

# PERFORMANCE AND STRUCTURAL INTEGRITY OF TFC REVERSE OSMOSIS MEMBRANES USING ACID ACCEPTOR IN INTERFACIAL POLYMERIZATION

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**ABSTRACT:**Hydrochloric acid can be produced when trimesoyl chloride (TMC) and m-phenylenediamine (MPDA) mix at the interface. In order to make MPDA less reactive, this acid goes back to the water phase after its creation and adds a proton. The result is a decrease in polymer production and an improvement in the membrane's performance. It is also possible to use the IP to study different acid acceptors (AAs) in order to make a polyamide-based barrier layer that acts as a reverse osmosis membrane. The main goals were to (1) remove the hydrochloric acid that is formed during IP and (2) build a barrier that could reject a large amount of salt while still allowing a large amount of salt to pass through. Several AAs, including TEACSA, TPP, SH, and TSP, sought to learn more about membranes and how they worked. There was some variation in the concentrations used for each. Subsequently, scanning electron microscopy (SEM), atomic force microscopy (AFM), a surface profilometer, energy-dispersive X-ray spectroscopy, and a contact angle goniometer were used to analyze the membrane samples. The addition of organic AA improved the membranes' water permeability and salt rejection capabilities simultaneously, according to the data. Optimal membranes were produced for TEACSA, TPP, SH, and TSP with AA concentrations of 3.4, 0.15, 0.02 and 0.19 weight percent, respectively. Adding AA to the membranes enhanced their hydrophilicity, water flow, and surface area difference. Using organic AAs resulted in a thicker polyamide layer and more cross-links in the membrane when compared to artificial AAs. The physical changes to the membranes during IP for the formation of polyamide nanocomposite membranes also proved that the AA successfully removed hydrochloric acid and stopped the formation of amine salts.

**Keywords:** *TFC, RO, Acid Acceptor, Polyamide Layer, Chemical Stability, Surface Properties, Desalination*

## 1. INTRODUCTION

Hybrid membrane was created by Cadotte and colleagues in the 1970s. A polysulfone substrate membrane with holes in it and a thin coating of polyamide (PA) made it up. Condensation polymerization was used to synthesize the PA in situ from branching polyethyleneimine and 2,4-diisocyanate. Since then, the interfacial polymerization (IP) reaction method has become the go-to for PA-based thin film composite (TFC) membranes owing to its high selectivity,

convenience of use, and high efficiency. To generate aromatic PA-TFC membranes that filter water to make it drinkable, in-situ IP techniques usually use M-phenylenediamine (MPDA) and trimesoyl chloride (TMC) or different forms of these chemicals.

The aromatic PA-TFC membrane's ability to remove salt from water is influenced by the molecular chemistry, molecular amount, and structural composition. The membrane's chemical make-up, surface

charge, and hydrophilicity are all intrinsic properties. Additionally, the IP films' cross-link density, thickness, and form are all set in advance. Research on reverse osmosis (RO) and nanofiltration (NF) membranes has focused on the structure-function link of the active layer, surface shape, and irregularities. The formation of IP-induced PA films is governed by kinetics and diffusion, which are self-limiting processes. If you're making an IP or PA film, acid chloride is one organic monomer that won't break.

After passing through a PA film, the organic component and the polymer interface undergo a rapid reaction involving the acid chloride and the water-soluble monomer, such as an amine. Several IP reaction possibilities that reflect the structural features have been identified, allowing for the creation of a unique IP film. An effort at a membrane was made in one of these experiments by combining a water-based solution of an amine or organic acid chloride with other compounds. Hybrid membranes can have their physical and chemical properties changed by adding catalysts, polar and apolar fluids, surfactants, metal/metal oxide nanoparticles, and other compounds. Two types of additives exist, distinguished by the effects they have on the IP film: those that change the film's physical properties while still being trapped in the PA matrix, and those that change the film's qualities outside of the matrix. The first sort of addition improves the TFC membrane's ability to remove salt and water by speeding up the IP reaction.

The intrinsic properties of the PA barrier layer are impacted, either directly or indirectly, by this. The presence of a polar solvent in the aqueous phase, like dimethyl sulfoxide (DMSO), allows the water

molecules and the monomer of the aqueous phase to flow through the IP sheets more easily. Without drastically reducing the membrane's salt rejection capacity, this technique raises water flow. If two solutions don't mix well, acetone can help narrow the solubility gap just like dimethyl sulfoxide (DMSO) can. Kong et al. developed TFC NF membranes by combining the organic phase with acetone, a co-solvent.

Because of this, they were able to change the width of the active layer using nanopores. Mansourpanah et al. changed the PA layer's properties by incorporating detergents into an organic phase. Triton X-100, which is not ionic, and cetyltrimethylammonium bromide, which is cationic, were these surfactants. Researchers found that the membranes improved performance and increased the PA layer thickness by facilitating the entry of more amine monomers into the organic phase. The second group of additives comprises catalysts, tiny particles, metal oxides, and metal salts that have been mechanically or chemically trapped in the PA matrix. For example, zeolite, silica, and TiO<sub>2</sub> nanoparticles improved the TFC nanomembranes' ability to draw water, retain their shape, and avoid fouling. They also outperformed expectations.

Other materials can be used to build a TFC membrane, but an AA catalyst is still the only way to neutralize hydrochloric acid. Figure 1 shows that the IP reaction between MPDA and TMC continues, with hydrochloric acid being a result. This causes a drop in pH in the reaction media. The protonation of MPDA makes the membrane less reactive, allowing the acid that results to seep back into the water. Consequently, the membrane's efficacy drops and less polymer is produced.

Further, triethylamine (TEA) and other organic AA (catalyst) compounds have been used to inhibit amine protonation and provide repeatable, consistent improvements in TFC membrane performance.

To achieve the desired synergistic effect, AA was mixed with the other chemicals to form multifunctional PA membranes. For example, monosodium phosphate, sodium hydroxide, triethylamine, and N,N-dimethyl piperazine are common AAs used to construct poly(piperazine amide) TFC NF membranes. A catalyst in a water-based monomer phase was tetrabutylammonium bromide, which Jayarani and Kulkarni used to change the shape of the TFC poly(ester amide)-based membrane. AA is usually found in amounts between 0.1% and 1% by weight. The adding process flattened an IP answer. Adding an AA, such TEA, to the watery medium thickens the membrane without changing the pore size, as shown in the study. There has been considerable discussion in the literature about using aromatic PATFC reverse osmosis (RO) membranes, but no comprehensive examination of the impact of AAs on membrane structure and performance has been conducted.

The function and properties of TFC membranes and the function of AAs as an IP trigger are investigated in this work. When conducting an IP reaction with solutions of organic acid chloride or aqueous amine, several acid acceptors have been employed to avoid the formation of amine compounds. Thicker, rougher, surface area difference (SAD), shaped, contact angle, chemically composed, and crosslink density membranes were shown to be more effective and easier to build. Test results

show that membranes made entirely of TEACSA altered in the physicochemical structures mentioned before, had an increase in water flow, and a salt rejection rate that nearly approached >98%.

## 2. EXPERIMENTAL

### Materials

Dow Chemicals was our US vendor of choice for the polysulfone (PSF) membrane material. The chemicals MPDA and TMC were sent by the American company SigmaAldrich Co. Hexane, dichloromethane, chloroform, triphenyl phosphate (TPP), trisodium phosphate (TSP), sodium carbonate, sodium hydroxide (SH), and sodium carbonate were among the chemicals bought from Merck & Co., USA. In India, D(+)-10-camphorsulfonic acid (CSA) was sold by Spectrochem Pvt. Ltd.

### Membrane preparation

Figure 1 shows the steps used to construct TFC membranes: hexane with a TMC solution and Milli-Q water with a new MPDA solution. We mixed water into the MPDA solution with the measured amounts of triethylamine camphorsulfonic acid (TEACSA) salt, SH, TSP, and other AA salts. Shortly after that, TPP was included into the TMC hexane mixture. To make TFC membranes, the amounts of AAs and monomers are listed in Table 1. For the first three minutes of its creation, the PSF base support membrane was immersed in a water MPDA solution. To create an IP film, it was dried on the surface and then exposed to a TMC solution produced in hexane for 50-60 seconds. The membrane was oven-dried for five minutes at 80 °C after the excess TMC solution was removed. A sodium carbonate solution with a concentration of

0.2 (w/v%) was then used to clean it at 50 °C. After the membranes were rinsed with distilled water, they were sealed in a container to be tested and characterized for performance.

### Membrane characterization

The surface profiler (Dektak 150 Stylus Profiler, Veeco Instruments Inc., USA) was used to measure the thickness of the separated PA thin films that were placed on glass slides. The first step in removing the PSF barrier was to remove the non-woven polyester material. After that, a glass slide was covered with a PSF membrane that had been coated with PA, with the PA side facing the glass. The top layer of PSF was removed by dripping chloroform and dichloromethane from the burette. Once it had dried, the PA film stuck to the window pane. The use of a stylus to move across the glass slide and touch the thin layer of polyamide revealed minimal vertical features, often known as vertical height. The glass slide surface was pushed with a force of  $9.8066 \times 10^{-6}$  N using a diamond pen to produce a thin film with a thickness of 12.1  $\mu\text{m}$  and a total scan length of around 1000–2000  $\mu\text{m}$ . The scan length function was used to measure the change in height of the vertical pen.

Table 1; Compositions of aqueous and organic phase monomers used for membrane preparation by IP.

| Membrane | Aqueous phase            |                         |                       | Organic phase TN (w/v%) |
|----------|--------------------------|-------------------------|-----------------------|-------------------------|
|          | MPDA (wt.%) <sup>a</sup> | AA (wt.%)               | pK <sub>a</sub> of AA |                         |
| TFC0     | 2.25                     | -                       | -                     | 0.125                   |
| TFCSH    | 2.25                     | Sodium hydroxide (0.02) | 13.8                  | 0.125                   |
| TFCTSP   | 2.25                     | TSP (0.19)              | 11.8                  | 0.125                   |
| TFCTC    | 2.25                     | TEACSA salts (3.4)      | 10.8 [25]             | 0.125                   |
| TFCTTP   | 2.25                     | TPP <sup>b</sup> (0.11) | 10 [26]               | 0.125                   |

<sup>a</sup> pK<sub>a</sub> value of MPDA is 5.11 [27]

<sup>b</sup> TPP was added in TMC solution in hexane.

We used field emission gunscanning electron microscopy (FEG-SEM) (JEOL,

JSM-7600F) to look at the membranes' surface composition. To keep the membrane from charging, a 10 nm layer of platinum was sputter-coated (JFC-1800) on top of it. A 10 kV voltage boost was used to take SEM pictures. Isolated polyamide thin plates were analyzed for C, N, and O using energy-dispersive X-ray spectroscopy (EDAX). An Atomic Force Microscope (AFM) in tapping mode and a Nanoscope IV scanning probe microscope with a 6642J scanner (Digital Instruments Multimode, Singapore) were used to investigate membranes and assess the roughness of the PA surface. We used the AFM pictures to find the roughness factors, surface area difference, root mean square, and roughness (R<sub>q</sub>).

A contact angle goniometer (DIGIDROP, GBX Instruments DS Model, France) was used to assess the water-friendliness of the PA membrane surface after the membrane samples were dried and affixed to the glass slide.

### Desalination performance

A feed solution containing 2000 parts per million NaCl was pumped at 1.5 MPa (225 pressure) using a cross flow permeation cell made in the USA by Sterlitech Corporation. The flat sheet membrane and 42 cm<sup>2</sup> active area are characteristics of this cell. An hour after that, we took water permeate to figure out the flow (J, lm-2d-1) and rejection (R, %) for each. Using a conductivity meter (Orion 145A+), the salt content in the feed (C<sub>f</sub>) and permeate (C<sub>p</sub>) was computed. Using the standard calibration curve, we were able to determine the real concentration of NaCl. The water permeability (P, m/Pa s) and rejection (R, %) were then determined using the aforementioned formulas (1) and (2), respectively.

$$R = \left(1 - \frac{C_p}{C_f}\right) \times 100$$

$$P = \frac{J_v}{A \cdot t \cdot \Delta P}$$

The amount of water that moves ( $J_v$ ) and the time it takes ( $t$ ) are also given. The unit of membrane area is  $m^2$ , and the unit of transmembrane pressure is Pa.

### 3. RESULTS AND DISCUSSION

#### Membrane performance and AAs optimization

The properties of the IP-produced thin film dictate how effective the TFC-RO membrane is. Similarly to how IP rates can be changed, the properties of the resulting PA film can also be changed. The new MPDA water mix had a pH greater than 8 when the IP operation started. The IP reaction kinetics investigation showed that the pH of the reaction medium steadily dropped as the IP reaction went on because the diamine content went down. One further thing that causes the pH drops is the hydrochloric acid that is generated during the IP, as seen in Figure 1.

When exposed to strong acids like hydrochloric acid, MPDA interacts with acyl halides less readily, and it is easily protonated. Slower growth of the PA barrier layer reduces the polymer yield.

An AA is necessary for the PA hybrid membrane to operate at its optimal level. When the strength of AAs is higher than that of MPDA ( $pK_a(AA) > pK_a(MPDA)$ ), they can inhibit the synthesis of amine compounds by reacting with hydrochloric acid.

Table 1 shows that the  $pK_a$  values of the several AAs chosen for this study are greater than hydrochloric acid's ( $pK_a -8$ ). A proton removal by AAs is thus anticipated to be necessary for the

formation of a conjugate acid capable of reacting with hydrochloric acid. Consequently, the protonation of MPDA will be reduced. Here we can see the IP reaction scheme (Figure 2) that is used to make PA membranes. With a higher  $pK_a$  (5.11), diamines like MPDA act as AAs (bound as hydrochloride compounds) when no AA is present, allowing hydrochloric acid ( $pK_a -8$ ) to deprotonate more quickly and facilitating diamine hydrolysis.

This is shown in the IP diagram. A critical step in the IP process is the breakdown of diamine, which controls the pace at which the reactant reaches the organic phase. Synthetic AAs (SH, TSP) and organic AAs (TEACSA salt) were added to the water phase because to their great solubility in water. However, TMC was able to degrade an organic AA TPP in hexane, which is the organic phase.

Testing the membrane's ability to remove salt from water helped establish the optimal AA content for TFC membrane development. Figure 3 shows that the capacity of the membrane to exclude salt and permit water to pass through is proportional to the concentration of AA. Increasing the concentration of AAs enhanced the water-transfer capabilities of the membranes. The water-repellent properties of the membrane were enhanced as the organic AA content rose. With a rise in AA content, however, membranes were produced with a diminished ability to reject salt. A small reduction in salt rejection was seen upon the addition of inorganic AA.

It was constantly observed that the flow through the AA-construct membrane was higher than that via the non-AA-construct membrane. We found that 0.02 weight percent inorganic AAs SH and 0.185

weight percent TSP were the best concentration levels. Once concentrations beyond that threshold, membranes exhibited decreased rejection rates and increased flow. A concentration of 0.15 weight percent resulted in these improvements.

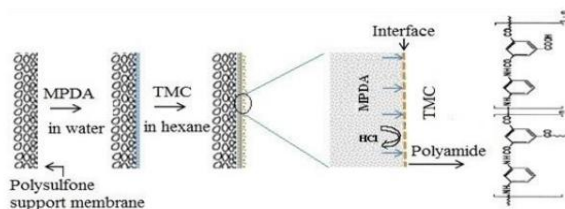


Fig. 1. Schematic of IP technique for TFC membrane preparation.

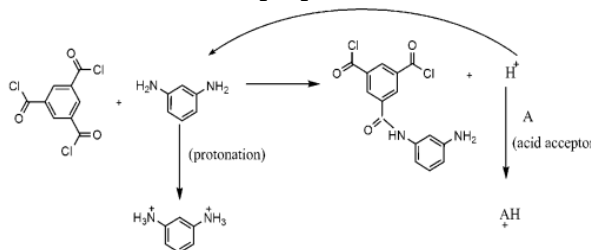


Fig. 2. Schematic of IP reaction mechanism in the presence of AA.

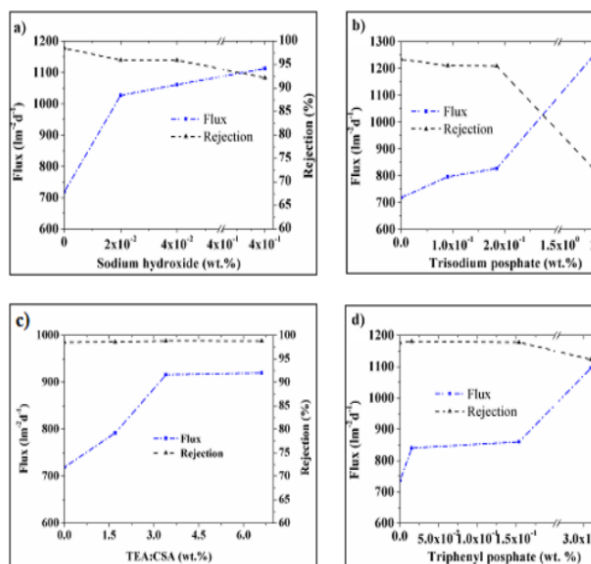


Fig. 3. Flux and rejection profile of TFC membranes made using different concentration of AAs (a) SH, (b) TSP, (c) TEACSA, and (d) TPP.

### Physiochemical properties of membranes

The physiognomies, water flow, and salt rejection of composite membranes made

with the correct amount of AA are shown in Table 2. Types of composite membranes that are devoid of AA include TFC0, TFCSH, TFCTSP, TFCTC, and TFCTPP. This membrane has the correct amounts of SH, TSP, TEACSA, and TPP. The correct quantity of organic AA was used to form the membrane, which maintained its ability to reject salt while allowing a lot more water to pass through. More dependable in terms of letting and blocking water flow, the AA-made barrier was shown by the standard deviation data. This TFC membrane might find a place in RO.

The usual height profile distribution of the PA thin film after detaching it from the TFC membranes is shown in Figure 4. We measured and recorded the height profiles of small vertical features by scanning the PA surface and glass surface at a predefined distance using a diamond pen. Membranes with TFCTC and TFCTPP PAs were thicker than those with TFCSH and TFCTSP PAs. The average PA thickness of the TFC0 membrane, on the other hand, was extremely thin. As a consequence of organic AAs hastening the IP process and easing the transit of water-soluble monomers over the interface, the PA membrane thickened.

Owing to the high flux, organic AA-made membranes were able to overcome the thicker PA layer. These things happen because organic AAs and other organic solvents dissolve more amine, which speeds up the water flow [6]. To make the network holes larger and increase the amount of water that can pass through, organic chemicals such as TEA are added to the TFCTC membrane [29]. The addition of an artificial AA to the water phase caused two reactions: (i) The water phase's catalytic role was to increase the

amine's reactivity by creating a small reaction zone, thanks to its pH range of 10–11.5. (ii) Once the inorganic AA and TMC's acid chloride groups were joined, the  $pK_a=3.11$  acid chloride was more likely to dissolve since sodium hydroxide is a strong basic. This can create an open layer on top. Because of the inherent tension between the two processes, thinner, more hydrophilic higher and flux membranes evolved upon the introduction of artificial AA.

Using a scanning electron microscope (SEM), Figure 5 shows the hybrid membranes' surface shapes. The surface of the membrane has a noticeable rough texture. There are big, closely spaced protuberances that seem like folds on TFCSH and TFCTSP. TFC0 had sharp edges and closely spaced protuberances that looked like folds, but TFCTPP and TFCTC had huge, unrelated asperities. These features of TFC membranes with the right amount of AA are listed in Table 2.

| Membranes | Flux ( $\text{lm}^2\text{d}^{-1}$ ) | Rejection (%) | Properties     |                       |         |               |
|-----------|-------------------------------------|---------------|----------------|-----------------------|---------|---------------|
|           |                                     |               | Thickness (nm) | (rms, Roughness (nm)) | SAD (%) | Contact angle |
| TFC-0     | 719±130                             | 98.5±0.3      | 204            | 66.3                  | 5.1     | 63.1          |
| TFCSH     | 1061±25                             | 95.8±0.4      | 116            | 79.8                  | 8.4     | 61.3          |
| TFCTSP    | 828±24                              | 96.7±0.2      | 159            | 64.9                  | 7.7     | 58.5          |
| TFCTC     | 916±12                              | 98.8±0.1      | 260            | 75.2                  | 8.3     | 60.6          |
| TFCTPP    | 860±23                              | 98.5±0.2      | 178            | 69                    | 7.9     | 60.8          |

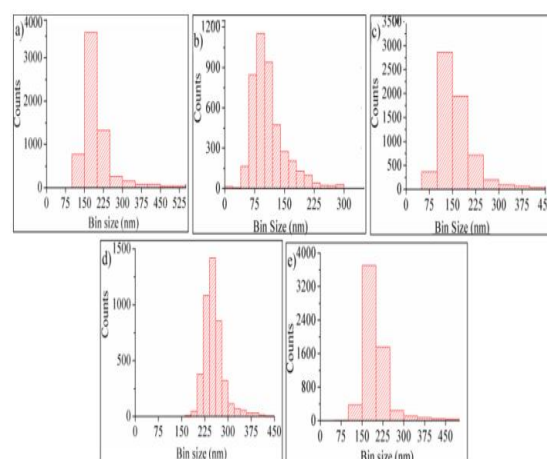


Fig. 4. Profilometry histograms showing thickness distribution of isolated PA film from (a) TFC0, (b) TFCSH, (c) TFCTSP, (d) TFCTC, and (e) TFCTPP membrane.

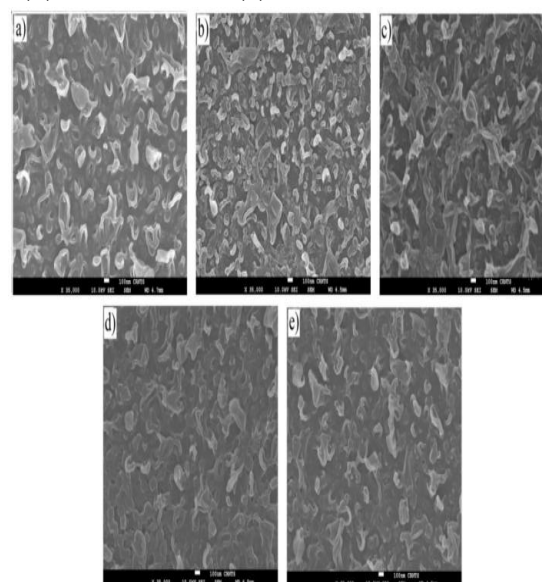
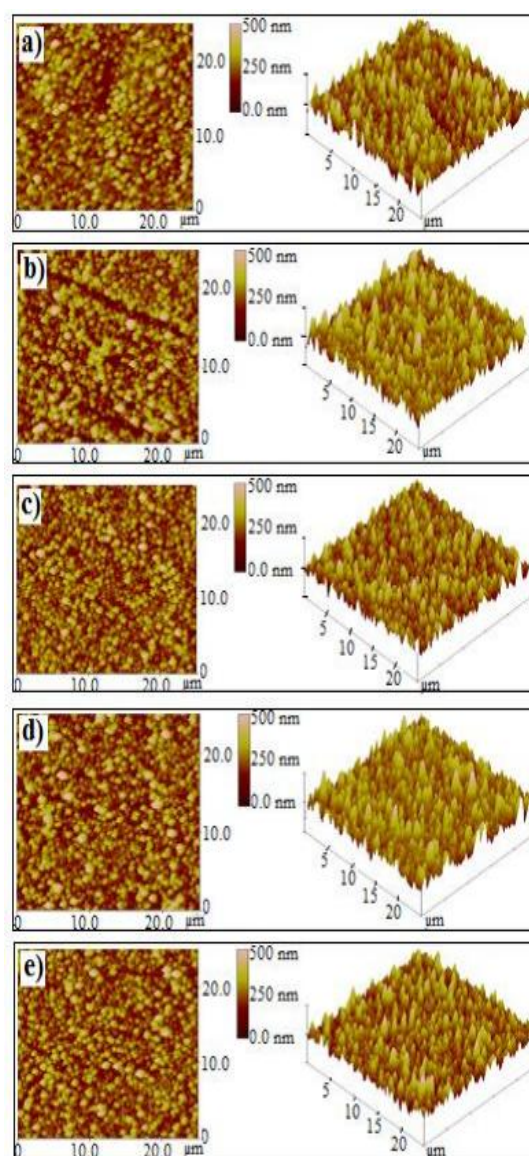


Figure 5 shows the FE-SEM structure of TFC membranes that were produced with and without AA, with the former including SH (0.02% weight percent), TSP (0.19 weight percent), TEACSA salts (3.4 weight percent), and TPP (0.15 weight percent).

Figure 6 shows the 2D and 3D surface topography images obtained from AFM for all composite PA membranes made with the correct amount of AA. The images have a projection area of  $25\text{ }\mu\text{m} \times 25\text{ }\mu\text{m}$ . Surface roughness and SAD were among the physical properties that were statistically assessed using AFM.

Topographical pictures clearly show that AA-containing TFC membranes had more ridge-and-valley structure than AA-free membranes. A bar on the right side of each image shows the height changes of the membrane surface; darker sections show the membrane's dip or depression, while lighter parts show the membrane's peak. In comparison to TFC0, the surfaces of TFCTSP, TFCTC, TFCTPP, and TFCSH seem rougher. There is some evidence that the surface shape of TFC membranes affects the flow and rejection parameters. As shown in Figures 5 and 6, the PA surface of TFC membranes exhibited striking roughness, accompanied by massive spikes of inorganic AA of 300 to 500 nm in size. This may have led to more aggregate holes, which in turn would have produced flaws like nanopores that may have let salt and water pass through. In terms of organic AA, it seems that PA TFC membranes have a greater number of 100-300 nm broad spikes on their surface. The net effect can be an increase in water flow without a decrease in salt rejection due to fewer flaws and larger holes in the network.



Images of TFC membranes with and without AA, created using AFM, are shown in Figure 6 as 2D and 3D landscapes. TEACSA salts (3.4 weight percent), SH (0.02% weight percent), TSP (0.19 weight percent), and TPP (0.15% weight percent) were the ingredients utilized to make the membranes.

Using the appropriate amount of AA, Table 2 displays the roughness characteristics of membranes. The surface roughness and SAD of TFC membranes produced with AAs were noticeably worse than those of TFC membranes produced without AAs. The higher water flow rates compared to TFC0 are caused by the

rougher surfaces, higher SAD, and stronger hydrophilia of TFCSH, TFCTSP, TFCTC, and TFCTPP. Chemical composition, cross-link density, and physiological features were only a few examples of how the molecular structure affected the membranes' effectiveness. This clarified the effect of AA on the synthesized PA membranes for us. Researchers used EDAX on a separate PA film to study the effects of AA on the chemical composition, specifically amide bonds. Table 3 displays the relative oxide, nitrogen, and carbon concentrations in the TFC membranes as evaluated by EDAX. Also shown are the N/O, O/C, and N/C ratios. To find out what the PA barrier layer really is chemically, we employed a standard PA chemical formula to break it down into its cross-linked and linear components (Figure 7). According to the formula, the linear section has free pedant carboxylic groups, but the cross-linked section has an extra amide bond. Table 3 shows the relative ratios of atomic amounts, which we used to identify the chemicals in the PA matrix's cross-linked (x) and linear (y) components.

By utilizing the chemical formulae for the cross-linked component (C<sub>18</sub>H<sub>12</sub>N<sub>3</sub>O<sub>3</sub>) and the linear component (C<sub>15</sub>H<sub>10</sub>N<sub>2</sub>O<sub>4</sub>), the values of N/O and x+y=1 can be determined. The x and y values shown in Table 4 are derived from this estimate. In TFCTPP (2.1) and TFCTC (5.2), the ratio of cross-linked polyamide to linear polyamide is larger than in TFCTSP (1.5) and TFCSH (1.5). But TFC0's ratio of 1.8 shows that adding synthetic AAs sodium hydroxide (TFCSH) and trisodium phosphate (TFCTSP) decreases the amount of cross-linked part.

As a first step, the water molecules cross the membrane and reach the surface.

Hydrogen bonds are formed with the PA layer as they pass across the membrane. Transmembrane pressure, however, forces them to leave the surface of the membrane. This mechanism is called diffusion penetration via RO membranes. A PA RO membrane's water flux is proportional to its barrier thickness and the number of hydrogen bonding sites it contains.

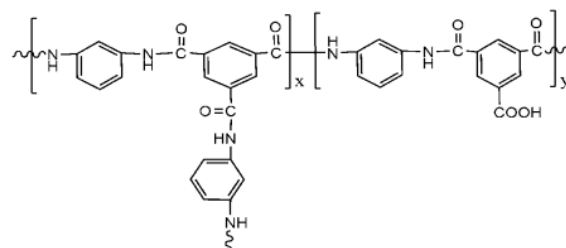


Fig. 7. Schematic of chemical formula of PA membrane showing cross-linked and linear repeating unit.

Table 3 Chemical composition of the TFC membranes.

| Membranes | Catom % | Natom % | Oatom % | N/O  | O/C  | N/C  |
|-----------|---------|---------|---------|------|------|------|
| TFC0      | 58.73   | 18.19   | 23.08   | 0.79 | 0.39 | 0.31 |
| TFCSH     | 56.76   | 18.76   | 24.48   | 0.77 | 0.43 | 0.33 |
| TFCTSP    | 55.82   | 19.14   | 25.04   | 0.76 | 0.45 | 0.34 |
| TFCTC     | 54.19   | 21.72   | 24.09   | 0.9  | 0.44 | 0.40 |
| TFCTPP    | 56.18   | 19.61   | 24.21   | 0.81 | 0.43 | 0.35 |

The presence of strong acid acceptor catalysts in SH and TSP membranes can cause TMC hydrolysis to leave behind a mostly carboxylic acid group in PA. There is less resistance to mass movement and more water dispersion due to the thinner PA barrier. For whatever reason, the higher crosslink section in TFCTC and TFCTPP membranes suggests that there are more amide bonds. This occurs because the organic AA helps diamine migrate into the organic phase and decreases the difference in mixing efficiency between the two phases of the

solution. So, this controls the stress at the boundary between incompatible phases during IP.

This suggested that higher crosslink densities in TFCTC and TFCTPP membranes were more effective in preserving the rejection capability. Thicker membranes may not be able to improve water diffusional movement as much as thinner ones with more amide connections and network pores because of hydrogen bonding through these holes.

In Table 5, we can see the results of desalination screens made with TEACSA and with and without organic additions. Table 5 shows that compared to membranes without the acid coating, all membranes built with the organic acid acceptor (TEACSA) permitted a higher water flux. The discovery that TFNCM containing silica nanoparticles permitted two to three times the water to pass through compared to TFNCM without TEACSA was also made, as shown in Figure 8. Utilizing an acid acceptor catalyst during IP for TFC membrane synthesis not only resulted in a more highly crosslinked membrane, but it also ensured a consistent IP reaction and membrane production, leading to repeatable results in water flow and salt rejection.

## 4. CONCLUSION

The goal of this research was to find an AA-based solution that could neutralize the hydrochloric acid that is generated during the IP process. With the injection of AA during IP, the average water flow through all membranes was enhanced. The inorganic acid acceptor's salt rejection went down a notch, but it was still over 96%. Even at its most robust, the organic

AA membrane persisted in rejecting all substances. Organic AA, being an AA, absorbed the hydrochloric acid that was created, allowing the organic and watery stages to combine more easily. Thus, the IP response was made easier. An increased SAD and a thicker, more hydrophilic membrane were the results of organic AA's presence. In the presence of artificial AA, the IP reaction diluted the TFC membrane and decreased the cross-link density. Because of this, water may flow through with ease. In addition, the most effective TFC RO screens have been developed by integrating diverse inorganic (such as nanoparticles) and organic (such as DMSO) components with TEACSA acid acceptor.

Table 4 Cross-linked and linear fraction of PA matrix

| Membrane | Cross-linked portion with amide linkage (%) | Linear portion with pendant COOH (%) |
|----------|---------------------------------------------|--------------------------------------|
| TFC-0    | 64                                          | 36                                   |
| TFCSH    | 60                                          | 40                                   |
| TFCTSP   | 60                                          | 40                                   |
| TFCTC    | 84                                          | 16                                   |
| TFCTPP   | 68                                          | 32                                   |

Table 5 Effect of TEACSA salt on membranes water permeability (P) and rejection (R).

| Membranes    | AA/additive (wt.%)                     | P ( $10^{12}$ m/Pa s) | R (%) | Ref.       |
|--------------|----------------------------------------|-----------------------|-------|------------|
| TFC          | -                                      | 5.3                   | 98.5  | This study |
| TFC-TEA      | TEA-CSA (1.1)                          | 6.8                   | 98.2  | This study |
| TFC-DMSO     | DMSO (2)                               | 7.8                   | 97.1  | [8]        |
| TFC-DMSO     | TEA-CSA/DMSO (1.1/2)                   | 14                    | 97.2  | [8]        |
| Silica-TFNCM | Silica nanoparticle (0.01)             | 2.7                   | 93.6  | [32]       |
| Silica-TFNCM | Silica nanoparticle (0.01)             | 6.5                   | 95.9  | This study |
| Silica-TFNCM | TEA-CSA/Silica nanoparticle (0.01/1.1) | 8.3                   | 96    | This study |

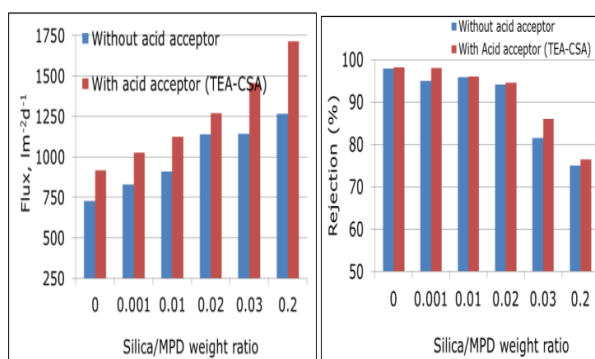


Fig. 8. Interested in learning about the flux and salt rejection performance of thin-film nanocomposite membranes exposed to TEACSA that include different concentrations of silica nanoparticles.

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