Evaluating the performance of chitosan and chitosan-palm membrane for water treatment: preparation, characterization and purification study

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1. Introduction

The membrane technology has arisen as a new approach to regulate drinking water contamination because of its intrinsic features [1,2], in comparison with those other techniques like adsorption; distillation; and extraction. The lack of drinking water has become a significant challenge around the globe in recent years. Due to the rapid progress in humans’ population and industrial water pollution, drinking water resources have been reduced [3]. Human actions have contaminated the water with vast quantities of pesticides, minerals, drugs, and various toxic metals [4–8]. Consequently, novel inventions and resources are being taken into account for the purification of water. Several membranes developed from polymers with biomaterials exhibit vast prospective for water treatment [9]. Various membranes are used for separating particles with several sizes through microfiltration, conventional filtration, ultrafiltration, reverse osmosis, and nanofiltration [10]. Nanofiltration (NF) membrane is among the most effective wastewater treatment activities [11]. It is a comparatively modern improvement in membrane application, and it might be aqueous or non-aqueous. Nanofiltration has substituted reverse osmosis in several technologies owing to lesser energy intake and greater flux rates [12,13]. The NF membrane features lie among non-porous reverse osmosis membranes and porous ultrafiltration membranes [14]. This nanofiltration (NF) is a type of separation membrane technology.

Most recently produced NF membranes are composite membranes comprising an active layer and a support layer. Because of their surface charge, the separation properties of this type of membrane can be determined by the Donnan effect’s co-effect. However, their surface nano-sized pores and mass transport will allow diffusion and convection [15].

Additionally, NF employs many mechanisms to reject salts and inorganic contaminants. Size exclusion is one of these mechanisms used by NF. Ion transport is considerably affected by hydration strength and hydrated radii due to size variations. NF membranes can reject that ions can pass through the pores of the membrane using diffusion approach [15,16].

In this situation, the addition of biopolymers like pure Chitosan and mixing with other biomaterials greatly improves the membranes’ flexibility and performance. Over recent decades, researchers and scientists have found membrane-coated adsorbents to be prevalent, enticing methods for extracting hazardous substances from wastewater, such as volatile organic materials, heavy metals, and dyes. Chitosan-based membranes have evolved to remove numerous pollutants and toxic heavy metals from several water resources among these membrane adsorbents. Chitosan is obtained from chitin deacetylation and is considered to be the second most common natural polysaccharide as a natural polymer. Because of their biodegradability, reactivity, being environmentally-friendly, anti-toxicity, and
desirable hydrophilicity chitosan biopolymers, and their compounds have attracted more attention. Using Chitosan, which is vital to the separation characteristics and active surface substances, can enhance the efficiency of NF membranes. The Chitosan contains 2-amino-2-deoxy- (1, 4)-D-glucopyranose and it is easily formed from the crabs shells, shrimps and prawns [16].

Moreover, Chitosan can be used for a wide application, such as water and wastewater purification [17], elimination of heavy metal ions from aquatic environment [18,19], biomaterials [20, 21], membrane materials [22,23]. Recently Chitosan and its derivatives have been used with nanomaterials for fabrication of NF composite membranes [24–26]. Membranes for nanofiltration applications were prepared from Chitosan, which contains quaternary amine groups.

In the present study, the chitosan membrane was prepared using Chitosan’s biopolymer material, and modified Chitosan with a local natural source, and a palm tree. These membranes have attained great consideration due to their biodegradability, nontoxic, hydrophilicity, and high performance.

2. Experimental

2.1. Materials and methods

Small molecular mass chitosan having a deacetylation extent around 82% and viscosity of 200–800 cP (1% in 1% acetic acid) was purchased from Sigma-Aldrich. Glacial acetic acid was obtained from Asia Pacific Specialty (APS), and Polysulphone supports PS-20, Sepro, USA. In addition, sodium chloride, magnesium chloride, sodium sulphate, calcium chloride, and magnesium sulphate were purchased from Sigma-Aldrich, USA. In this analysis, both solutions and dilutions are developed using Milli-Q® water (resistivity of 18.2 Mcm). Palm was used as a natural material. It was supplied from Al-Hofuf Stars Establishment for Trading, Riyadh, Saudi Arabia, in size 8 mm. Table 1 displays palm material specification.

Table 1. Palm material specifications.

| Resin properties   | Value          |
|-------------------|----------------|
| Lignin            | 21.23%         |
| Hemicellulose     | 20.13%         |
| Cellulose         | 32.11%         |
| Other             | 22.02%         |
| Flash Point       | 200°C          |
| Organic Matter    | 50–60%         |
| Average Density @ 23°C | 1.298 g/cm³ |

The Chitosan solution was made by disintegration 0.5 g of Chitosan in 100 ml of diluted acetic acid. The solution was then heated at 70–80°C for 3–4 h and stirred until the Chitosan was fully soluble for 6 h.

The prepared solutions were then kept overnight at room temperature to cool down. The solution was homogeneous and then isolated to eliminate any insoluble chitosan by a 5.0 µm hydrophobic polytetrafluoroethylene (PTFE) membrane. The final solution was divided into two groups following the filtration.

(i) Chitosan: produced with a homogenous chitosan solution (0.5% w/v) with no addition (Figure 2).

(ii) Chitosan-Palm: Palm micro-particles have been synthesized to diffuse in a homogeneous chitosan solution (0.5% w/v) (Figure 2).

2.2. Palm preparation

Palm was grinded utilizing a crusher machine into different sized particles and then using a sieving shaker machine (FRITSCH, Germany) to use particles with a mesh size of less than 63 µm.

2.3. Preparing of chitosan and chitosan-palm solution

The chitosan solution was made by disintegration 0.5 g of Chitosan in 100 ml of diluted acetic acid. The solution was then heated at 70–80°C for 3–4 h and stirred until the Chitosan was fully soluble for 6 h.

The prepared solutions were then kept overnight at room temperature to cool down. The solution was homogeneous and then isolated to eliminate any insoluble chitosan by a 5.0 µm hydrophobic polytetrafluoroethylene (PTFE) membrane. The final solution was divided into two groups following the filtration.

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2.4. Fabrication of coating membrane

The membrane was fabricated using a custom-made unit and a rectangular polysulphone (PS) membrane. The solution Chitosan and Chitosan-Palm was deposited on the surface of the PS membrane (6.0 cm × 12.0 cm) and then was casted by using roll tools to make the
surface more homogenous, which was typically operated at room temperature (21°C). Membranes were washed with sodium hydroxide (NaOH) followed by Milli-Q water to remove the remaining acetic acid, and the surface of membranes becomes neutral. The membranes were then dried for 24–48 h in a temperature-controlled at 21°C (Figure 2).

2.5. Characterization and instrumentation

2.5.1. Surface morphology
Scanning electron microscope (FEI Nova-Nano SEM-600, Netherlands) was adopted to examine membrane surface morphology.

2.5.2. Contact-angle assessment
The membrane’s contact angles are normally evaluated via a water droplet (2 µL) on the membrane surface owing to determine the hydrophobicity of the surface of the membrane. Using the sessile fall technique (Data Physics® SCA20 Goniometer), which is set using a digital camera, the developed membranes contact angles are calculated. All samples were mounted flat on a microscope glass plate, and water droplets of 2-µL were found on the membrane layer.

2.5.3. Thermogravimetric analysis
The thermogravimetric analysis (TGA) of the Chitosan and chitosan-palm membranes was carried out using a Pyris 1 TGA system (PerkinElmer, USA). The TGA experiment conditions are as follow (scan rang room temperature up to 800°C), the heating rate maintained during the analysis was 10°C/min, and this experiment was carried out in the atmosphere of nitrogen gas using a ceramic pan at a rate of flow of 20 ml/min.

2.5.4. Zeta potential
A SurPASS electrokinetic analyzer was applied to estimate the charge of the surface of the membrane. Zeta potential (ZP) analysis was performed employing 10 mM KCl of the ambient electrolyte solution, and automated titration has been used to change the pH 3–10 using HCl and KOH solutions.

2.5.5. Permeability and salt-rejection
The NF/RO cross-flow method (Figure 3) was used to test water permeability and salt-rejection attitudes for all membranes. At a pressure of 22 bar, Milli-Q water has been used for all membranes to compress the membranes before the filtration process. Membrane compression was performed for approximately 1 h until a stable baseline flux was achieved. The deionized water permeates flux were subsequently tested at various imposed pressures to determine water membranes' permeability. The salt rejections were examined, applying five electrolyte salt solutions such as sodium chloride, magnesium chloride, magnesium sulphate, calcium chloride, and sodium sulphate. Salt concentrations were kept 2 g/L individually. The feed solution’s temperature was kept at 20 ± 2°C and the crossflow speed was set at 34.7 cm/s (100 L/h crossflow). The membrane thickness is equivalent to 40 cm². The different salt concentrations in feed and water permeability were tested using a calibrated conductivity meter and pH meter. Figure 3 displays a diagram of the cross-flow filtration system. The percentage of salt rejection noted (R%) is determined using the following theory from the feed and permeate samples.

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

Where \(C_p\) is permeated salt concentration and \(C_f\) is feed salt concentrations correspondingly.

The experiment was performed primarily at a crossflow rate of 34.7 cm/s by measuring the flux of water permeate, followed by salt aggregation in the feed solution to make the concentration of 2 g/L of salt. This step was evaluated at the various applied pressures i.e. 6 and 22 bar. To estimate the effect of solution in salt rejection of pH, the solution’s pH was stepwise raised to pH 10 by the addition of little quantity of 1 M KOH and then a step-by-step reduction in pH by 1 M HCl accumulation.
3. Results and dissection

3.1. Surface morphology

The surface morphology of the Chitosan and chitosan-palm and Polysulphone support (PS-20) was carried out by scanning electron microscope (SEM) at a magnification of 50 k in Figure 4. The image of Chitosan and polysulphone’s membrane has shown a smooth surface compared to the chitosan-palm membrane. The images have clearly shown that adding palm to Chitosan markedly changes the morphology of the membrane formed. In addition, the developed membranes’ pore size increased compared to the images taken for the chitosan membrane. In the production of membranes with large pore size, the flux is expected to be higher as well. Therefore, it is confirming that larger pore size is affecting both the flux rate and salt rejection.

3.2. Contact angle assessments

Contact angles of water droplets on the nanofiltration membranes surfaces containing polysulphone, Chitosan, and chitosan-palm were determined. Measured contact angles for the Chitosan and chitosan-palm membranes are displayed in Table 2. As observed from the results, the contact angles were 89.26° for chitosan-palm and 83.46° for chitosan membrane. The contact angle of both the developed membranes is less than 90°, which means that they suffer less from membrane fouling in water treatment. It is ascribed to the membrane surface hydration by water molecules, which avoids foulant from direct interaction with membranes’ surface. This hydrophilicity nature offers high polarity to the surface that attracts polar molecules such as water; no extra pressure is essential to initiate permeation. This may explain why the chitosan-palm has hydrophilic surface higher than Chitosan, and both membranes have a higher hydrophilicity surface than polysulphone due to the palm, which also has hydroxyl (OH) groups on the surface as shown in Figure 5 which comes from cellulose and hemicellulose that increase the hydrophilicity [27–29].

3.3. Thermogravimetric analysis

Figure 6 exhibits the thermogravimetric analysis of both developed membranes using Chitosan and chitosan-palm on a polysulphone as support. It is clearly indicating from Figure 6 that the thermal degradation of both membranes involved two main steps, the first degradation step 59–60% weight loss ensued at temperatures within the range of 375–475°C, and the other decomposition phase was noticed at temperatures in the range of 475–700°C. It is perceived that our attained outcomes are in covenant with those accomplished by other
inventors or researchers [30]. Remarkably, at 100–170°C temperature range in PS a minor degradation phase 3% weight loss was witnessed owing to the elimination of absorbed water. This degradation phase was perceived in PS only, and it was not exhibited in other developed chitosan membranes. In this developed, chitosan and chitosan-palm membranes are relatively more stable than PS because the peaks are produced by sulphone base and amide linkage. At this point, amide and sulphone linkage degradation was initiated only when the temperature was in high circumstances. The fabricated membranes exhibit high stability and the degradation temperatures were around 475 ± 10°C. This stability level in the polymer chain might be accredited to the existence of sulphonic acid groups. These conclusions are reliable with those described by other research scholars in this field [31]. The different degradation phase near 525 ± 3°C was initiated by cross-linking and polymerization processes in the chitosan membrane development [32]. Also, Figure 6(a) displays the residual weights of the membrane after thermal degradation at 800°C. The amount of remained weights was found to be 20–23.1% of the initial sample masses.

3.4. Zeta potential analysis

The zeta potential of a membrane is a conceptual model of the electrical potential of its membrane surface. By studying the pH impact on the membrane’s zeta potential, it is possible to achieve its membrane surface’s overall acidity or fundamentality. The developed chitosan and chitosan-palm membranes surface charges...
were estimated by using zeta potential. The outcomes are drawn in terms of pH, as displayed in Figure 6(b). The outcomes exhibited that the membranes were neutral around pH from 4 to 8 in both the developed chitosan membranes and polysulphone. The chitosan-palm membrane was marginally negative after pH 6 and marginally positive below pH 4; the negative charge was very high noticed in the polysulphone. Those findings distinctly are shown in Figure 6(b), that they have no ionizable chitosan membrane attached moieties. The considerably positive and negative charge at lower pH than four and pH higher than eight correspondingly are perhaps owed to the dispersant proton gain and proton loss process of the Chitosan, chitosan-palm membranes residuals in the membrane matrix [33–35]. These outcomes agree with the earlier studies [36], which exhibited that chitosan isoelectric point is neutral around pH 8.6. Rashid et. al., developed a membrane with charges higher than this isoelectric point of pH 8.6 [24]. Zhan et al. [37] developed CNT–CS BP membranes adopting an identical method and described the isoelectric point at pH amount to 5, within the range of pH 4–8 i.e. conveyed in our present work.

3.5. Water permeability

As mentioned in the experimental part, the developed membranes water permeability is examined and exhibited in Table 2 and Figure 7. The surface area is about 40 cm², where Figure 7 is drawn to permeate flux vs. applied pressure bar of the membrane. The permeability of water was determined from the linear correlation slopes in the permeate flux and the pressure applied. The Chitosan and chitosan-palm membrane water permeate flux significantly increases with higher applied pressure [15]. Chitosan-palm membrane displayed the permeability of water after 8 h of process around 3.04 ± 0.12 L m⁻² h⁻¹ bar⁻¹. This water permeability is nearly two times more than the Chitosan membranes water permeability i.e. 1.68 ± 0.04 L m⁻² h⁻¹ bar⁻¹. This confirms that the palm plays a major role in pore size and permeate flux in chitosan-palm membrane. An increase in pore size affects the increase in permeate flux correspondingly [30]. Besides, that palm increases the hydrophilicity on the surface because of carboxylic and hydroxide groups on cellulose’s chemical structure [27] as shown in Figure 6.

3.6. Salt-rejection capability

Tables 3 and 4 exhibit the salt rejection of the two developed membranes on polysulphone support (Chitosan, chitosan-palm). The salt rejection was examined with five NaCl, MgCl₂, MgSO₄, CaCl₂, and Na₂SO₄ inorganic electrolyte solutions using the system as displayed in Figure 3. Such tests were performed as a single salt solution, 2 g/L of salt concentrations were maintained, and varying pressures were applied for 8 h at a temperature of 20 ± 2°C, and at pH equal to 7. Generally, an increase in permeate flux causes an increase in salt rejection. In chitosan membrane, MgCl₂ salt rejection (7–90%) was the maximum among the five electrolyte solution
Table 3. Relationship between applied pressure and salt rejection for chitosan membrane.

| Applied pressure (bar) | MgCl2.6H2O | CaCl2 | NaCl | MgSO4 | Na2SO4 |
|------------------------|------------|-------|------|-------|--------|
| 6                      | 70.83      | 55.13 | 31.65 | 12.67 | 5.45   |
| 10                     | 86.37      | 80.57 | 37.54 | 22.10 | 10.58  |
| 14                     | 87.37      | 81.59 | 44.73 | 27.74 | 11.68  |
| 18                     | 88.20      | 83.55 | 49.61 | 33.77 | 13.84  |
| 22                     | 88.13      | 83.69 | 55.80 | 37.08 | 16.89  |

pH = 7, temperature = 20°C, the crossflow speed = 34.7 cm/s, salt concentration = 2 g/L, and membrane area = 40 cm².

Table 4. Relationship between applied pressure and salt rejection for chitosan-palm membrane.

| Applied pressure (bar) | MgCl2.6H2O | CaCl2 | NaCl | MgSO4 | Na2SO4 |
|------------------------|------------|-------|------|-------|--------|
| 6                      | 76.16      | 68.93 | 33.20| 24.19 | 4.86   |
| 10                     | 85.05      | 79.33 | 36.89| 32.82 | 7.93   |
| 14                     | 84.05      | 80.05 | 46.12| 38.40 | 10.85  |
| 18                     | 83.04      | 80.44 | 48.19| 39.97 | 12.62  |
| 22                     | 83.04      | 79.94 | 50.70| 41.24 | 15.30  |

pH = 7, the crossflow speed = 34.7 cm/s, salt concentration = 2 g/L, and membrane area = 40 cm².

chitosan membranes. This MgCl2 salt rejection value was nearby more than 42% compared to NaCl rejection and more than 13 and 6 times of Na2SO4 and MgSO4 correspondingly. On the other hand, chitosan-palm was exhibiting a similar behaviour of chitosan membrane for all salts.

It is illustrious that Na2SO4 rejection in two membranes was quite low i.e. 5–16%, as exhibited in Figures 8(a and b). The accomplished divalent salts MgSO4 and Na2SO4 low salt rejections might be described by the non-existence of membrane surface charge [22]. These results indicated that both developed membranes under the working conditions follow the rank of MgCl2 > CaCl2 > NaCl > MgSO4 > Na2SO4. These outcomes are associated with the salt rejection efficiency of nanofiltration polyamide membranes, in which the divalent salts salt rejection is more than the monovalent salts [16,38,39]. It is important that the membranes fabricated from polyamide carried a negative charge near pH equal to 7. In the case of salt rejection of cations and anions, they are most affected by the electrostatic interaction, and this plays a huge part in salt rejection. In this study, the chitosan membrane is neutral. Thus, Columbia interaction is not predicted as a main mechanism of rejection. The order of rejection is mentioned here agrees with the descending Kiel-land [40] rank of Cl− (0.19 nm) > Na+ (0.1 nm) > Mg2+ (0.09 nm) unhydrated ionic radius. The SO42− unhydrated ionic radius does not exist in the literature. The surface charge of the fabricated membranes at pH 7 is neutral, which could explain the size impact for the higher rejection rate of monovalent ions (Cl−) than for multi-valent ions (SO42−). These present outcomes are reliable to the earlier investigation by Tongwen et al [41]. Tongwen et al. exhibited that the rejection of various electrolytes was present in the sequence of MgCl2 > NaCl > MgSO4. This mentioned order and surface negative charge are associated similarly with our current work. The separation of MgCl2 could be higher in their study of a positively charged membrane than that of Na2SO4 and NaCl, as stated by Rios et al. [42]. Correspondingly, the membrane charging offers the separation reliance on electrolyte valence. The salt rejection by both charged membranes, which mostly results from the surface contact between the membrane and the ions.

3.7. PH effect

The salt rejection of NaCl, MgSO4 and MgCl2.6H2O of Chitosan and chitosan-palm membranes was examined at the temperature of 20°C within the range of pH from 3 to 10, and at a pressure of 22 bar. The salt rejection efficiency as a pH function was shown in Figure 9(a and b) and Table 5. The feed solutions pH turn into acidic caused to be increased in the salt rejection
Table 5. Salts rejection as function of pH for Chitosan and chitosan-palm membranes.

| pH   | NaCl  | MgSO₄ | MgCl₂.6H₂O | NaCl  | MgSO₄ | MgCl₂.6H₂O |
|------|-------|-------|------------|-------|-------|------------|
| 10.00 | 9.38  | 28.44 | 7.21       | 7.44  | 18.69 | 1.42       |
| 7.00  | 43.23 | 36.22 | 84.56      | 42.69 | 26.07 | 73.70      |
| 3.00  | 52.61 | 36.80 | 74.46      | 51.84 | 23.49 | 68.29      |

Pressure = 22 bar, the crossflow speed = 34.7 cm/s, salt concentration = 2 g/L, and membrane area = 40 cm².

of all membranes. The NaCl, MgSO₄, and MgCl₂.6H₂O salt rejection increase in both membranes concerning smaller pH might result from the protonation of the available amino moieties in Chitosan [24]. The earlier investigations stated that NH₂ on Chitosan might gain proton at small pH. Consequently, the NH₃⁺ moiety on the Chitosan might play a significant part because the group is mainly accountable for interactions with anions and negatively charged surfaces [43,44].

Furthermore, Figure 9(a) also exhibits that the chitosan membrane had a smaller higher salt rejection than the chitosan-palm membrane. This might be endorsed to the charge repulsion, which might lead to greater salt rejection rates depending on the steric interactions. Also, it might be evident that MgCl₂ salt rejection for both membranes was greater amongst the other salts types, essentially at low and neutral pH. This might be owing to unhydrated ionic radius of Mg²⁺ (0.09 nm), which is lower than the other ionic radius [40]. A comparison of the salt rejection results stemmed from the previous works [45–49] using different membranes with chitosan-palm membrane for nanofiltration is illustrated in Table 6. In summary, the data obtained shows that the manufactured membrane offers new exciting opportunities for nanofiltration membranes.

4. Conclusion

Chitosan and Chitosan with palm membranes coated on polysulphone as support have been developed and characterized about their properties to investigate their water purification application. The SEM results confirmed that the palm was played a role on Chitosan’s surface and the contact angle of the chitosan-palm membrane is high 89.26° compared to the chitosan membrane 83.46°. In comparison, the water permeability for membrane chitosan with palm was 3.04 ± 0.12 L m⁻² h⁻¹ bar⁻¹, i.e. two times greater than the average value of the permeability of water of chitosan membrane 1.68 ± 0.04 L m⁻² h⁻¹ bar⁻¹. These data

Figure 9. Salts rejection as function of pH for (a) chitosan and (b) chitosan-palm membrane. (Pressure = 22 bar, temperature = 20°C, the crossflow speed = 34.7 cm/s, salt concentration = 2 g/L, and membrane area = 40 cm²).

Table 6. Comparison of chitosan-palm membrane with other membranes in the literature for salt rejection.

| Membrane materials | Membrane type | Water flux (Lm⁻²h⁻¹) | Salt type | Applied Pressure (bar) | Rejection (%) | Ref. |
|--------------------|---------------|----------------------|-----------|------------------------|---------------|-----|
| GO                 | NF            | -                    | NaCl      | 15                     | 35.48         | [45]|
| Carboxylated GO    | NF            | -                    | NaCl      | 15                     | 48.2          | [45]|
| rGO/TiO₂ embedded TFN | NF          | -                    | NaCl      | 10                     | 36.6          | [46]|
| PEI₁.₅/GO₀.₃/PEI₃.₀ | NF           | -                    | NaCl      | 5                      | 38.1          | [47]|
| GO/POLYSULPHONE    | NF            | -                    | NaCl      | 4                      | 59.5          | [48]|
| GO/polyamidoamine-amide | NF         | -                    | NaCl      | 6                      | 56.8          | [49]|
| LbL GO/polyethyleneimine | NF    | -                    | NaCl      | 5                      | 38.1          | [50]|
| UiO-66-NH₂         | NF            | -                    | NaCl      | 4                      | 28            | [51]|
| CuBTC              | NF            | -                    | NaCl      | 8                      | 44.9          | [52]|
| PVA-Ag₂O₃         | NF            | 25                   | NaCl      | 6                      | 3             | [53]|
| AqpZ-DOPC         | NF            | 3.6                  | NaCl      | 1                      | 20            | [54]|
| AqpZ-ABA          | NF            | 34.2                 | NaCl      | 4                      | 32.9          | [55]|
| Chitosan-palm     | NF            | 3.04                 | NaCl      | 22                     | 50.7          | This work |
indicated that the performances of water permeate flux and salt rejection were greater than the unmodified membrane. Moreover, the salt rejection was improved (from 5% for NaCl to 70% for MgCl2 at the same condition). Therefore, these findings have shown that the chitosan and chitosan-palm membranes produced are more significant for water treatment implementations.

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References

[1] Al-Hobaib AS. Characterization and evaluation of reverse osmosis membranes modified with Ag2O nanoparticles to improve performance. Nanoscale Res Lett. 2015;10(1):379.
[2] Werber JR, Osuji CO, Elimelech M. Materials for next-generation desalination and water purification membranes. Nat Rev Mater. 2016;1(5):1–15.
[3] Teow YH, Mohammad AW. New generation nanomaterials for water desalination: a review. Desalination. 2019;451:2–17.
[4] He Y. Preparation and characterization of a novel positively charged composite hollow fiber nanofiltration membrane based on chitosan lactate. RSC Adv. 2019;9(8):4361–4369.
[5] Thakur VK, Vennerberg D, Kessler MR. Green aqueous surface modification of polypropylene for novel polymer nanocomposites. ACS Appl Mater Interfaces. 2014;6(12):9349–9356.
[6] Basheer AA. Chemical chiral pollution: impact on the society and science and need of the regulations in the 21st century. Chirality. 2018;30(4):402–406.
[7] Basheer AA, Ali I. Stereoselective uptake and degradation of (±)-o,p-DDD pesticide stereomers in water-sediment system. Chirality. 2018;30(9):1088–1095.
[8] Ali I. Artificial neural network modelling of amido black dye sorption on iron composite nano material: kinetics and thermodynamics studies. J Mol Liq. 2018;250:1–8.
[9] Lee A, Elam JW, Darling SB. Membrane materials for water purification: design, development, and application. Environ Sci: Water Res Technol. 2016;2(1):17–42.
[10] Charcosset C. Ultrafiltration, microfiltration, nanofiltration and reverse osmosis in integrated membrane processes. Integr MemberSystProcess. 2016(1):1–22.
[11] Zhou D. Development of lower cost seawater desalination processes using nanofiltration technologies – a review. Desalination. 2015;376:109–116.
[12] Gozalvez JM. Modelling of a low-pressure reverse osmosis system with concentrate recirculation to obtain high recovery levels. Desalination. 2002;144(1-3):341–345.
[13] Cadotte J. Nanofiltration membranes broaden the use of membrane separation technology. Desalination. 1998;70(1-3):77–88.
[14] Shon HK. Nanofiltration for water and wastewater treatment—a mini review. Drink Water Eng Sci. 2013(6):47–53.
[15] Petersen RJ. Composite reverse osmosis and nanofiltration membranes. J Membr Sci. 1993;83(1):81–150.
[16] Miao J, Chen G-h, Gao C-J. A novel kind of amphoteric composite nanofiltration membrane prepared from sulfurated chitosan (SCS). Desalination. 2005;181(1-3):173–183.
[17] Eikebrokk B, Saltines T. Removal of natural organic matter (NOM) using different coagulants and lightweight expanded clay aggregate filters. Water Sci Technol Water Supply. 2001;1(2):131–140.
[18] Bassi R, Prasher SO, Simpson BK. Effects of organic acids on the adsorption of heavy metal ions by chitosan flakes. J Environ Sci Health Part A. 1999;34(2):289–294.
[19] Jeon C, Höll WH. Application of the surface complexation model to heavy metal sorption equilibria onto aminated chitosan. Hydrometallurgy. 2004;71(3-4):421–428.
[20] Sashiwa H, Alba S-I. Chemically modified chitin and chitosan as biomass materials. Prog Polym Sci. 2004;29(9):887–908.
[21] Chen H, Tian X, Zou H. Preparation and blood compatibility of new silica-chitosan hybrid biomaterials. Artif Cells Blood Substit Biotechnol. 1998;26(4):431–436.
[22] Struszczyk MH. Chitin and chitosan. Part II. Applications of chitosan, Polymery. 2002;47:396–403.
[23] Qurashi MT, Blair HS, Allen SJ. Studies on modified chitosan membranes. J Appl Polym Sci. 1992;46(2):255–261.
[24] Rashid MH-O. Synthesis, properties, water and solute permeability of MWNT buckypapers. J Membr Sci. 2014;456:175–184.
[25] Alshahrani AA. Synthesis and characterisation of MWNT/chitosan and MWNT/chitosan-crosslinked buckypaper membranes for desalination. Desalination. 2017;418:60–70.
[26] Rashid MH-O. Nanofiltration applications of tough MWNT buckypaper membranes containing biopolymers. J Membr Sci. 2017;529:23–34.
[27] Huzailaf MR. Effect of fibre loading on the physical, mechanical and thermal properties of sugar palm fibre reinforced vinyl ester composites. Fibers Polym. 2019;20(5):1077–1084.
[28] Mahapatro A, Singh DK. Biodegradable nanoparticles are excellent vehicle for site directed in-vivo delivery of drugs and vaccines. J Nanobiotechnol. 2011;9(1):55.
[29] Wang X. High water permeable free-standing cellulose triacetate/graphene oxide membrane with enhanced antibiofouling and mechanical properties for forward osmosis. Colloids Surf A. 2016;508:327–335.
[30] Al-Hobaib AS. Reverse osmosis membranes prepared by interfacial polymerization in n-heptane containing different co-solvents. Desalin Water Treat. 2016;57(36):16733–16744.
[31] Guan R. Polysulphone sulfonate by chlorosulfonic acid and its membrane characteristics. Eur Polym J. 2005;41(7):1554–1560.
[32] Zuo J, Chung T-S. Design and synthesis of a fluoro-silane amine monomer for novel thin film composite membranes to dehydrate ethanol via pervaporation. J Mater Chem A. 2013;1(34):9814–9826.
[33] Childress AE, Elimelech M. Relating nanofiltration membrane performance to membrane charge (electrokinetic) characteristics. Environ Sci Technol. 2000;34(17): 3710–3716.

[34] Childress AE, Elimelech M. Effect of solution chemistry on the surface charge of polymeric reverse osmosis and nanofiltration membranes. J Memb Sci. 1996;119(2): 253–268.

[35] Ma Y. Introducing membrane charge and membrane potential to T cell signaling. Front Immunol. 2017;8:1513.

[36] Rashid M. Carbon nanotube membranes: synthesis, properties, and future filtration applications. Nanomaterials. 2017;7(5):99.

[37] Zhan Y. Carbon nanotube–chitosan composite electrodes for electrochemical removal of Cu (II) ions. J Alloys Compd. 2011;509(18):5667–5671.

[38] Musale DA, Kumar A. Effects of surface crosslinking on sieving characteristics of chitosan/poly (acrylonitrile) composite nanofiltration membranes. Sep Purif Technol. 2000;21(1-2):27–37.

[39] Afonso MD, De Pinho MN. Transport of MgSO4, MgCl2, and Na2SO4 across an amphoteric nanofiltration membrane. J Memb Sci. 2000;179(1-2):137–154.

[40] Rios GM. Investigation of ion separation by microporous nanofiltration membranes. AIChE J. 1996;42(9):2521–2528.

[41] Amuda OS, Giwa AAM, Bello IA. Removal of heavy metal from industrial wastewater using modified activated coconut shell carbon. Biochem Eng J. 2007;36(2):174–181.

[42] Li X. Preparation of supported lipid membranes for aquaporin Z incorporation. Colloids Surf B. 2012;94:333–340.

[43] Zhong PS. Aquaporin-embedded biomimetic membranes for nanofiltration. J Memb Sci. 2012;407:27–33.