulted in the formation of polyamide loaded myrrh composite as a thin layer on top of the PSf surface. Dense layer of polyamide occurs in a short time (seconds) due to the rapid condensation polymerization between MPD and TMC. The polyamide forming reaction is illustrated in polyamide membrane preparation from m-phenylenediamine (MPD) and trimesoyl chloride.

2.2.6. Antimicrobial Assays

(1) Antifungal Activity. Six isolates of *Aspergillus flavus*, *A. fumigatus*, *A. niger*, *A. ochraceus*, *Paecilomyces variotii*, and *P. chrysogenum* which were isolated from Dawmat Al-Jandal Lake, Dawmat Al-Jandal City, Al-Jouf, Saudi Arabia, were used in this study. Fungi were cultured and maintained on Potato Dextrose Agar (PDA) medium. In an isolation cabinet and under the aseptic conditions, 1 ml of conidial suspension of each fungus was placed in a sterile petri dish and then 15 ml of the warm melted PDA medium poured

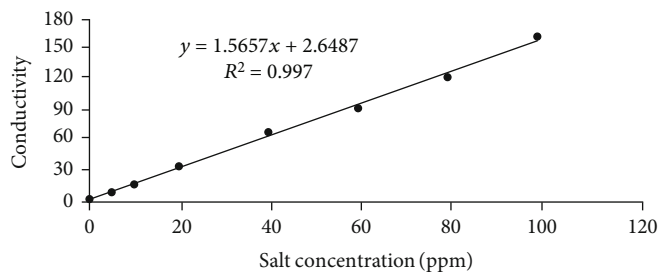


FIGURE 1: Calibration curve of conductivity and rejection of salt.

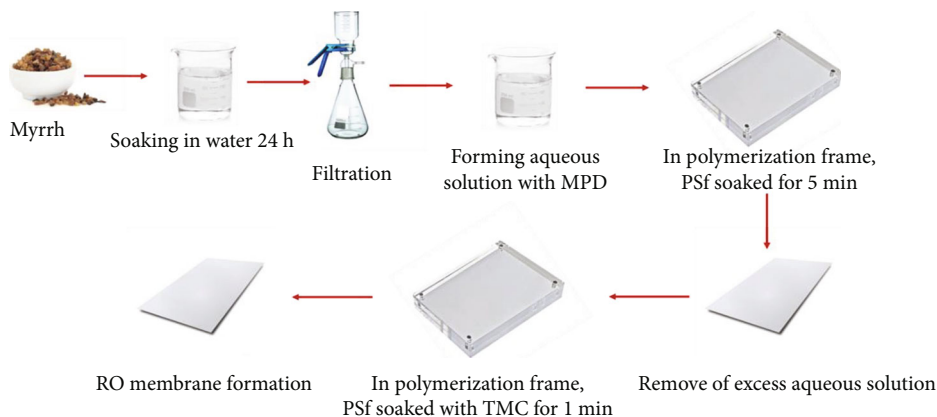


FIGURE 2: Preparation of modified polyamide sheet.

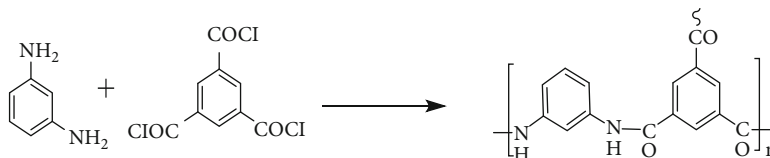


FIGURE 3: Polymerization reaction forming polyamide membrane.

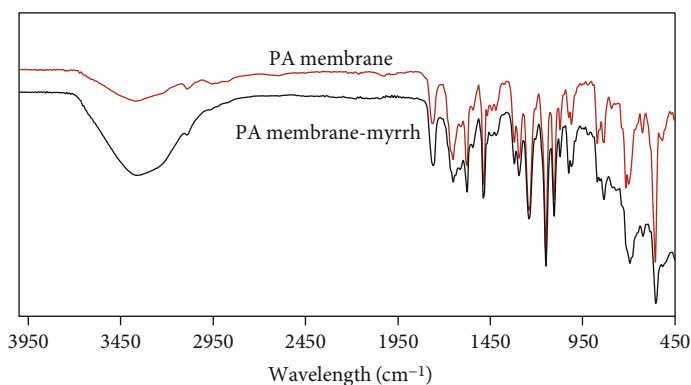


FIGURE 4: FT-IR spectrum of the PA membrane.

over the conidial suspension. Dishes were left until solidification, and then, each dish was supplemented with pieces of polymer with myrrh (0.1%Wt/V) (10 × 5 mm). Tested plates were wrapped with parafilm, placed in sterile bags, and incubated at 27°C for 6 days. The diameter of inhibition zones and inhibition percentage were measured, and results

were recorded. All isolates were tested against polymer without myrrh as a control. Three discs were maintained as replicates for each isolate.

Inhibition percentage in each isolate was calculated according to the following formula used by Derballah et al. [40]:

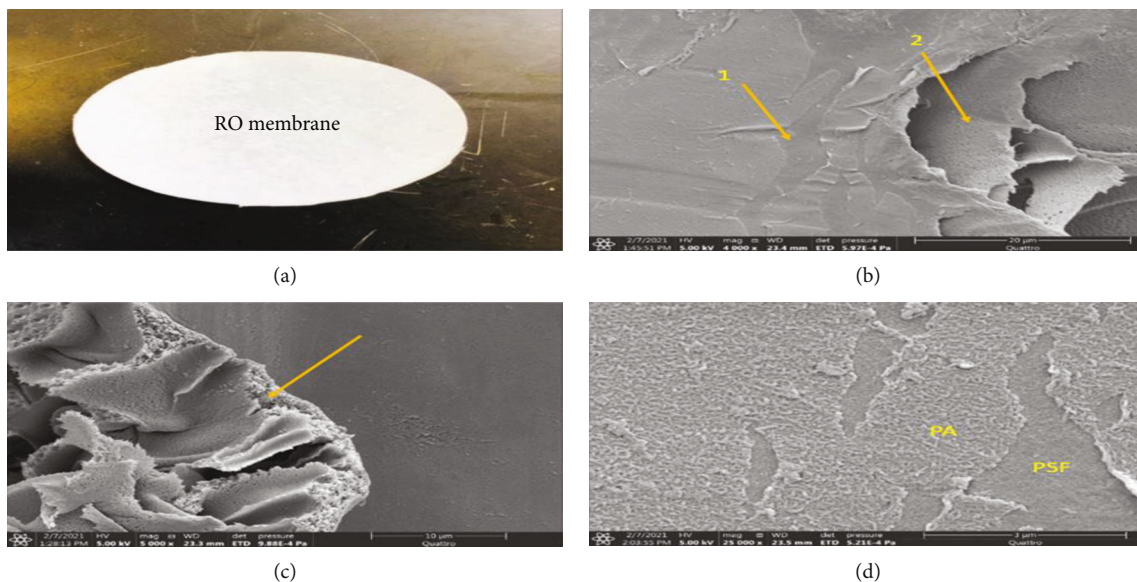


FIGURE 5: SEM images of polyamide membrane. (a) Shows the RO membrane sheet that is used in the flux cell. (b) Illustrates two layers of composite membrane. (c) Illustrates polysulfone layer. (d) Shows the upper layer (PA) and the ground layer (PSF).

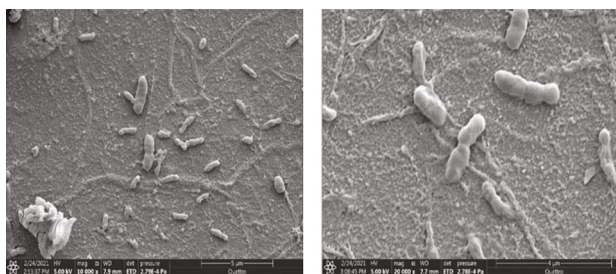


FIGURE 6: SEM images of bacteria on modified polyamide membrane after addition of myrrh.

$$\text{Inhibition potential} = [(C - T) \div T] \times 100, \quad (1)$$

where C is the size of the colony on control and T is the size of the colony on test.

(2) *Antibacterial Activity.* An isolate of gram-negative bacterium (*Escherichia coli*) and an isolate of gram-positive bacterium (*Bacillus subtilis*) which was obtained from water of Dawmat Al-Jandal Lake, Dawmat Al-Jandal City, Al-Jouf, Saudi Arabia, were used. Each isolate was cultured on a Nutrient Broth (NB) and incubated at 35°C for 24 hours. In an isolation cabinet and under the aseptic conditions, 1 ml of NB medium containing the bacterial inocula was placed in a sterile petri dish and then, 15 ml of the warm melted NA medium poured over the inocula. Dishes were left until solidification, and then, each dish was supplemented with small pieces of polymer with myrrh (0.1%Wt/V) (10 × 5 mm). Tested plates were wrapped with parafilm, placed in sterile bags, and incubated at 35°C for 48 hours. The diameter of inhibition zones and inhibition percentage were measured, and results were recorded as previously methods in testing antifungal activity.

(3) *Detection of Aflatoxin by Using TLC Techniques.* Liquefied fungal samples were extracted with chloroform, filtered by using filter paper (24 cm Whatman No. 1), washed by dH₂O, and concentrated to 2 ml. Quantitation of the fungal aflatoxins was performed according to 123 with minor modifications. Briefly, 25 μl of the concentrated extracts was spotted onto a silica gel plates (Silica gel F254 10 × 20 cm). We used 3 developing systems of solvents: chloroform:acetone (9:1, v/v), followed by two: toluene:ethyl acetate:90% formic acid (5:4:1, v/v/v) migrations. UV light box was used to examine TLC plates at 365 nm before quantification of aflatoxins by a densitometer with a scanning resolution of 0.025 mm and 16 readouts/point. Linear standard curves were plotted against the peak areas of the applied 33 quantities of the standard aflatoxins.

Concentrations of aflatoxins were computed by the formula $C_p = (S * Y * V) / (X * W)$, where C_p is the concentration of aflatoxin (μg/kg), S is the microliter aflatoxin standard which matches the unknown, Y is the concentration of aflatoxin standard micrograms per milliliter, V is the microliter of final dilution of sample extract, X is the microliter of sample extract spotted giving fluorescent intensity equivalent to standard, and W is the wt in grams of the sample contained in final extract.

3. Results and Discussion

Through interfacial polymerization, the interaction of trimesic chloride with m-phenylenediamine resulted in the formation of a reverse osmoses (RO) polyamide membrane in this study (Figure 3).

RO polyamide membrane was modified with the addition of an aqueous solution of myrrh. The aim of myrrh addition is to enhance the antimicrobial activity of polyamide membrane. The polyamide sheet was characterized using

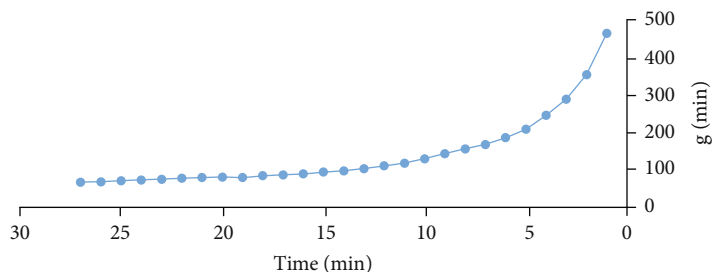


FIGURE 7: Membrane flux after permeability is fixed after applying 16 bar of pressure.

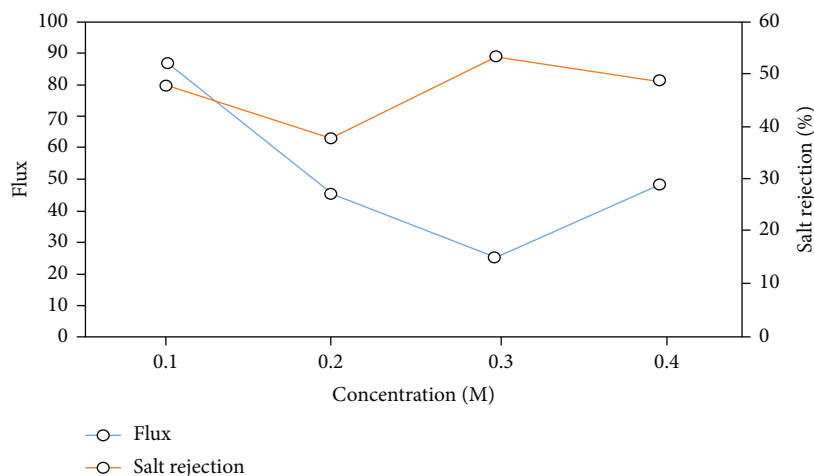


FIGURE 8: Influence of organic solution concentration on the membrane flux and salt rejection.

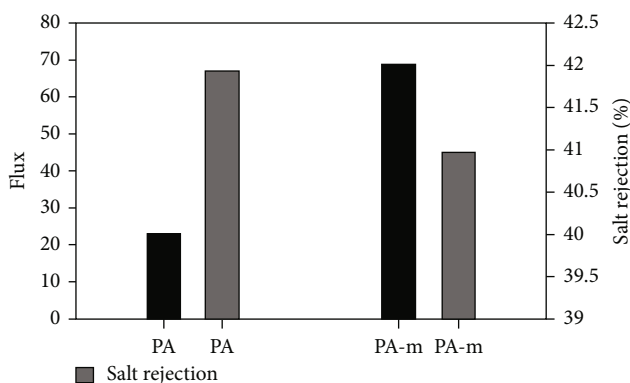


FIGURE 9: Flux and salt rejection of unmodified membrane (PA) and modified membrane (PA-m) of feeding water.

Fourier transform infrared spectroscopy (FT-IR) to identify its functional groups. The morphological studies were carried out using a scanning electron microscope (SEM). The membrane performance was determined by measuring of water flux and rejection of salt during desalination of 2000 ppm of Dawmat Al-Jandal Lake water samples.

3.1. Characterization of PA Sheet

3.1.1. FT-IR Analysis. The amide I, amide II, amide III, and amide A bands are labeled as amide characteristic peaks. Figure 4 exhibits the notable IR characterizations of amide

at 1760 cm^{-1} , 1650 cm^{-1} , 1100 cm^{-1} , and 3350 cm^{-1} which are assignable to amide I (C=O str), amide II (C-N str+C-N-H bend), amide III (C-N str+C-N-H bend), and amide A (N-H str), respectively. These bands confirm the formation of amide group after polymerization reaction [41].

FT-IR spectrum of the PA membrane and PA membrane with myrrh showed that there is no difference after addition of myrrh to the PA membrane. It could be attributed to the low percentage of myrrh quantity.

3.1.2. SEM Analysis. Scanning electron microscopy images showed that there were two layers. The top thin layer confirms the formation of polyamide layer during the interfacial polymerization. The substrate layer is representing the polysulfone layer showed in SEM images in Figure 5. Figure 5(a) presents the image of RO membrane sheet that is used in the flux cell while Figure 5(b) shows SEM image illustrating two layers of composite membrane (polyamide and polysulfone). Polysulfone layer is illustrated in Figure 5(c), while Figure 5(d) shows the upper layer polyamide and the ground layer polysulfone.

The ability of modified membrane to resist bacterial growth was tested, and SEM images had been taken. In Figure 6, it shows that there was limited growth of bacteria on membrane surface. In addition, the shape of bacterial walls illustrated imperfection which leads to proceed to the approach to add antimicrobial studies in Section 3.4.

TABLE 1: Inhibition zone diameters of modified and unmodified polyamide sheet.

Isolates	Diameter of inhibition zone (mm)		
	Unmodified polyamide sheet	Modified polyamide sheet before water treatment	Modified polyamide sheet after water treatment
<i>Aspergillus flavus</i> (JU-F 0140)	3 ± 2.1*	34 ± 0.1	32 ± 0.1
<i>A. fumigatus</i> (JU-F 0141)	0	25 ± 0.12	25 ± 0.2
<i>A. niger</i> (JU-F 0142)	0	31 ± 0.2	29 ± 0.2
<i>A. ochraceus</i> (JU-F 0143)	1 ± 0.9	28 ± 0.1	28 ± 0.1
<i>Paecilomyces variotii</i> (JU-F 0144)	0	19 ± 0.16	19 ± 0.1
<i>P. chrysogenum</i> (JU-F 0145)	1 ± 1.2	39 ± 0.12	36 ± 0.2
<i>E. coli</i> (JU- F 0146)	0	29 ± 0.1	29 ± 0.1
<i>Bacillus subtilis</i> (JU-F 0147)	0	16 ± 0.1	16 ± 0.1

*Diameter of inhibition zone (mm) = average zone of growth inhibition diameter ($n = 3$).

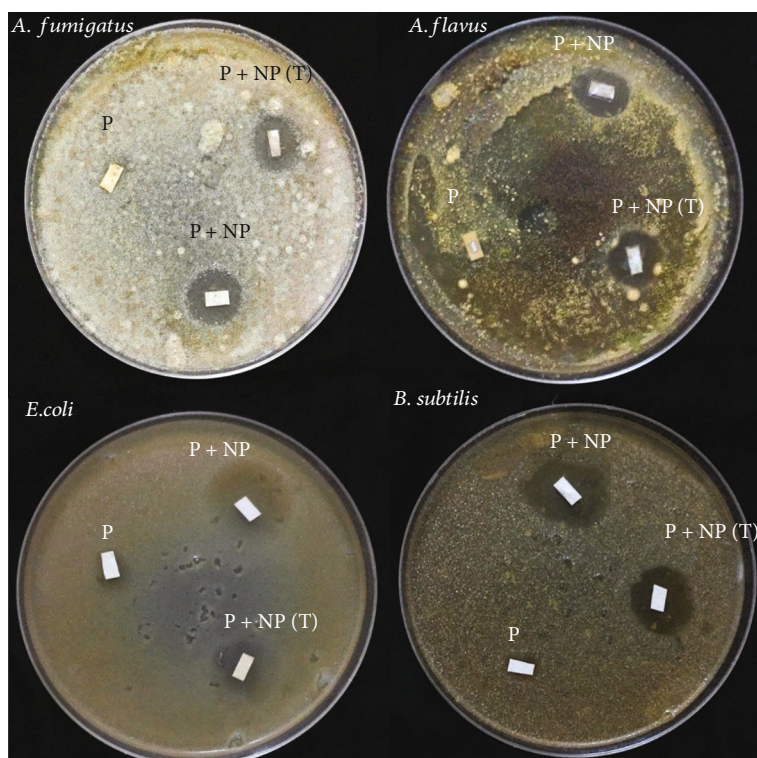


FIGURE 10: Effect of basic unmodified polymer (P), modified polymer with myrrh before treatment (P+NP), and modified polymer with myrrh after treatment (P+NP(T)) on the growth of different microorganisms.

3.2. Flux and Salt Rejection. The performance of the membrane in terms of flux and salt rejection was calculated using a solution of salted samples. Figure 7 indicates that after adding 16 bar pressure, the flow of the membrane dropped drastically in the first 15 minutes, which is due to the membrane layers being compressed as a consequence of the high pressure. After 15 minutes, the flow of the membrane was steady, allowing for a valid measurement. The calculation of flux is obtained after one hour when the flux of the membrane is stable. Then, the flux amount is figured out depending on the average of the last 10 records according to this procedure.

The organic solution plays an important role in the formation of polyamide layer as an active layer in RO membrane. Therefore, a series of organic solutions was prepared (0.1, 0.2, 0.3, and 0.4 M) and used to form the polyamide layer. This membrane performance (flux and salt rejection) is measured and illustrated in Figure 8.

In general, the flux of prepared membranes was decreased as a normal result of increasing of cross-linking of polyamide layer. However, the prepared membrane with high concentration of organic solution (0.4 M) showed some increasing of the flux but there were some defects in solution preparation. On the other hand, the salt rejection increased

TABLE 2: Levels of aflatoxins in the isolated fungal species.

Sample	AFG1	AFG2	AFB1	AFB2
<i>Aspergillus flavus</i>	1.61* ± 0.21	4.35 ± 0.24	3.89 ± 0.60	2.56 ± 0.23
<i>A. fumigatus</i>	—	—	3.19 ± 0.1	2.21 ± 0.09
<i>A. niger</i>	—	—	5.46 ± 0.32	3.26 ± 0.02
<i>A. ochraceus</i>	—	—	1.46 ± 0.32	2.26 ± 0.02
<i>Paecilomyces variotii</i>	—	—	—	—
<i>P. chrysogenum</i>	—	—	—	—

*ppb: parts per billion.

in general because the cross-linking of polyamide increased. The salt rejection of the prepared membrane with high concentration started to decrease as a result of defects in solution preparation. As a result, the prepared membrane with a concentration of 0.3 M was selected in this work.

3.3. Modification of Membrane. Modification of membrane with natural product, myrrh, was investigated according to the flux and salt rejection of feeding water samples. Figure 9 shows the flux of unmodified membrane and modified membrane. It is obvious that there was no remarkable difference between the two membranes. The similarity in flux indicated that there was no change on membrane performance when the modification of membrane with myrrh was done.

3.4. Antimicrobial Studies. This is the first study that describes the activity of myrrh as an efficient and safe natural product additive to polyamide in RO process for water desalination against different microorganisms in water, which shows that myrrh has a strong and distinct antimicrobial action, mainly against certain fungi and bacteria; according to our findings and its unique property, myrrh's low toxicity and low proclivity for antibiotic resistance development imply that it can be evolved into a viable and perfect antimicrobial with lower dose needs [42].

In this study, the antimicrobial activities were evaluated by determination of inhibition percentages of studied polymer sheets (Table 1).

The antimicrobial activities for modified polyamide sheets (after addition with myrrh) before and after water fluxing process were studied. By comparing the inhibition percentages and the diameters of inhibition zones of polyamide sheets before and after water flux, we can conclude that there are no significant differences in inhibition efficiencies, which confirms that the effect of myrrh continued for long period as an antimicrobial agent. These results confirm the main objective of this work which is aimed at using a myrrh as an efficient and safe antimicrobial agent as additive to polyamide sheet for water desalination (Figure 10).

3.5. Detection of Aflatoxin by Using TLC Technique. Table 2 shows the concentrations of aflatoxins (AFG1, AFG2, AFB1, and AFB2) detected in the isolated fungi. The concentration of the total aflatoxins (TA) was 12.41, 8.72, 5.4, and 3.72 ppb in *Aspergillus flavus*, *A. niger*, *A. fumigatus*, and *A. ochraceus*, respectively. *Aspergillus flavus* demonstrated a higher

concentration of total aflatoxins than *A. fumigatus*, *A. niger*, and *A. ochraceus*. In addition, *Aspergillus flavus* comprised a proportion of each one of the four types of aflatoxins, while *A. fumigatus*, *A. niger*, and *A. ochraceus* samples comprised only two types of aflatoxins (AFB1 and AFB2).

No aflatoxins have been detected in any of *Paecilomyces variotii* and *P. chrysogenum*.

Generally, it is worthy to mention that the concentration of both individual and total aflatoxins still lasts under the action levels recommended by FDA.

Mycotoxins are toxic low molecular weight biomolecule secondary metabolites produced by pathogenic fungi under suitable growth conditions that lead to disease or death to humans or animals when ingested. All isolated fungi produced mycotoxins. Table 2 shows the concentration of aflatoxins in isolated fungi. Aflatoxin G1, aflatoxin G2, aflatoxin B2, and aflatoxin B1 were detected in *A. flavus* only, while aflatoxin B1 and aflatoxin B2 were detected in *A. niger*, *A. fumigatus*, and *A. ochraceus*. The average concentration of aflatoxins was 5.04 ppb, the total isolated fungi did not exceed the maximum range recommended by FDA which is 20 ppb. Banu et al. isolated 13 different fungi from sources of drinking water; five isolates of *Aspergillus flavus*, isolated from the drinking water samples, were further screened for its production of aflatoxin by TLC, HPTLC, and IR and quantified by HPLC [42]. This ranged from 0.00052 to 0.00075 µg/l. For the evaluation of ability of two mycotoxigenic species, *Aspergillus flavus* and *Aspergillus niger*, to produce aflatoxin B1 (AFB1) and ochratoxin A (OTA), respectively, the results indicate that *A. flavus* has a higher optimum temperature for mycotoxin synthesis than *A. niger* and takes greater advantage of drier conditions for maximum AFB1 production [43].

4. Conclusions

In this study, polyamide sheet resulting from polymerization of trimesoyl chloride and m-phenylenediamine was prepared as RO membrane for desalination process. The polyamide sheet was modified with myrrh addition aiming to enhancement of antimicrobial properties. All membranes were characterized with IR and SEM to confirm the polymer formation. In addition, water flux and salt rejection were determined using Dumat Al-Jandal Lake water as feeding water. Unmodified RO membrane showed 25 and 65% for flux and salt rejection, respectively, while the modified membrane showed 42 and 41% for flux and salt rejection,

respectively. Modification of RO membrane with myrrh showed promising results in terms of microorganisms' prevention. Results of microbial growth tests present less rate of bacterial growth on modified membrane. In contrast, unmodified membrane had high growth rate of microorganisms.

Data Availability

The data presented in this study are included in this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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