Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(5): 2217 – 2235 (2024)
www.ejabf.journals.ekb.eg

Performances of Nanofiltration and Reverse Osmosis Membranes in Desalination of Tagounite Brackish Water, Morocco

Abdellah Lachheb[1]*, Miloud Chakit[2] , Mohamed Taky[1], Mahassine El Amrani[1] , Azzeddine Elmidaoui[1]

[1]Separation Processes Laboratory, Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco
[2]Biology and Health Laboratory, Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco

[*]Corresponding Author: abdellah.lachheb@uit.ac.ma

ARTICLE INFO

Article History:
Received: May 26, 2024
Accepted: Oct. 24, 2024
Online: Oct. 30, 2024

Keywords:
Desalination,
Reverse osmosis,
Nanofiltration,
Brackish water,
Comparison,
Energy consumption

ABSTRACT

Like many countries around the world, Morocco is facing problems with water supply due to increasing demand and the decrease in conventional resources. To address water shortages, Morocco has long been utilizing non-conventional water resources, such as wastewater reuse and desalination. Initially, desalination was limited to the southern and coastal regions, but it has gradually expanded to the central areas. In many regions of Morocco, the salinity of brackish water significantly exceeds acceptable standards. In Tagounite (located in the southern region of Morocco), where this study was conducted, the salinity of brackish water often exceeded the Moroccan standards, particularly in terms of chloride and sodium content. This contamination is primarily attributed to saline intrusion. The aim of the current study was to evaluate the performance of nanofiltration (NF) for desalinating brackish groundwater in Tagounite and to compare the results with those of reverse osmosis (RO). The desalination process was monitored by assessing performance parameters such as permeability, salinity, chloride, and sodium levels. Several configurations were tested to optimize the process. According to the results, NF membranes demonstrated the potential to produce water of satisfactory quality with high permeate fluxes compared to reverse osmosis.

INTRODUCTION

In the 21st century, the concern over potential freshwater shortages is becoming more prominent. To tackle water scarcity issues across various regions, seawater is increasingly being recognized as a viable resource, even for countries previously considered to have limited freshwater supplies **(Asfers *et al.*, 2016a)**. Recent global industry forecasts indicate significant growth in the desalination sector over the past three years, with expectations for continued expansion. Desalination is emerging as a common solution for providing freshwater in areas where it is otherwise scarce. Among the various desalination technologies, reverse osmosis (RO) remains the most widely utilized worldwide **(Abouzaid *et al.*, 2003; Abuhabib *et al.*, 2013)**. Over the past four decades, the reverse osmosis process has seen significant advancements, leading to a 44% increase in global desalination production capacity. Meanwhile, another membrane technology, nanofiltration (NF), is gaining attention as a potential alternative to RO for desalting specific brackish waters. NF membranes are more permeable and operate at lower pressures compared to RO membranes. Additionally, nanofiltration often produces water that requires less extensive remineralization, or, in some cases, only minimal post-treatment compared to RO **(Cüneyt *et al*., 2020)**.

Morocco is among the Mediterranean countries threatened by the problem of dwindling freshwater resources. Water stress is leading toward water scarcity, especially in the southern part of the country, where water availability is below 1000m³ per capita per year. In some southern regions of Morocco, groundwater is unsuitable for both drinking and irrigation **(Asfers *et al*., 2016b; Lotfi *et al*., 2020a; Ait Messaad *et al*., 2022a)**. Generally, the salinity of these waters ranges from 1 to 14g/ L. It is worth noting that these salinity levels tend to increase over the decades due to the significant reduction in rainfall rates. Moreover, the drinking water standards prescribed by the WHO are becoming increasingly stringent (salinity below 1g/ L) **(Rosentreter *et al*., 2021)**.

Desalination is crucial in the southern regions of Morocco, which experience arid conditions. In 1975, Morocco inaugurated its first brackish water desalination plant in Tarfaya, utilizing electrodialysis for water with a salinity of 5g/ L. This plant was replaced in 1983 by a reverse osmosis unit with a capacity of 125m³/ day. The National Office of Drinking Water and Electricity (ONEE) in Morocco has recognized the need to expand seawater desalination facilities using reverse osmosis and plans to develop more plants over the next two decades. The establishment and operation of these desalination units have built valuable expertise and introduced effective techniques in Morocco **(Boulahfa *et al.*, 2019)**. Membrane desalination processes have demonstrated their global effectiveness, with numerous studies conducted at the laboratory scale on desalting brackish waters and industrial effluents. This research focuses on achieving drinking water quality by desalting brackish water with a salinity of approximately 5g/ L using a semi-industrial Nanofiltration/Reverse Osmosis pilot system. The study compares two nanofiltration membranes (NF90 and NF270) and one reverse osmosis membrane (TM710) in terms of both quantitative and qualitative performance, including an evaluation of energy consumption.

Considering the above, this research is characterized by its innovative approach to enhancing the performance of reverse osmosis membranes. By integrating functional nanomaterials and manufacturing techniques supported by advanced simulations, our study aimed to develop more efficient and durable membranes. Furthermore, we explored the impact of operational parameters on membrane performance, thereby providing a comprehensive understanding of the underlying mechanisms.

MATERIALS AND METHODS

1. Characteristics of the feed water

The study was conducted using synthetic brackish water. Table (1) presents a summary of the physicochemical properties of this water, along with WHO and Moroccan drinking water standards for comparison. This brackish water is notable for its high hardness and elevated levels of sulfate, bicarbonate, chloride ions, and sodium.

Table 1. Physicochemical characteristics of the brackish water to be treated

Parameter	Synthetic brackish water	WHO standards	Moroccan standards
pH	7.6	6.5-8.5	6.5-8.5
Temperature (°C)	25	25	25
Turbidity (NTU)	<1	<5	<5
TDS (mg/L)	5067	<1000	1000-2700
Total hardness (TH) (°F)	94	50	-
Total alkalinity (TAC) (°F)	24	-	-
Ca^{2+} (mg/L)	248	<270	<500
Mg^{2+} (mg/L)	79	<50	100
Na^{+} (mg/L)	1453	<200	<200
K^{+} (mg/L)	6	-	-
HCO_3^{-} (mg/L)	318	-	-
SO_4^{2-} (mg/L)	317	<200	200
Cl^{-} (mg/L)	2483	<250	350-750
NO_3^{-} (mg/L)	40	<50	<50

2. Unit pilot testing

The experiments were conducted using an NF/RO pilot plant (E 3039) supplied by TIA Company (Technologies Industrielles Appliquées, France). The operations were performed in continuous mode, as illustrated in Fig. (1). The membrane pressure can be manually adjusted from 5 to 70 bar using the valves. The pilot plant consists of two identical modules operating in series, each containing a single element. The system experiences a total pressure drop of around 2 bar, with each module contributing approximately 1 bar. The tested setup involves a single pass in continuous mode.

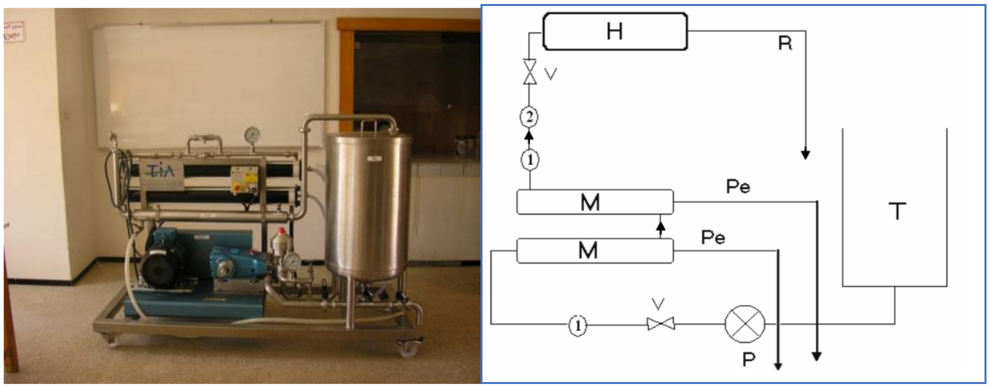

Fig. 1. Variation of permeate flow as a function of applied pressure
T: tank; P: feed pump; V: pressure regulation valves; M: nanofiltration and reverses osmosis module; Pe: permeate recirculation; R: retentate recirculation; H: heat exchanger; 1: pressure sensor; 2: temperature sensor

The different configurations compared during these studies are:

• Configuration 1: Desalination using reverse osmosis membranes, with two TM710 membranes, each in a separate pressure tube.

• Configuration 2: Desalination using a nanofiltration NF90 membrane, with one membrane per pressure tube.

• Configuration 3: Desalination using a nanofiltration NF270 membrane, with one membrane per pressure tube.

• Configuration 4: Desalination using a combination of two types of nanofiltration membranes, with an NF270 membrane in the first pressure tube and an NF90 membrane in the second pressure tube.

Table (2) provides the characteristics of the membranes used. After the run, the membranes were cleaned with alkaline and acidic cleaning solutions according to the manufacturer's recommendations.

Table 2. Characteristics of the membranes

Membrane	**Cut-off (Da)**	**Surface Area (m^2)**	**Material**
NF90*4040	200	7.6	Polyamide(spiral)
NF270*4040	300	7.6	Polyamide(spiral)
TM710	–	7.1	Polyamide(spiral)

3. Theoretical analysis

The theoretical analysis of the tested membrane characteristics was performed using standard membrane transfer methods as previously described by **Touir *et al.* (2021)**.

The ion rejection rate was determined by the ratio of the permeate concentration Cp (mg/L) to the initial concentration C0 (mg/L), expressed by relation (1):

$$R(\%) = \left(\frac{(1-CP)}{C0}\right) \times 100 \qquad (1)$$

The conversion rate Y (%) was represented by relation (2). It is the quotient of the produced water flow rate by the feed water flow rate:

$$Y(\%) = \frac{Qpermeate\ flow}{Qfeed\ flow} \qquad (2)$$

The permeate flow Jp ($L/h.m^2$) was determined by relation (3). It is the expression of the permeate flow rate Qp ($l.h^{-1}$) relative to the active membrane surface area S(m^2):

$$JP = \frac{Qp}{S\ active} \qquad (3)$$

The permeability of the tested membranes was expressed by relation (4):

$$A = \frac{Jp}{\Delta P} \qquad (4)$$

Where, Jp is the permeate flux, and ΔP (bar) is the transmembrane pressure.
Energy consumption was proportional to the pressure and is given by relation (5):

$$E = \frac{\Delta p.100}{\eta.y \times 36} \qquad (5)$$

with E in $kW.h/m^3$, ΔP being the transmembrane pressure in bars; η the overall pump efficiency (equal to 80%), and Y the conversion rate.

RESULTS

1. Influence of pressure on the performance of the different membranes studied

In this section, we compared the performance of the different membranes studied at various pressures. The applied pressures were: 7, 10, 15, 20, and 25 bars. The parameters monitored include permeate flow rate, conversion rate, rejection rate, TDS (Total dissolved solids), energy consumption, and the concentration of sodium and chloride ions.

1.1. Effect of pressure on permeate flow

A comparative study was conducted on the reverse osmosis membrane (TM710) and the two nanofiltration membranes (NF270 and NF90) by determining the permeability of the membranes as a function of the applied pressures. Permeate flux is one of the key factors in evaluating membrane performance, as it reflects the amount of water produced and demonstrates the efficiency of the membrane.

The calculation of raw water permeability was performed for each of the three tested membranes. The curve showing the variation of transmembrane pressure as a function of the permeate flow rate, for each applied pressure, allows for the determination of permeability values for the three tested membranes, as shown in Table (3).

Table 3. Permeability values of the three tested membranes with raw water

Membrane	Permeability with Raw Water (L/h·m²·bar)
NF270	7.02
NF90	3.6
TM710	3.4

The NF90 membrane is highly rough with a non-homogeneous surface structure and is denser, making it comparable to the reverse osmosis membrane TM710, which is the roughest among the three membranes used but has a more homogeneous surface morphology than NF90. This justifies their nearly identical permeability rates as a function of the applied pressure.

Fig. (2) illustrates the raw water permeability of the NF and RO membranes used, as a function of five different applied pressures **(Tian *et al*., 2021)**.

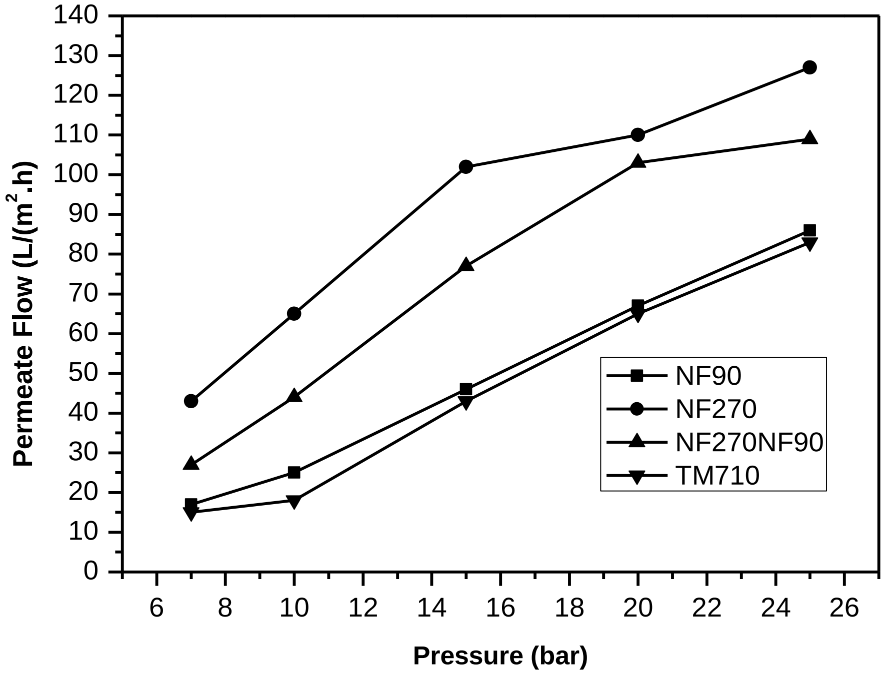

Fig. 2. Variation of permeate flow as a function of applied pressure

1.2. Effect of pressure on conversion rate

Pressure is a critical parameter considered in this study. To investigate the effect of pressure on the performance of the tested membranes, desalination trials were conducted under the following conditions for the three tested membranes: the applied pressures are 7, 10, 15, 20, and 25 bars.

Fig. (3) illustrates the performance results recorded in terms of pressure, a critical parameter in this study. To investigate the effect of pressure on the performance of the tested membranes, desalination trials were conducted under the following conditions for the three membranes: applied pressures of 7, 10, 15, 20, and 25 bars.

.

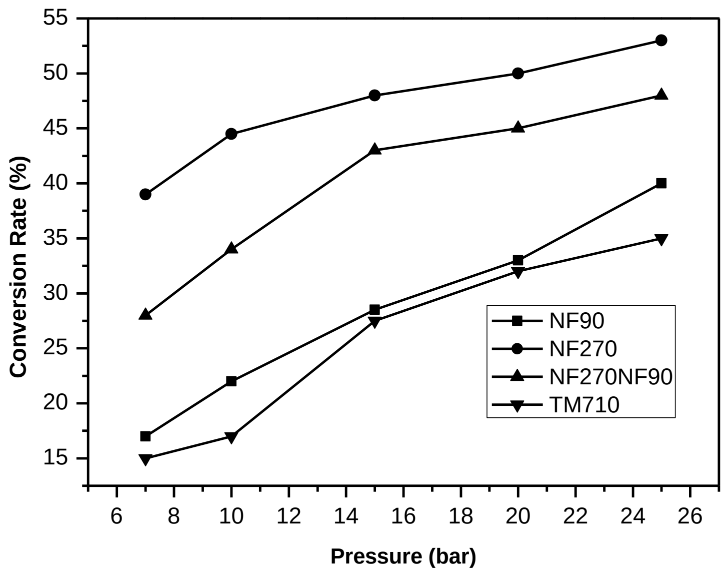

Fig. 3. Variation of conversion rate (Y%) as a function of applied pressure

Fig. (3) demonstrates that the conversion rate increases linearly with the operating pressure of the membranes. The applied pressure needed to overcome the membrane's resistance results in a higher conversion rate. The membranes can be ranked by conversion rate at different applied pressures in ascending order as follows: TM710 < NF90 < NF270/NF90 < NF270.

1.4. Effect of pressure on rejection rate

Fig. (4) illustrates the variation in the overall rejection rate of the NF and RO membranes used as a function of five different applied pressures.

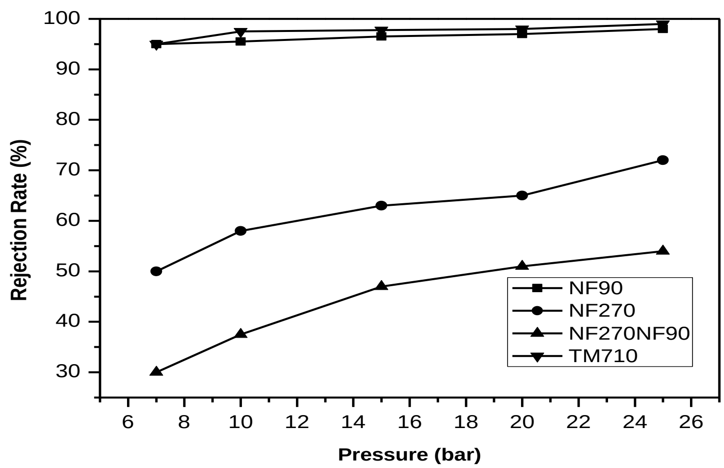

Fig. 4. Variation of the overall rejection rate as a function of applied pressure

1.5. Effect of pressure on sodium and chloride ions

To confirm the rejection rates for each membrane, we calculated the concentrations of sodium and chloride ions in the permeate for each applied pressure. Figs. (5 and 6) illustrate the results obtained, respectively.

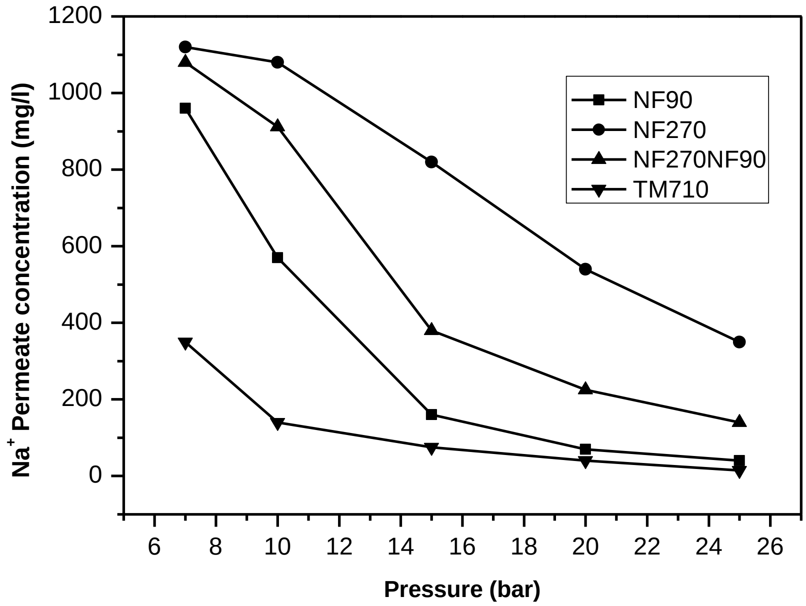

Fig. 5. Variation of Na^+ permeate concentration as a function applied pressure

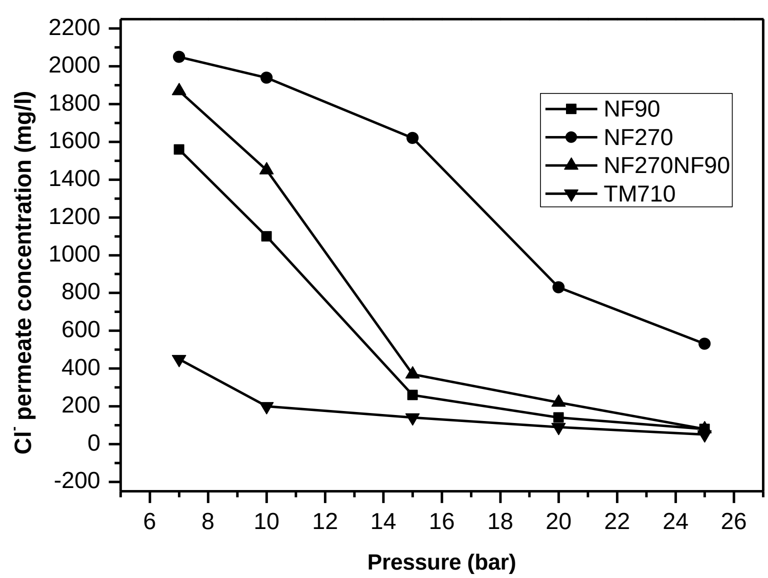

Fig. 6. Variation of Cl^- permeate concentration with applied pressure

1.6. Effect of pressure on TDS

Fig. (7) illustrates the variation in TDS concentration for the NF and RO membranes used, as a function of five different applied pressures.

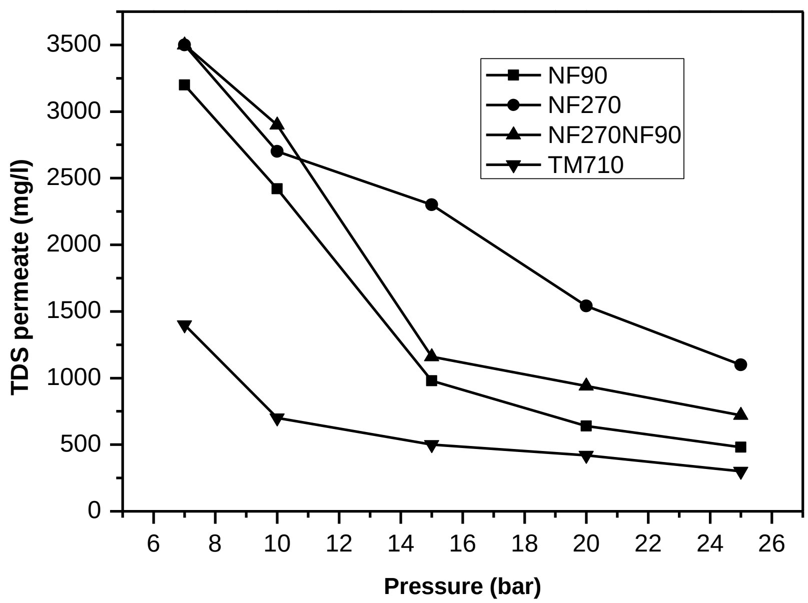

Fig. 7. Variation in TDS permeate concentration with applied pressure

The results show that the permeate quality obtained with the NF90 membrane is satisfactory. However, the water produced by the TM710 membrane is practically demineralized, necessitating a post-mineralization step.

1.7. Effect of pressure on energy consumption

Energy analysis is another powerful tool for determining the efficiency and performance of the membrane filtration process. Thus, the energy consumed during reverse osmosis and nanofiltration for water desalination was analyzed and is presented in Fig. (8).

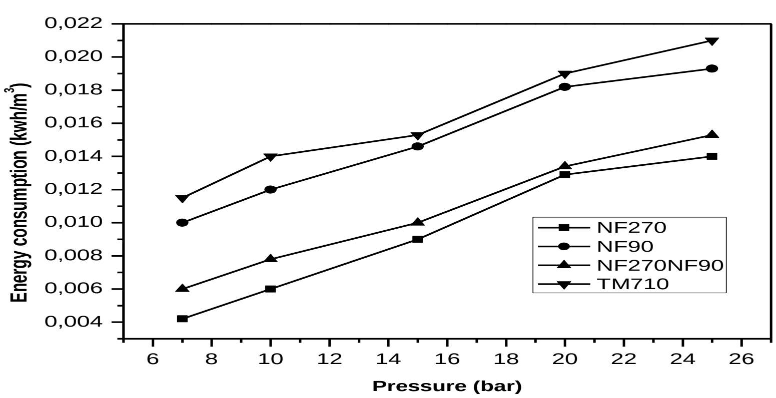

Fig. 8. Variation in energy consumption with applied pressure

The analysis of the results indicates that the energy consumed increases in the following order: NF270 < NF270/NF90 < NF90 < TM710. It was also noted that pressure gradually influences the increase in energy consumption, which is logical.

2. Influence of conversion rate on the performance of the studied membranes

The conversion rate is a crucial parameter for determining the operational performance of a desalination unit using membrane processes. This section compares the performance of the studied membranes at different conversion rates. The applied conversion rates are: 15, 45, 65, and 85%.

2.1. Effect of conversion rate on TDS

According to Fig. (9), which shows the variation of TDS as a function of the conversion rate, an increase in the conversion rate leads to a decrease in permeate quality. The NF90 membrane is the most suitable membrane for brackish water desalination and for achieving potable water quality with TDS < 1000mg/ L, in accordance with Moroccan standards, without being affected by the increase in the conversion rate (Fig. 9). However, for NF270 and the NF270/NF90 combination, the permeate quality decreases as the conversion rate increases, reaching values between 2000 and 2700mg/ L at a conversion rate of 85%.

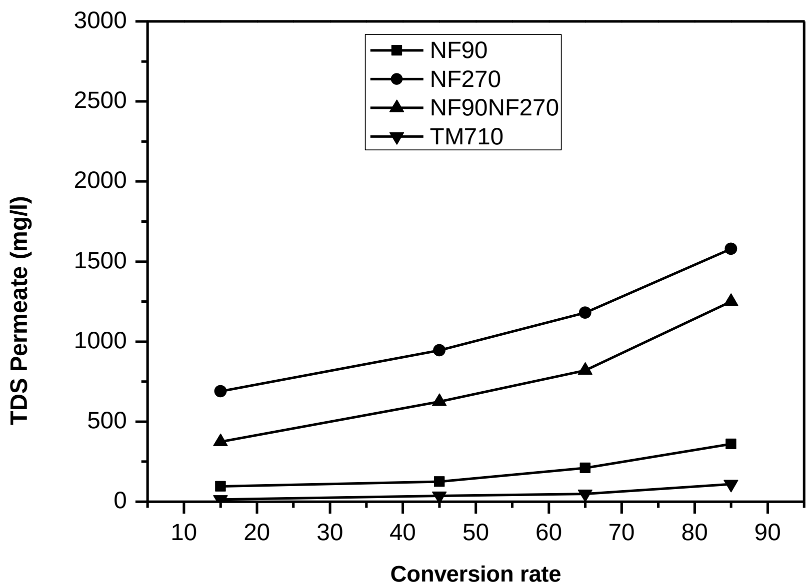

Fig. 9. Variation in permeate TDS as a function conversion rate

It is also observed that increasing the conversion rate leads to a decrease in the retention rate. This is due to the formation of the polarization layer at high conversion rates **(Talaeipour *et al*., 2017)**.

2.2 Effect of conversion rate on sodium and chloride ion concentration

Fig. (10) shows the variation in Cl^- concentration in the permeate of the NF and RO membranes used, as a function of the conversion rate.

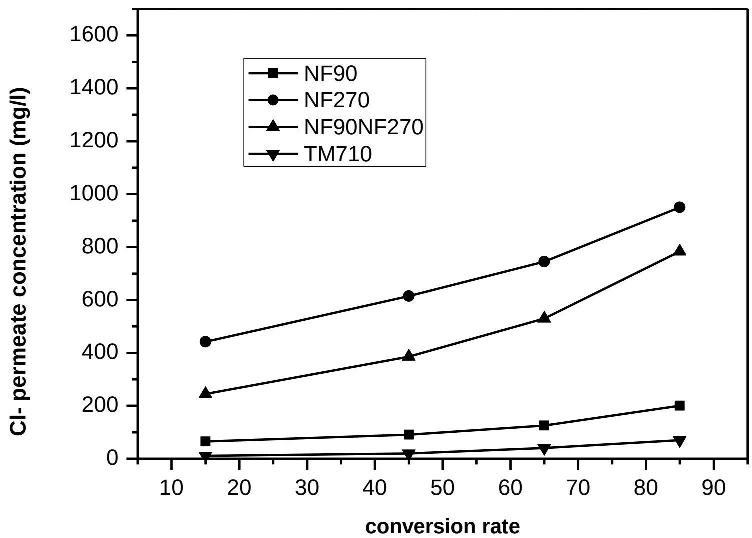

Fig. 10. Variation of Cl^- concentration in permeate with conversion rate

The treated brackish water has a sodium concentration of 1453mg/ L, while the WHO and Moroccan standards recommend a maximum level of 200mg/ L. Fig. (11) displays the sodium concentration results in the permeate for various membranes tested, illustrating how different membrane types and conversion rates affect the reduction of Na^+ concentration relative to the WHO limit **(Usha *et al*., 2021; Ait Messaad *et al*., 2022b)**.

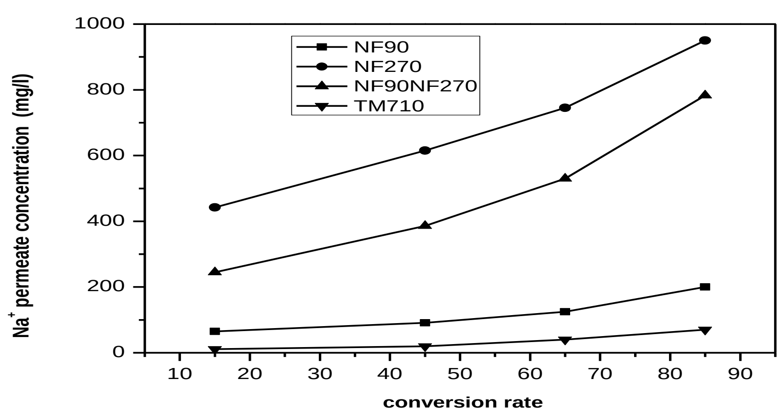

Fig. 11. Variation of Na^+ concentration in permeate with conversion rate

DISCUSSION

A comparative study was conducted on the reverse osmosis membrane (TM710) and the two nanofiltration membranes (NF270 and NF90). The obtained permeability of the used membranes can be ranked in ascending order as follows: NF270 > NF90 > TM710. This difference in permeability between NF and RO membranes can be explained by considering the transport through NF membranes resulting from two mass transfer mechanisms: convection and diffusion. The water transfer becomes more significant as it stems from the sum of these two transfer mechanisms.

The flow increases linearly with pressure. The high permeability for the three tested membranes is effective at a high pressure of around 25 bar. The NF270 demonstrates better permeability compared to NF90, NF270/NF90 and TM710 individually.

Nanofiltration (NF) membranes are more permeable to raw water than reverse osmosis (RO) membranes due to their nanopores, while RO membranes are dense. This difference is directly related to the variation in their pore diameters. Generally, higher permeability indicates greater porosity. Studies on the "Molecular Weight Cut-Off" (MWCO) of the membranes used, which is proportional to pore size, are summarized in Table (3). MWCO is a specification commonly used by manufacturers to describe a membrane's retention capabilities, indicating the molecular weight of a solute, typically polyethylene or proteins, where the membrane achieves a rejection rate of over 90%. This specification is frequently used to characterize ultrafiltration and nanofiltration membranes.

Table 3. Molecular weight cut-off (MWCO) of NF and RO membranes

Membrane	**NF270**	**NF90**	**TM710**
MWCO (Da)	300	200	80

The NF270 membrane has more open pores compared to the NF90 membrane, which explains its higher permeability and that of the NF270/NF90 combination. On the other hand, the NF90 membrane has more pores compared to the TM710, but their permeabilities are similar. The permeability of a membrane is also related to the thickness of the selective layer and the surface roughness of the membrane. This explains why the NF90 is highly rough with a non-homogeneous surface structure and is denser, making it similar to the reverse osmosis membrane TM710, which is the roughest among the three membranes used, but has a more homogeneous surface morphology than the NF90. This justifies their nearly identical permeability rates as a function of the applied pressure **(Medina Collana *et al*., 2024)**.

Recovery can be interpreted as the system's efficiency concerning flow. This operating parameter is inevitably a result of the fluctuation of both feed flow and permeate flow; it increases with the rise in one of the flows, leading to increased applied pressure. The increase in pressure results in an increase in the permeate flow, consequently causing an increase in the conversion rate related to the feed flow according to the previously presented conversion rate equation. The rise in pressure also leads to a higher concentration near the membrane and thus the solute transfer. There is also the effect of convective transfer becoming dominant, as the solute flux increases with the solvent flux **(Medina Collana *et al*., 2024)**.

At a pressure of 7 bar, the conversion rate of NF270 is approximately 32% higher than that of TM710 at the same pressure, leading to an increase in the feed water flow. Conversely, there is no a significant difference in conversion rates between the TM710 and NF90 membranes. The NF270/NF90 combination shows a conversion rate variation closer to NF270. The pressure required for a defined permeate flow and recovery rate depends on the membrane **(Ketharani *et al*., 2022)**.

When the conversion rate increases, there is a risk of deposition on the membrane surface of slightly soluble salts such as $CaSO_4$ or $CaCO_3$. In our case, for low pressure, the conversion rate of NF270 is around 38%, which makes this membrane more susceptible to fouling. However, membrane fouling results in a reduction of produced water flow, leading to higher operating costs. Frequent membrane fouling and cleaning lead to a gradual deterioration of membrane materials, affecting permeate water quality and ultimately resulting in a shorter membrane lifespan **(Walha *et al*., 2007)**.

The TM710 membrane exhibits the highest rejection rate for all ions. This aligns with expectations for such a dense reverse osmosis membrane, whose selectivity is primarily based on diffusion rather than pore size, making it highly suitable for desalination. The NF90 membrane shows performance in terms of rejection rate close to that of the TM710 and achieves high rejection rates at pressures below 10 bar. This is due to the nature of the nanofiltration membrane, whose selectivity is also based on diffusion.

According to the manufacturers' specifications, the rejection rates for TM710 and NF90 are 99.5 and 85-95%, respectively, which were achieved during the tests. In contrast, the NF270 membrane has a specified rejection rate of 40-60%, but a 50% rejection was not reached until a pressure of 25 bar. The rejection rate of the NF270/NF90 combination shows a dual rejection at a pressure of 10 bar, indicating that the combination benefits from the roughness and selectivity of the NF90 membrane **(Hssaisoune *et al*., 2020)**.

The variations in rejection for the TM710 and NF90 membranes are independent of pressure, with values between 95-99%. However, for the NF270, a 50% rejection rate is only achieved at a pressure of 25 bar. Such an increase in pressure can affect other desalination parameters, such as the conversion rate, feed flow rate, and the flow and quality of the permeate.

This analysis highlights that while the TM710 and NF90 membranes maintain consistent high rejection rates across different pressures, the NF270 requires significantly higher pressures to achieve comparable rejection rates, influencing the overall efficiency and operational parameters of the desalination process **(Berrabah *et al*., 2023)**.

As expected, the membrane with the highest removal of chloride and sodium ions is the TM710 membrane. This is logical for such a membrane, which retains monovalent ions more effectively, with a concentration reduction rate of approximately 85% at a pressure of 15 bar. Similar results were recorded for the NF90 membrane when compared to TM710.

The selectivity of the NF270 membrane toward chloride and sodium ions is highly dependent on pressure. At low pressure, the NF270 membrane retains less salt compared to NF90. Increasing the pressure leads to greater selectivity, explained by the combined convective and diffusive transfer mechanisms in NF. As pressure increases from low to high (from 7 to 25 bar), the convective character increases further for the NF270 membrane, achieving a reduction rate of chloride and sodium ions of about 26% at a pressure of 15 bar. Comparing the results of each membrane, it is observed that TM710 and NF90 are three times more effective at removing chlorides and sodium compared to the NF270 membrane **(Mohsen *et al.*, 2003)**.

In the case of the NF270 membrane, the water quality in terms of TDS is satisfactory, but the concentrations of Na^+ and Cl^- ions exceed the limits recommended by Moroccan legislation and the WHO for each applied pressure. This indicates the need for an additional treatment before distribution. The water quality obtained by combining NF270 and NF90 is slightly mineralized, thus requiring a post-treatment **(Mousavi *et al.*, 2022)**.

Concentration polarization refers to the accumulation of less permeable components on the high-pressure side of the membrane. This causes counter-diffusion, which reduces permeation flux and can also lead to fouling by components with limited solubility **(Santafé-Moros *et al*., 2005)**.

The only drawback of reverse osmosis is its high energy consumption; it is an energy-intensive process. At the same pressure of 7 bar, the TM710 membrane consumes twice as much energy compared to the NF270 nanofiltration membrane. As previously mentioned, the NF90 nanofiltration membrane performs similarly to the TM710 reverse osmosis membrane in terms of performance, and the same is true for energy consumption. Both membranes consume a significant amount of energy compared to the NF270/NF90 combination and NF270, which requires less energy at low pressure **(Alzahrani *et al*., 2013)**.

These results show that all the tested membranes reduced chloride and sodium ion concentrations. However, the TM710 and NF90 membranes succeeded in reaching the recommended concentration limits according to potable water standards. Under all operating conditions and conversion rates, the TM710 and NF90 membranes reduced Cl^- levels from 2483mg/ L to less than 125mg/ L and 375mg/ L in the permeate, respectively, and Na^+ levels from 1453mg/ L to less than 100mg/ L and 200mg/ L, respectively, for TM710 and NF90. The use of the NF90 membrane was very effective in achieving water compliant with Moroccan potable water standards and was competitive with the TM710 reverse osmosis membrane **(Yang *et al.*, 2018; Zhe *et al.*, 2018; Vandré *et al.*, 2019; Lotfi *et al.*, 2020b)**.

CONCLUSION

In this work, we compared the performances of nanofiltration and reverse osmosis membranes under running conditions in both simple pass and supplied modes. The study revealed the following key findings:

1. The performance of both nanofiltration and reverse osmosis membranes depends on working conditions such as pressure, time, membrane type, and configuration.
2. The behavior of the NF90 and TM710 membranes is similar.
3. The permeate water produced by the TM710 membrane requires a remineralization step. The properties of the NF90 membranes are comparable to those of RO membranes.
4. The NF270 membrane does not meet the recommended standards for drinking water; additional treatment is necessary before distribution.
5. The permeate water obtained from the NF90 membrane is satisfactory and falls within the range accepted by the WHO.

Overall, the NF90 membrane demonstrates better performance in brackish water desalination compared to the TM710.

REFERENCES

Abouzaid, A.; Mouzdahir, A. and Rumeau, M. (2003). Étude de la rétention des sels monovalents et bivalents par nanofiltration. Comptes Rendus. Chimie, 6 (4):431-436. doi : 10.1016/S1631-0748(03)00071-7. https://comptes-rendus.academie-sciences.fr/chimie/articles/10.1016/S1631-0748(03)00071-7/

Abuhabib, A.A.; Mostafa, G.; Mohamad, W.; Abderahman, R. and El-Shafie, A.H. (2013). Desalination of Brackish Water Using Nanofiltration: Performance Comparison of Different Membranes. Arabian Journal for Science and Engineering, 38:2929–2939. https://doi.org/10.1007/s13369-013-0616-z

Ait Messaad, S.; Chakit, M.; Lotfi, S. and Belghyti, D. (2022a). Epidemiological investigation of intestinal parasites in children of Sale city (Morocco). Egyptian Journal of Aquatic Biology and Fisheries. 26 (6):433-438.

Ait Messaad, S.; Chakit, M.; Lotfi, S. and Belghyti, D. (2022b). Contamination of Beach Sand by Cutaneous Larva Migrans in Rabat-Sale Area (Morocco) and their Health-Related Problems. Egyptian Journal of Aquatic Biology and Fisheries., 26(6): 173–183.

Alzahrani, S.; Mohammad, A.W.; Hilal, N.; Abdullah, P. and Jaafar, O. (2013). Comparative study of NF and RO membranes in the treatment of produced water-Part I: Assessing water quality. Desalination, 315:18-26. https://doi.org/10.1016/j.desal.2012.12.004

Asfers, Y.; Taouil, H.; Ibn Ahmed, S. and Chakit, M. (2016a) Metallic Pollution of Aquatic Ecosystems: Water of Oum Er-Rbia River. American Journal of Engineering Research. 5 (9):111-115.

Asfers, Y.; Taouil, H.; Ibn Ahmed, S. and Chakit, M. (2016b) Evaluating metallic pollution caused by iron, copper, lead and cadmium of Oum-Rabia river water. Journal of Bio Innovation. 5(1):59-67.

Berrabah, M.; Benyahia, K.; Zerfa, A. and Bouabdesselam, H. (2023). Feasibility of using Nanofiltration membranes to delay Reverse Osmosis membrane fouling and to reduce energy consumption (BWC desalination plant). Journal of Water and Environmental Nanotechnology, 8(4):384-395. https://doi.org/10.22090/jwent.2023.04.005

Boulahfa, H.;., Belhamidi, S.; Elhannouni, F., Taky, M., El fadil, A. and Elmidaoui, A. (2019). Demineralization of brackish surface water by reverse osmosis: The first experience in Morocco, Journal of Environmental Chemical Engineering, 7(2):102937. https://doi.org/10.1016/j.jece.2019.102937

Cüneyt, K.; Yakubu, A. J.; Ali Mohammed, M.; Enver, G.; Nalan, K.; Müşerref, A. and Mithat, Y. (2020). Seawater Desalination by Using Nanofiltration (NF) and Brackish Water Reverse Osmosis (BWRO) Membranes in Sequential Mode of Operation. Journal of Membrane Science and Research, 6 :40-46. DOI: 10.22079/JMSR.2019.107844.1264

Hssaisoune, M.; Bouchaou, L.; Sifeddine, A.; Bouimetarhan, I. and Chehbouni, A. (2020). Moroccan Groundwater Resources and Evolution with Global Climate Changes. Geosciences. 10(2):81. https://doi.org/10.3390/

Ketharani, J., Hansima, M.A.C.K.; Suresh, I.; Samarajeewa, D.R.; Madhubhashini, M.; JinadasK, B.S.N.; Weragoda, S.K.; Rathnayake, R.M.L.D.; Nanayakkara, K.G.N.; Yuansong, W.; Schensul, S.L. and Rohan, W. (2022). A comparative study of community reverse osmosis and nanofiltration systems for total hardness removal in groundwater. Groundwater for Sustainable Development, 18:100800. https://doi.org/10.1016/j.gsd.2022.100800

Lotfi, S.; Chakit, M. and Belghyti, D. (2020b). Groundwater quality and pollution index for heavy metals in Saïs plain, Morocco. Journal of Health and Pollution. 10 (26): 200603.

Lotfi, S.; Chakit, M.; Najy, M.; Talbi, F.Z.; Benchahid, A.; El Kharrim, K. and Belghyti D. (2020a). Assessment of microbiological quality of groundwater in the Saïs plain (Morocco). Egyptian Journal of Aquatic Biology and Fisheries. 24 (1):509–524.

Medina Collana, J.; Ancieta Dextre, C.; Rodriguez Taranco, O.; Carrasco Venegas, L.; Moñtaño Pisfil, J.; Diaz Bravo, P. and Vasquez Llanos, S. (2024). Brackish Water Desalination by Nanofiltration – Effect of Process Parameters. Journal of Ecological Engineering, 25(8):347-356. https://doi.org/10.12911/22998993/190165

Mohsen, M.S.; Jaber J. O. and Diná Afonso, M. (2003). Desalination of brackish water by nanofiltration and reverse osmosis. Desalination, 157(1–3):167. https://doi.org/10.1016/S0011-9164(03)00397-7

Rosentreter, H; Walther, M; Lerch, A. (2021). Partial Desalination of Saline Groundwater: Comparison of Nanofiltration, Reverse Osmosis and Membrane Capacitive Deionisation. Membranes. 11(2):126. https://doi.org/10.3390/membranes11020126

Saeedeh, S.M. and Ali, K. (2022). Water recovery from reverse osmosis concentrate by commercial nanofiltration membranes: A comparative study. Desalination, 528:115619. https://doi.org/10.1016/j.desal.2022.115619

Santafé-Moros, A.; Gozálvez-Zafrilla, J.M. and Lora-García, J. (2005). Performance of commercial nanofiltration membranes in the removal of nitrateions. Desalination,185(1–3):281-287. https://doi.org/10.1016/j.desal.2005.02.080

Talaeipour, M. ; Nouri, J. ; Hassani, H. and Mahvi, A.H. (2017). An investigation of desalination by nanofiltration, reverse osmosis and integrated (hybrid NF/RO) membranes employed in brackish water treatment. Journal of Environmental Health Science and Engineering, 15:18.DOI 10.1186/s40201-017-0279-x

Tian, J.; Zhao, X.; Gao, S.; Wang, X.; Zhang, R. (2021). Progress in Research and Application of Nanofiltration (NF) Technology for Brackish Water Treatment. Membranes, 11:662. https://doi.org/10.3390/membranes11090662

Touir, J.; El-Ghzizel, S.; Zeggar, H.; Belhamidi, S.; Elazhar, F.; Tahaikt, M.; Taky, M. and Elmidaoui A. (2021). Nanofiltration and reverse osmosis membrane for nitrate removal: performance study and economic evaluation. Moroccan journal of chemistry, 9(1):057-068. https://doi.org/10.48317/IMIST.PRSM/morjchem-v9i1.24357

Usha, K.; Kurella, S.; Ajita, G.; Rama, R.K. and Bhim, C.M. (2021). Chapter 8 - Global water challenge and future perspective. Green Technologies for the Defluoridation of Water, 197-212. https://doi.org/10.1016/B978-0-323-85768-0.00002-6

Vandré, B.B.; Fernando, C.; Adalberto, P. and Danúbia, P.C.F. (2019). Is nanofiltration better than reverse osmosis for removal of fluoride from brackish waters to produce drinking water? Desalination and Water Treatment.158:20-32. https://doi.org/10.5004/dwt.2019.24237

Walha, K.; Ben Amar, R.; Firdaous, L.; Quéméneur, F. and Jaouen, P. (2007). Brackish groundwater treatment by nanofiltration, reverse osmosis and electrodialysis in Tunisia: performance and cost comparison. Desalination, 207(1–3):95-106. https://doi.org/10.1016/j.desal.2006.03.583

Zhe, Y.; Xiao-Hua, M. and chuyang, Y.T. (2018). Recent development of novel membranes for desalination. Desalination, 434:37-59. https://doi.org/10.1016/j.desal.2017.11.046