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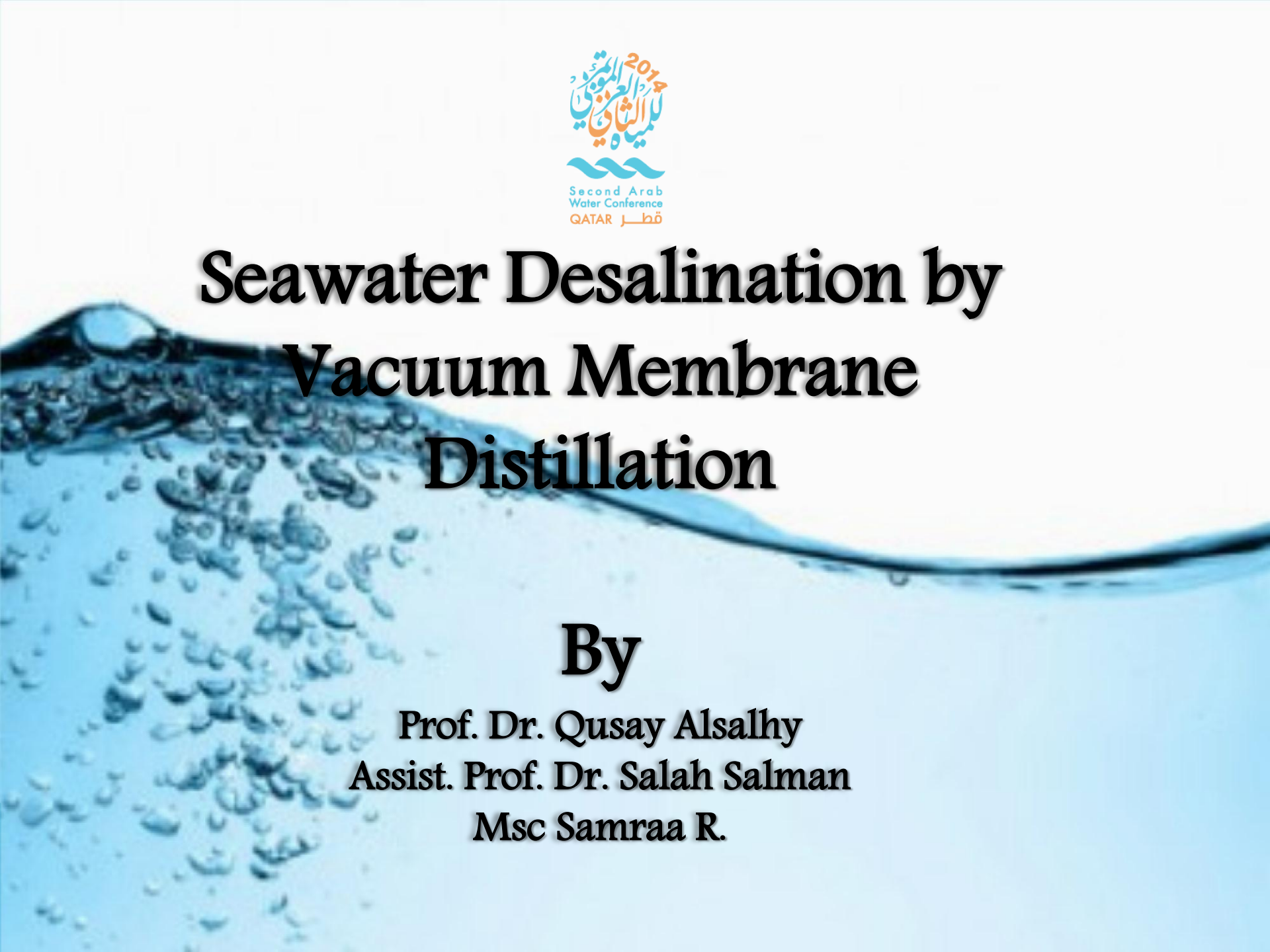
Seawater Desalination By Vacuum Membrane Distillation

Dr. Qusay Fadel Alsalhy



Seawater Desalination by Vacuum Membrane Distillation

By

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Introduction

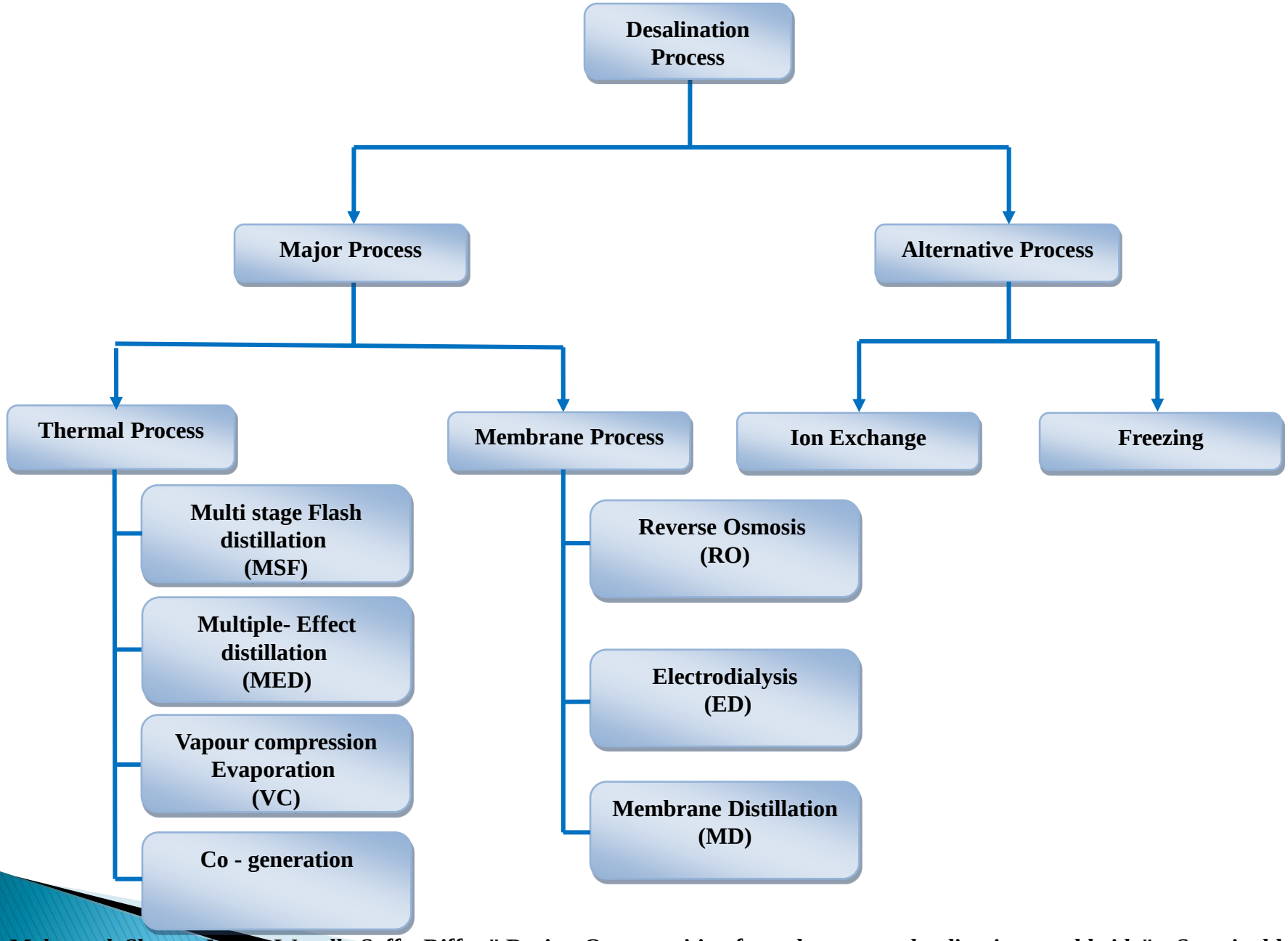
- Water covers over 70% of the earth surface but most of its unsuitable for human consumption.
- 97.5% of all water is salt water (oceans and seas).
- 2.5% as fresh water like rivers and ground water.
- The world population increased from 1.65 to 6 billion in the last century.
- The United Nations (UN) Environment Programme stated that one-third of the world's population lives in countries with insufficient freshwater. And by 2025 reached to two-third will face water scarcity.

Therefore, desalination of seawater and brackish water has become one of the most promising methods to produce fresh water.

Mahmoud et al.", Sustainable Cities and Society 9 (2013) 67–80.
Mahmoud et al. International Journal of Low-Carbon Technologies Advance Access published December 28, 2013.
Andy et al. Journal of Membrane Science 455 (2014) 131–142

Gulf countries suffer from a lack of water, thus the need arises to use a novel methods for seawater desalination. One of these novel methods used nowadays was membrane distillation (MD).

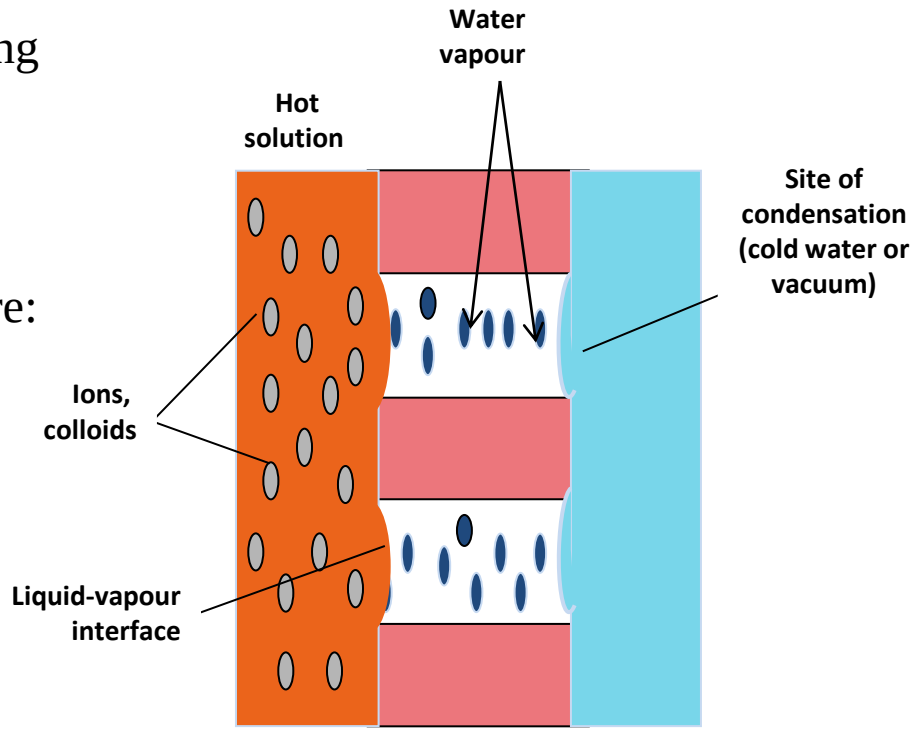
Membrane processes such as reverse osmosis (RO), electro-dialysis (ED) are conventional membrane separation processes and have some problems due to the formation of polarization films, fouling and for seawater desalination need high trans-membrane pressure (50-80) bar. This problems maybe overcome by using the alternative membrane technology such as membrane distillation.



Ref :Mahmoud Shatat, Mark Worall, Saffa Riffat," Review Opportunities for solar water desalination worldwide" , Sustainable Cities and Society 9 (2013) 67–80.

Membrane Distillation

Membrane Distillation (MD) is a thermally-driven separation process in which only vapor molecules are able to pass through a hydrophobic microporous membrane**.** The hydrophobic nature of the membrane prevents the penetration of aqueous solution into the pores, thus creating a vapor-liquid interface at each pore entrance. The driving force in MD is the vapor pressure difference between the two sides of the membrane. The interest of using MD process for desalination is increasing worldwide especially when using low grade heat source. The advantages of MD compared to other process for desalination are:



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2. Marek Gryta ,"Influence of polypropylene membrane surface porosity on the performance of membrane distillation process", jornal of membrane science 287(2007) 67-78.

- Operating at low temperature below the boiling point, vapour space than MSF and MED and can use alternative energy source such as solar energy, geothermal energy and low cost

- Operating at low pressure (atmospheric or vacuum pressure) and performance was not limited by high osmotic pressure, while RO (50-80 bar for seawater) .

- Capable of treating highly concentrated solution more than seawater.
- higher salt rejection 99.99-100% while RO 95-98%
- Reduced chemical interaction between membrane and process solutions.
- Less sensitive to fouling due to large pores 0.1- 1 μm and not limited by concentration polarization

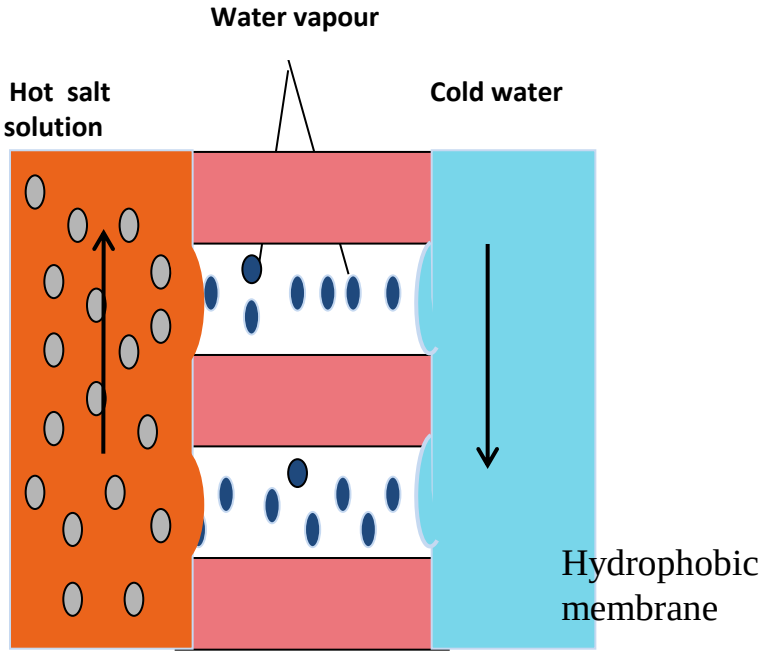
Membrane Distillation Configurations

A variety of methods may be employed to impose the vapour difference, which differ based on the nature of the cold side processing on the permeate in general there are four kinds of MD system configuration

- Direct contact membrane distillation (DCMD).
- Air gap membrane distillation (AGMD)
- Sweep gap membrane distillation (SGMD)
- Vacuum membrane distillation (VMD)

1. Direct contact membrane distillation (DCMD).

In this configuration a hot feed solution is in direct contact with one side of the membrane and colder water is in direct contact with the opposite side of the membrane. The vapor is moved by the pressure difference across the membrane to the permeate side and condense inside the membrane module. This is the simplest system in design because condensation is carried out inside the membrane module. Advantage of this configuration high permeate flux. The main drawback of this configuration is the heat loss by conduction. Application of this configuration in desalination, waste water treatment, Food industry, pharmaceutical industry



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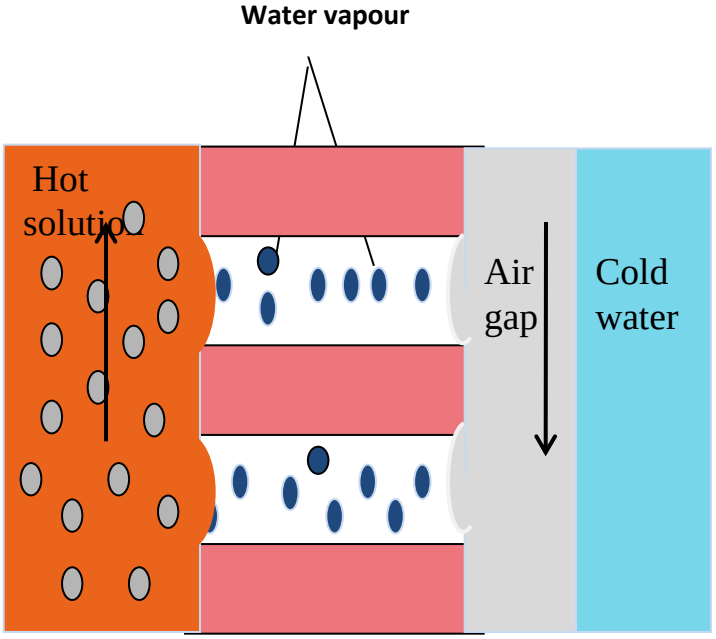
2. Tzahi Y. Cath, V.Dean Adams,Amy E. Childress,"Experimental study of desalination using direct contact membrane distillation: a new approach to flux enhancement", Journal of membrane science 228(2004)5-16.
3. Kevin W. Lawson, Douglas R. Liod, "Membrane distillation", journal of membrane science 124(1997)1-5

2. Air gap membrane distillation (AGMD)

The feed solution is in direct contact with the hot side of the membrane surface only. Stagnant air is introduced between the membrane and the condensation surface. The evaporated volatile molecules cross the membrane pore and the air gap to condense over the cold surface inside the membrane cell. The advantage of this configuration is low heat lost by conduction Due to the presence of air in the permeate side of the membrane. Disadvantage of this type low permeate flux due to additional resistance to mass transfer due to the presence of air gap between cold side of the assembly and permeate side of the membrane. Application of this configuration Desalination and water treatment, food industry, Chemical industry.



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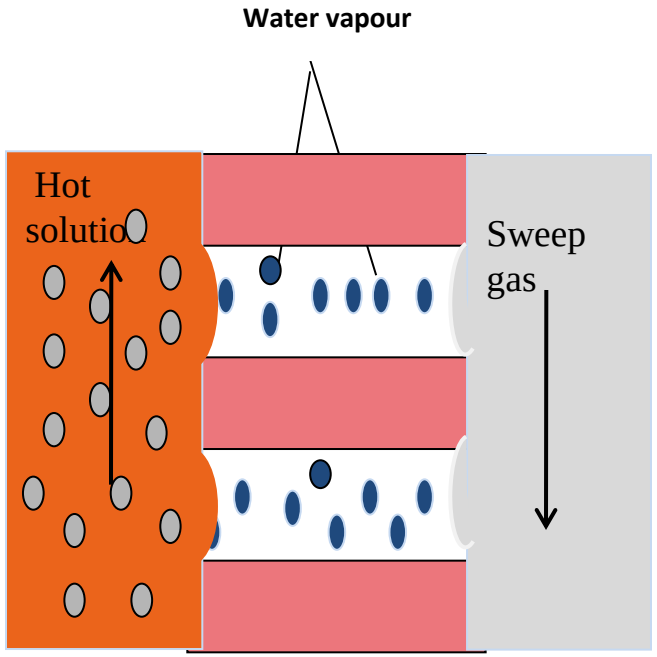
3. G.A.Mannella.V.L Carruba.V. Brucato," Evaluation of vapor mass transfer in various membrane distillation configurations: an experimental study", Received: 10 May 2011

3. Sweep gas membrane distillation (SGMD)

Inert gas is used to sweep the vapor at the permeate membrane side to condense outside the membrane module. There is a gas barrier reduce heat loss by conduction but this is not stationary which enhances the mass transfer coefficient and lead to high permeate flux. The flux in SGMD is independent on the temperature of the sweep gas. The pressure drop of the sweep gas increase as the velocity increase and the resistance in the boundary layer increase The main disadvantage of this configuration is that a small volume of permeate diffuses in a large sweep gas volume, requiring a large condenser.



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1. Kevin W. Lawson, Douglas R. Liod, "Membrane distillation", journal of membrane science 124(1997)1-5.
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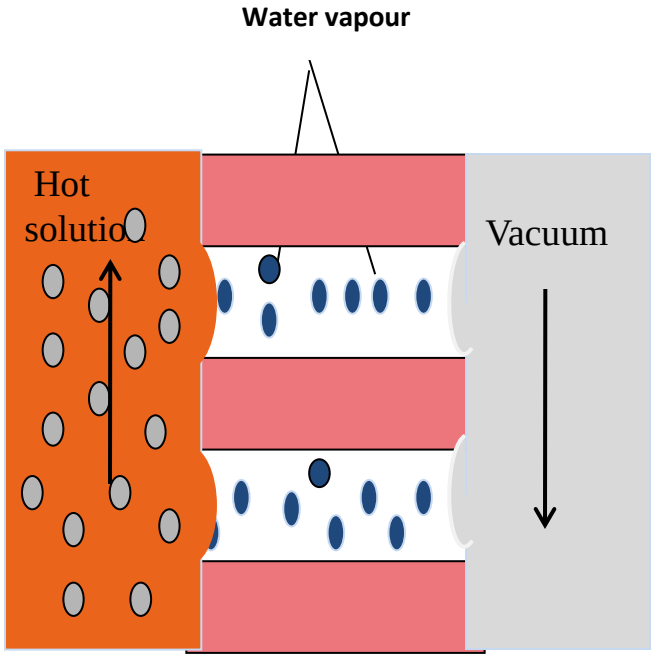
4. Vacuum membrane distillation (VMD)

In this configuration feed solution is brought in to contact with one side of hydrophobic micro porous membrane and vacuum pulled on the opposite side to create a driving force for mass transfer by a pump. Condensations take place outside the membrane module. VMD can be characterized by the following steps:

- Vaporization of the more volatile compounds at the liquid vapor interface
- Diffusion of the vapor through the membrane pores
- Withdrawal of water vapor from the membrane unit under vacuum



VMD has a number of advantage over conventional MD configuration, Production of pure distilled water at lower operating temperature, resulting lower in cost and lower energy requirements are need to achieve similar flux compared to other distillation and desalination process. VMD is a promising technology that has the potential to become as important as the conventional distillation and pressure driven membrane technology for water desalination.

Ref:

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2. Andy Chenggui Sun, Walter Kosar, Yufeng Zhang, Xianshe Feng"Vacuum membrane distillation for desalination of water using hollow fiber membranes" Journal of membrane science 455(2014)131-142.
3. M. Sivakumar, M. Ramezanianpour and G.O. Halloran," Mine water treatment by using a Vacuum membrane distillation system", APCBEE Procedia 5(2013)157-162.

MD configuration	Advantage	Disadvantage
DCMD	High permeate flux [2]	heat loss by conduction is high [1]
AGMD	heat loss by conduction is low due to the presence air gap in the permeate side of the membrane [1]	low permeate flux due to additional resistance to mass transfer due to the presence of air gap between cold side of the assembly and permeate side of the membrane [1]
SGMD	heat loss by conduction is low[1]	Difficult heat recovery [2]. small volume of permeate diffuses in a large sweep gas volume, requiring a large condenser [1]
VMD	Operating at low temperature with low cost [3] Operating at low pressure (vacuum pressure) [3] Low energy requirements are needed to chive similar flux with other desalination process[3] heat loss by conduction is neglected [1]. High permeate flux due to high vapour pressure difference between the two side [2]	risk of pore wetting is higher than other process can be avoided by using small pore size less than0.45 µm [1]

Ref:

1. Abdullah Alkhudhiri, Naif Darwish, Nidal Hilal," Membrane distillation: Acomprehensive review", Desalination 287(2012)2-18.
2. Alla Kullab,"Desalination using Membrane Distillation ",Doctoral Thesis 2011.
3. 3. M. Sivakumar, M Ramenzanianpour and G.O Halloran," Mine water treatment Using Vacuum Membrane Distillation System", APCBEE Procedia 5(2013)[illegible]162

❖ Aim of this work:

In this work, polypropylene (PP) hollow fiber commercial membrane was used for seawater and high-NaCl concentration desalination by using VMD process. Effect of different operating conditions such as feed temperature (i.e., 45-65 °C), feed concentration (i.e., 35000 to 100000 ppm), and feed flow rate (i.e., 0.3-0.6 l/min) on permeate flux were studied. Moreover, the permeation flux obtained in this study was compared with that reported in the literature.

EXPERIMENTAL WORK

Contact Angle

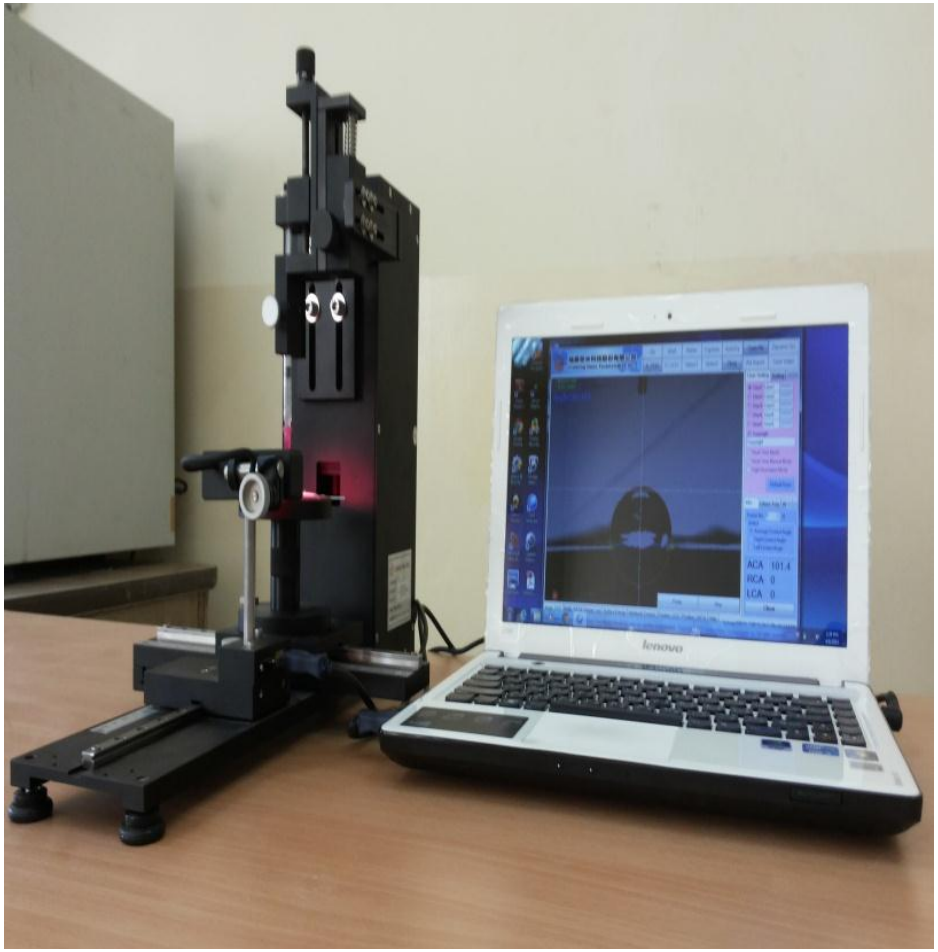
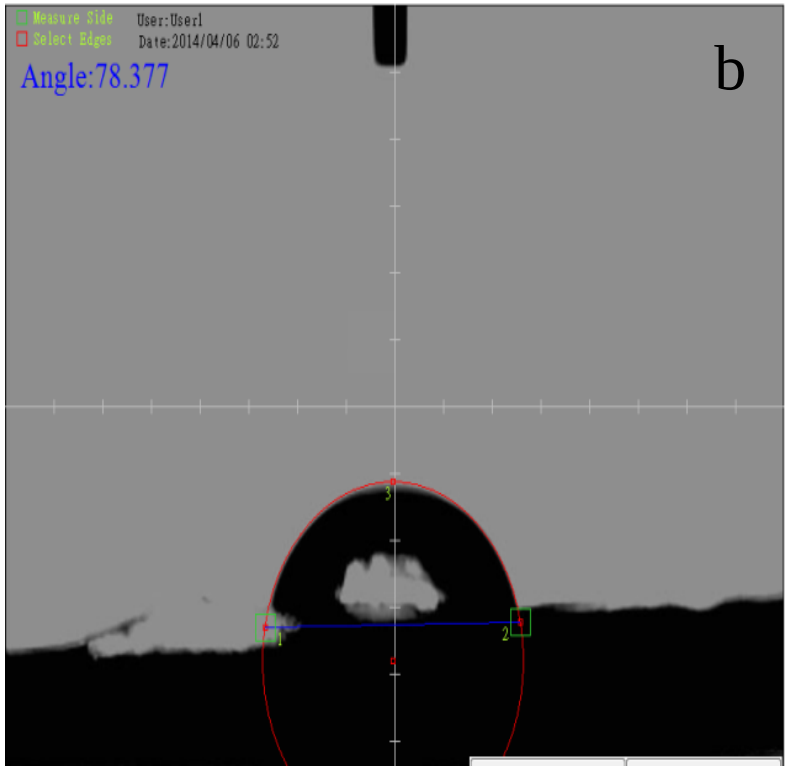


Fig (1) Contact Angle Meter



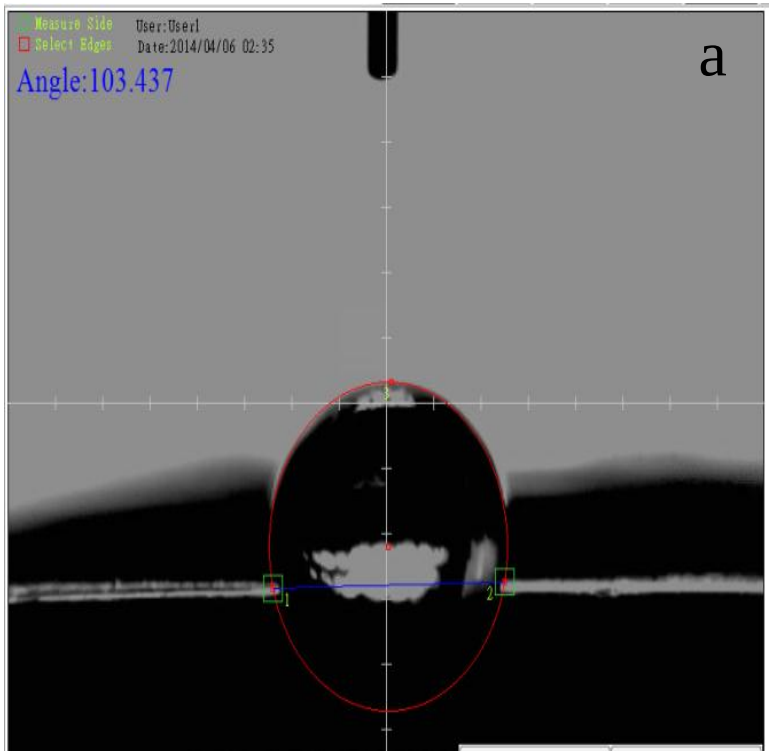


Fig (2) a: contact angle outer surface
b: contact angle inner surface

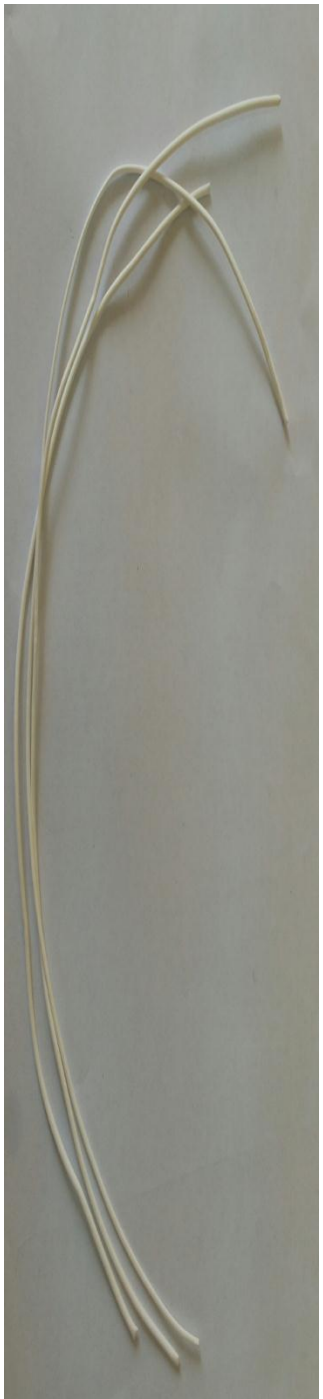
1. Prepare membrane module

stainless steel tube

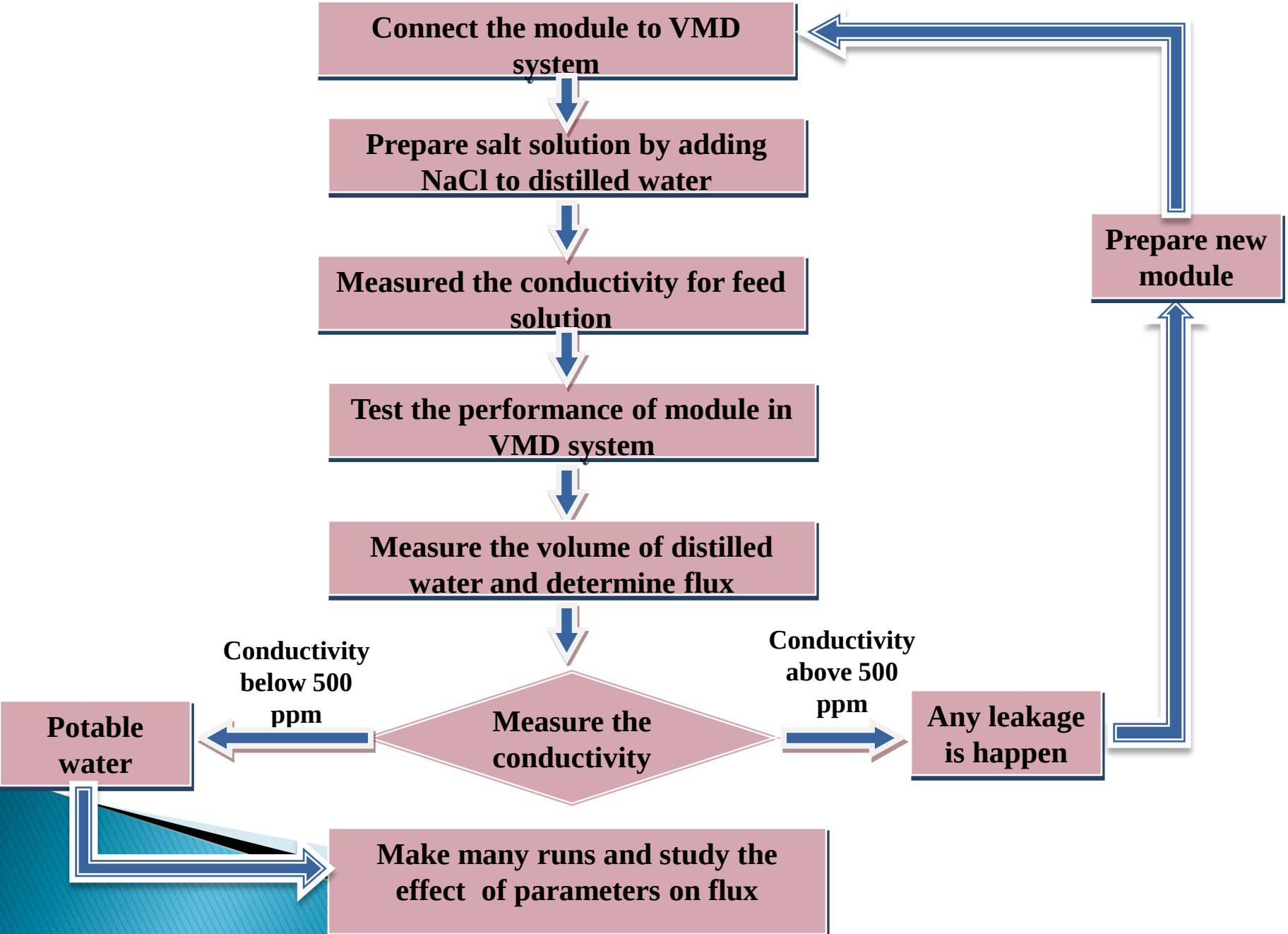
Connected to a Swagelok tube fitting on each end

Inserted the membrane in tube

Sealed both end with epoxy resin and hardener



2. Test the performance of module



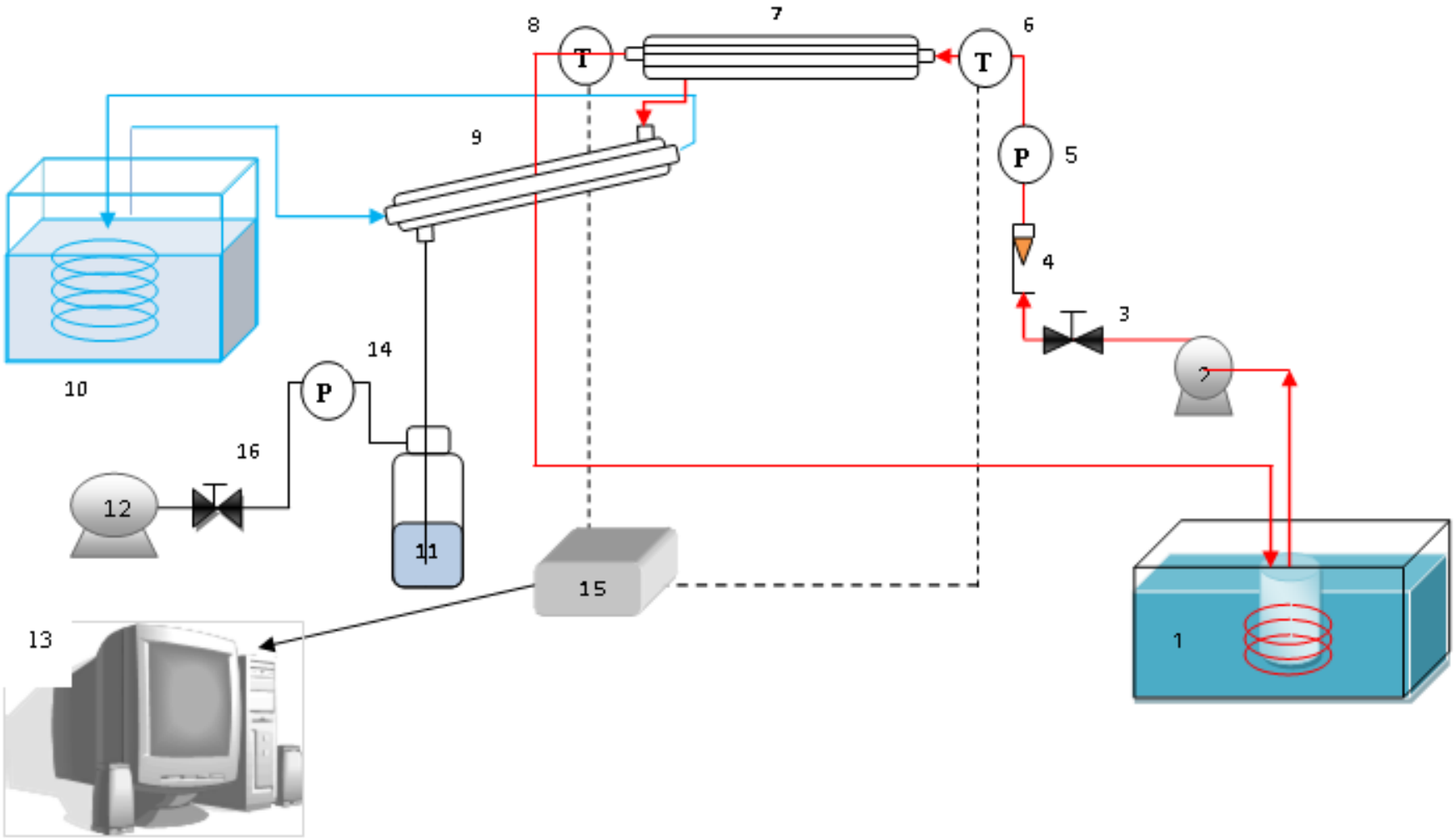


Fig (3)Schematic diagram of VMD

Fig (4)photograph picture of the system and equipment

Permeation flux and salt rejection measurement

The volume of the water permeated from hollow fiber membranes within a measured time was used to determine the water vapor permeation flux by using the following equation:

$$Jv=V\times\rho/A\times t \qquad (1)$$

where, Jv is water vapor permeation flux ($kg/m^2.hr$), V is volume of collected water (l), ρ is water density (kg/m^3), A is effective surface area of the membrane (m^2), and t is water collected time (hr). The salt concentrations of the feed and permeate into and out of the membrane module were measured by a conductivity meter (Model DDS 307 made in Germany). To calculate the salt rejection, the following equation was used:

$$R(\%)=[1-(C_P/C_F)]\times 100 \qquad (2)$$

where R is the salt rejection, C_P is the concentration of permeates solution and C_F is the concentration of the feed solution.

RESULTS & DISCUSSION

❑ Effect of feed temperature

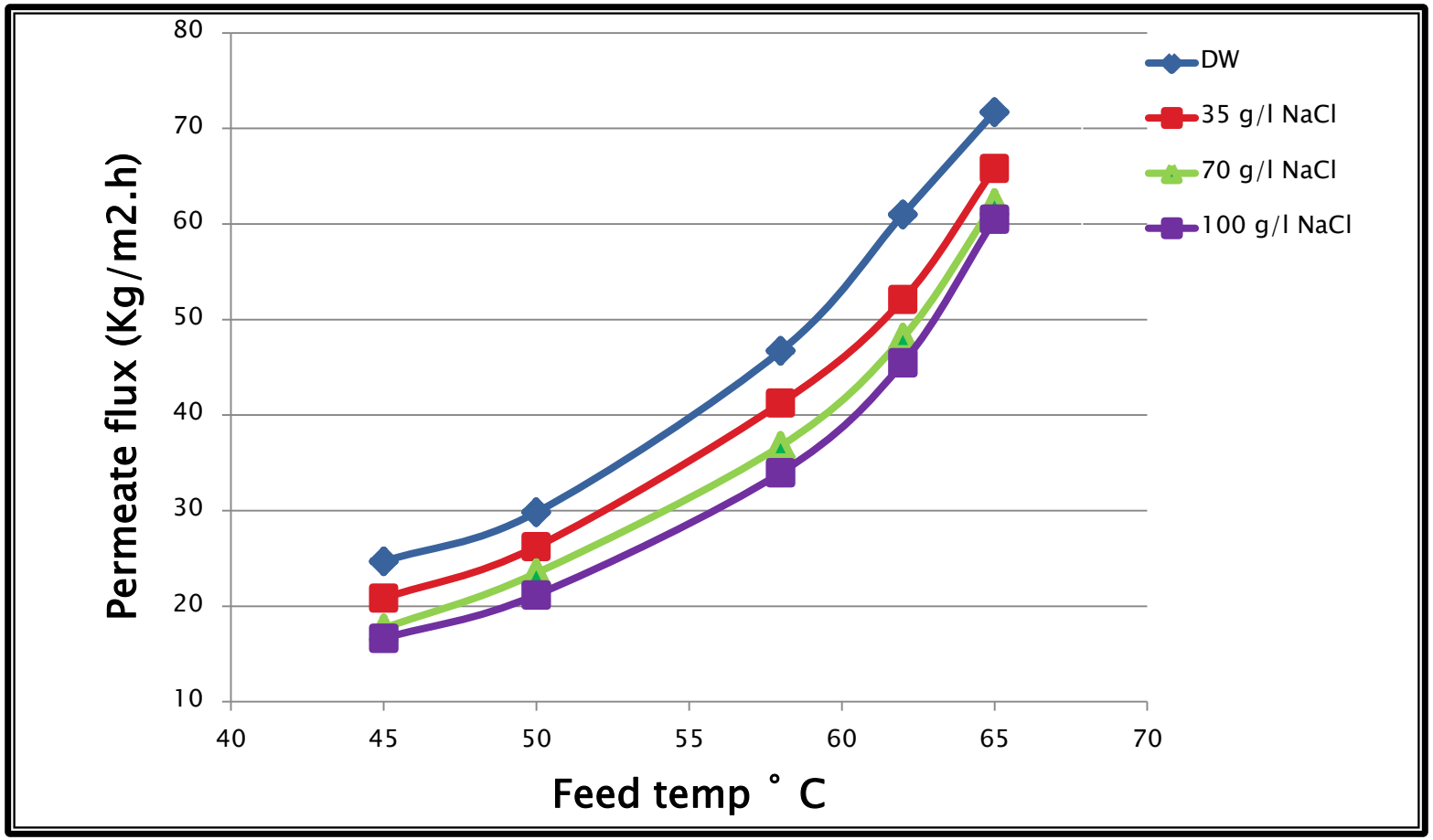


Fig (1) Effect of feed temperature on permeate flux at different concentration

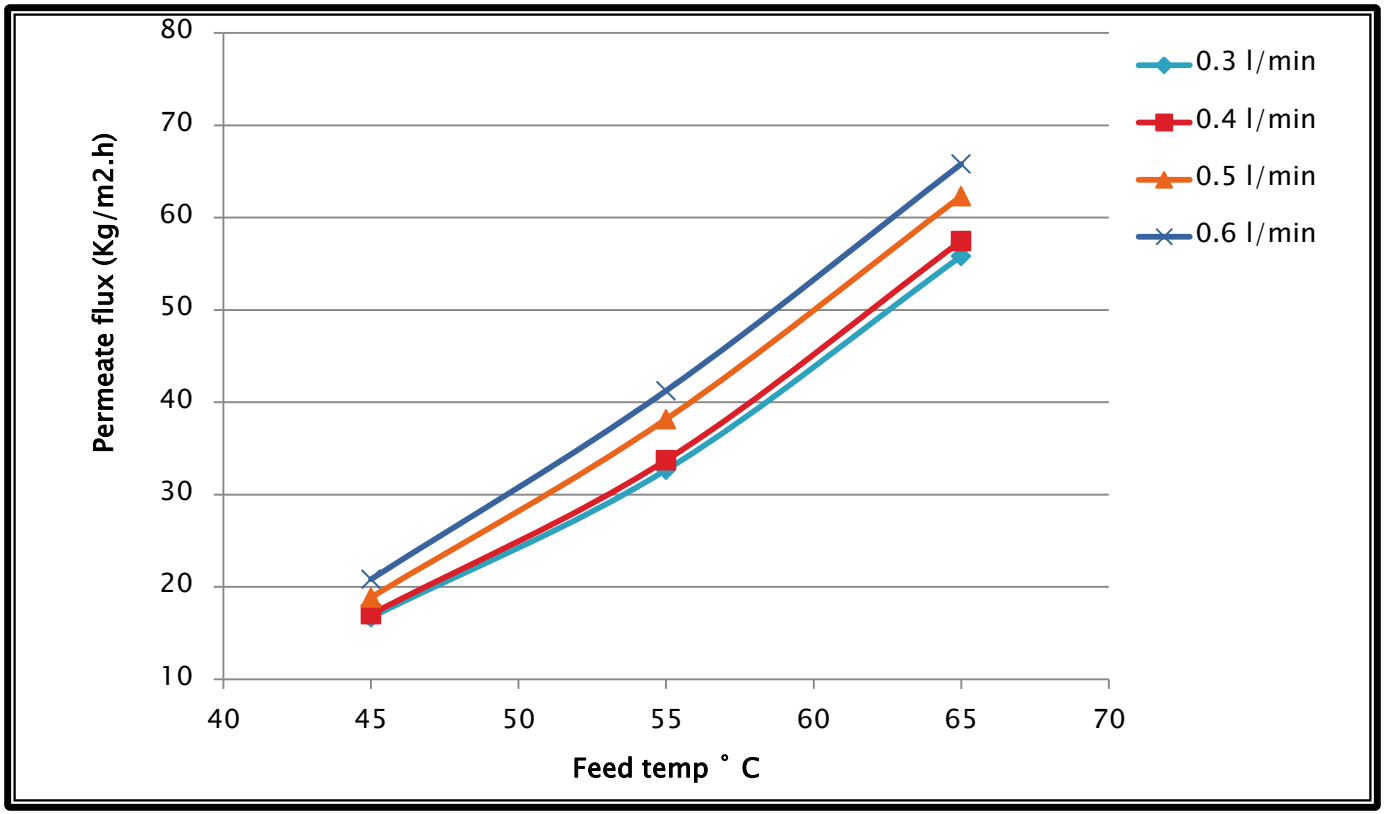
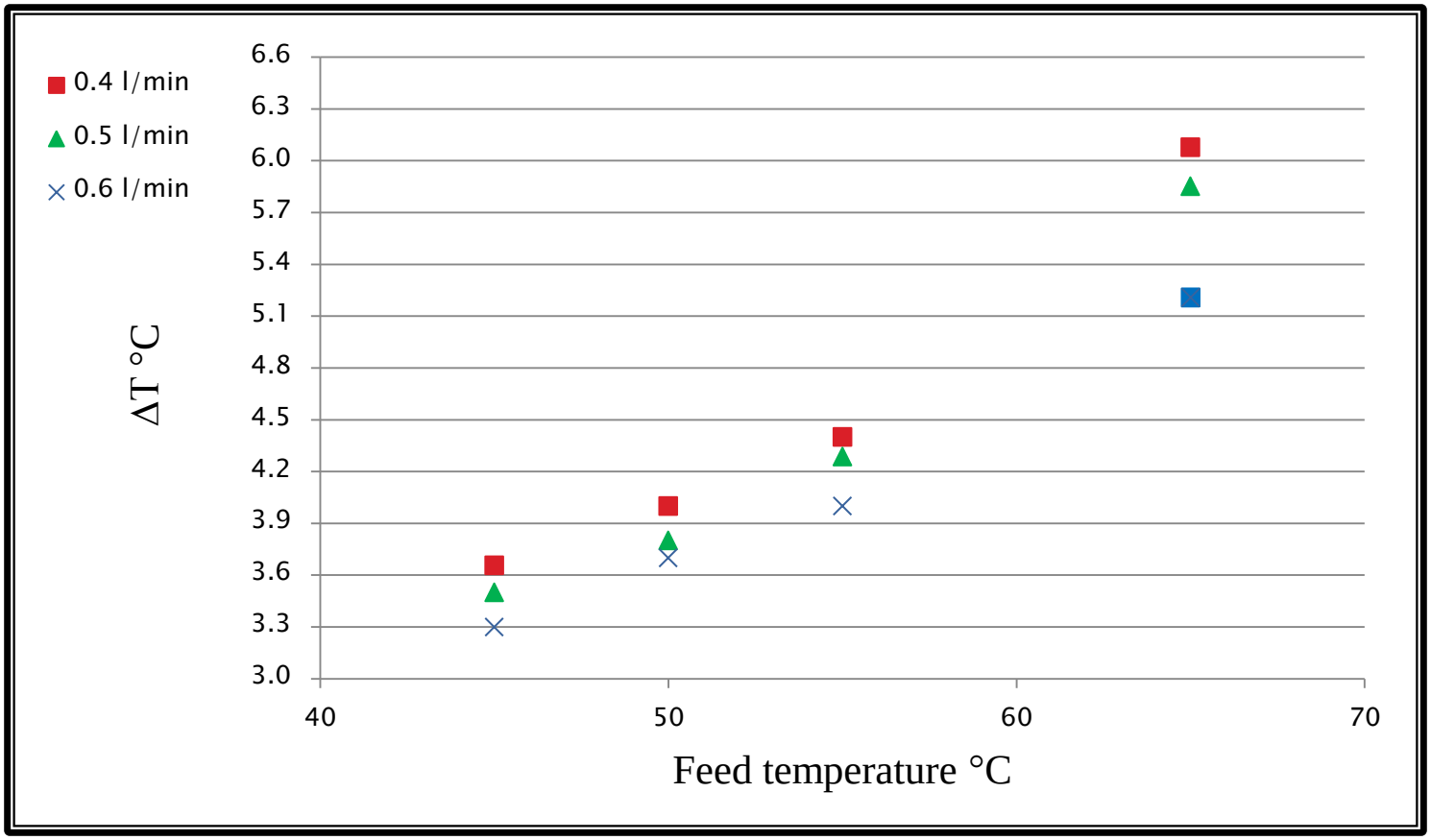
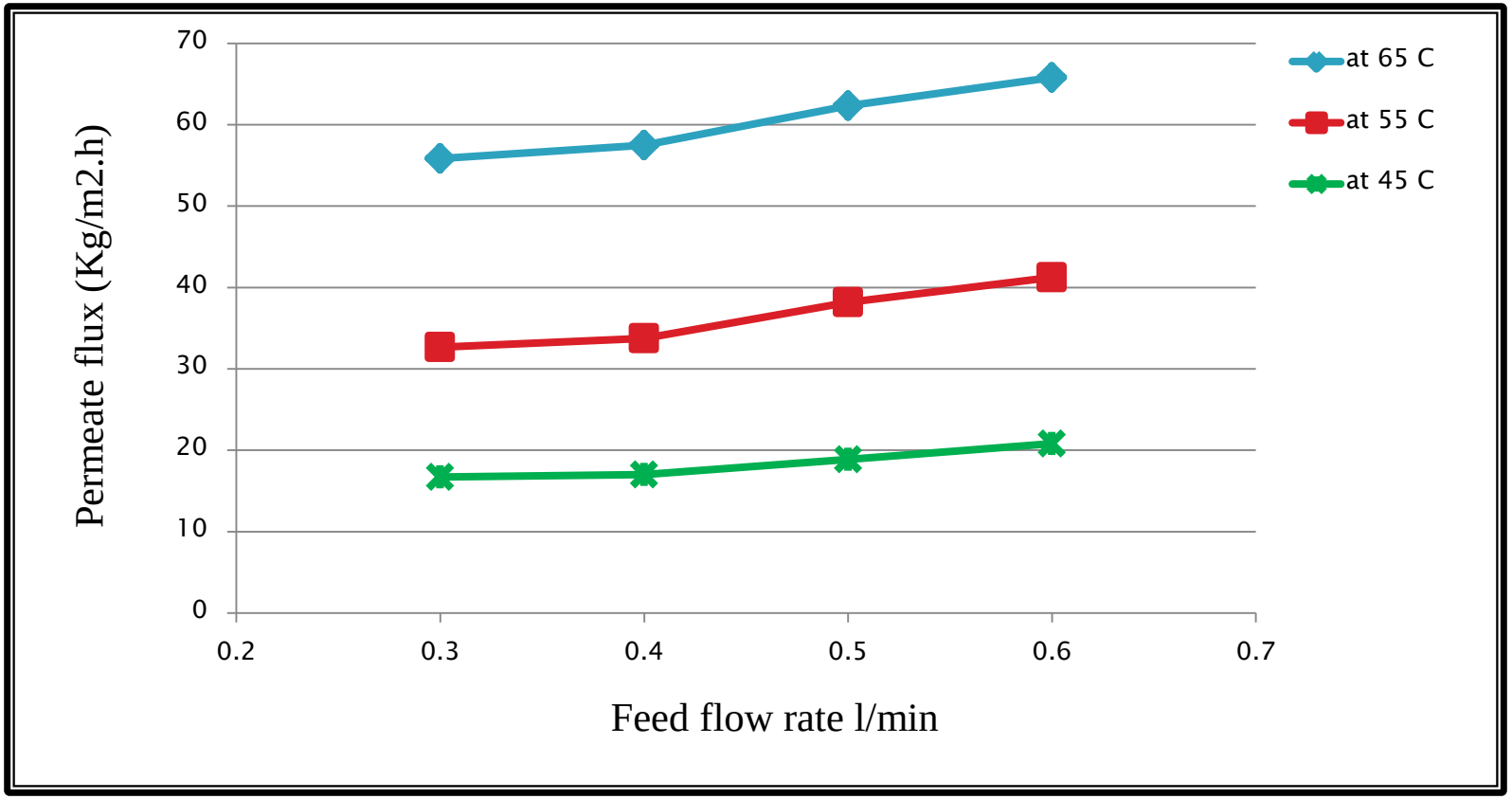


Fig (2) Effect of feed temperature on permeate flux at different flow rate



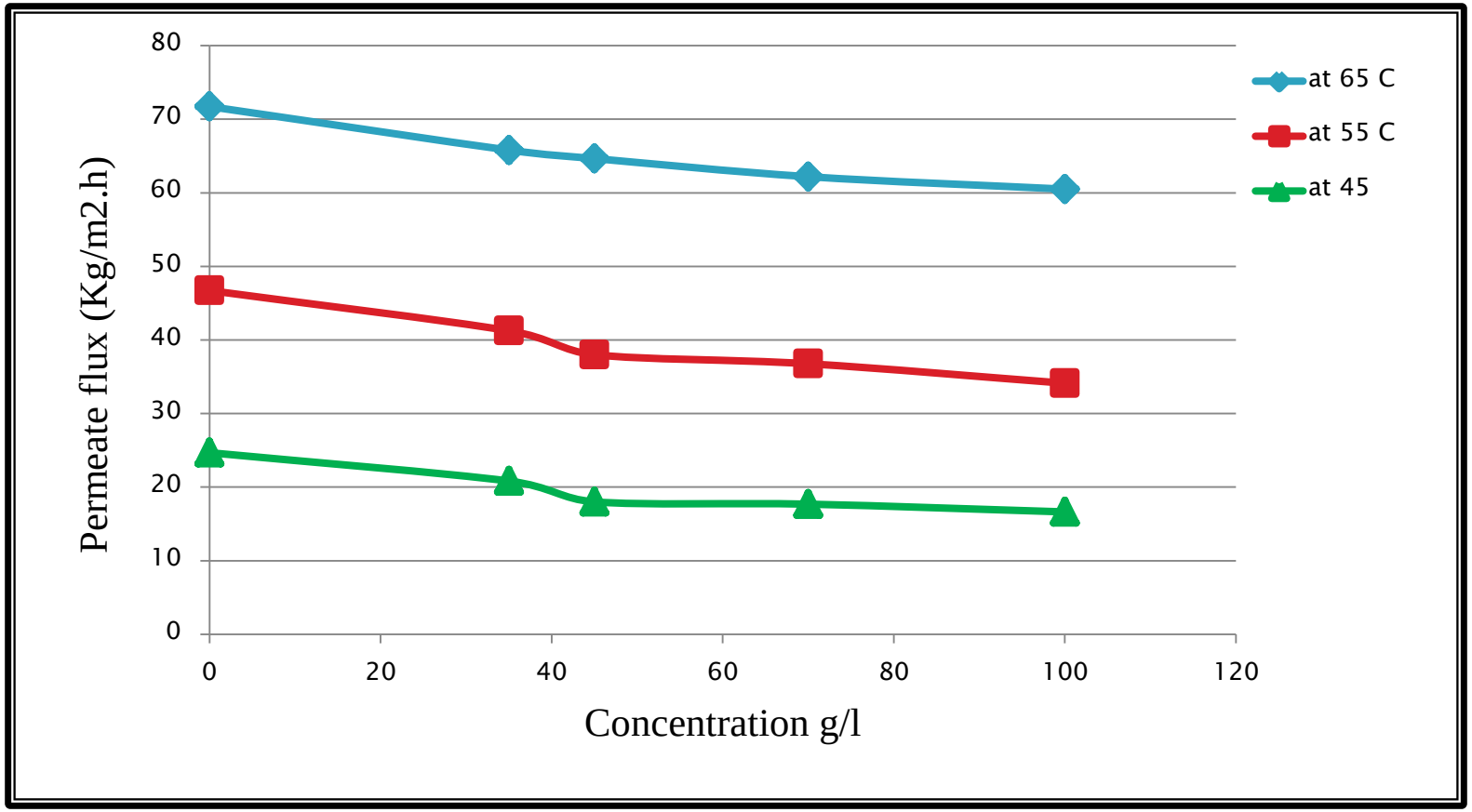
Fig(3)Difference of temperature between inlet and outlet of the module versus the feed temperature for the three flow rate for 35 g/l NaCl solution and 665 mmHg vacuum pressure

❑ Effect of feed flow rate



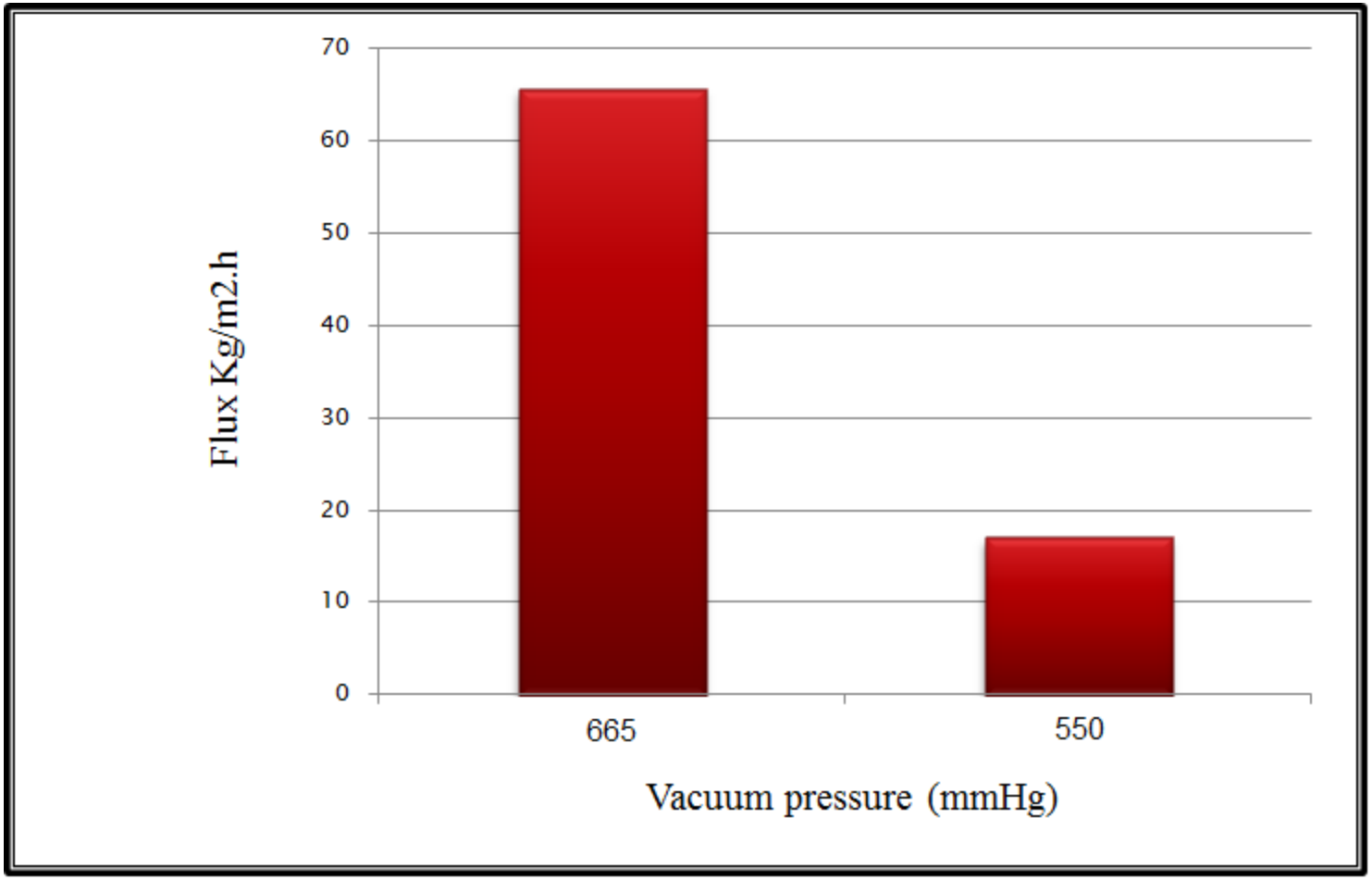
Fig(4) Effect of feed flow rate at different temperature

❑ Effect of feed concentration



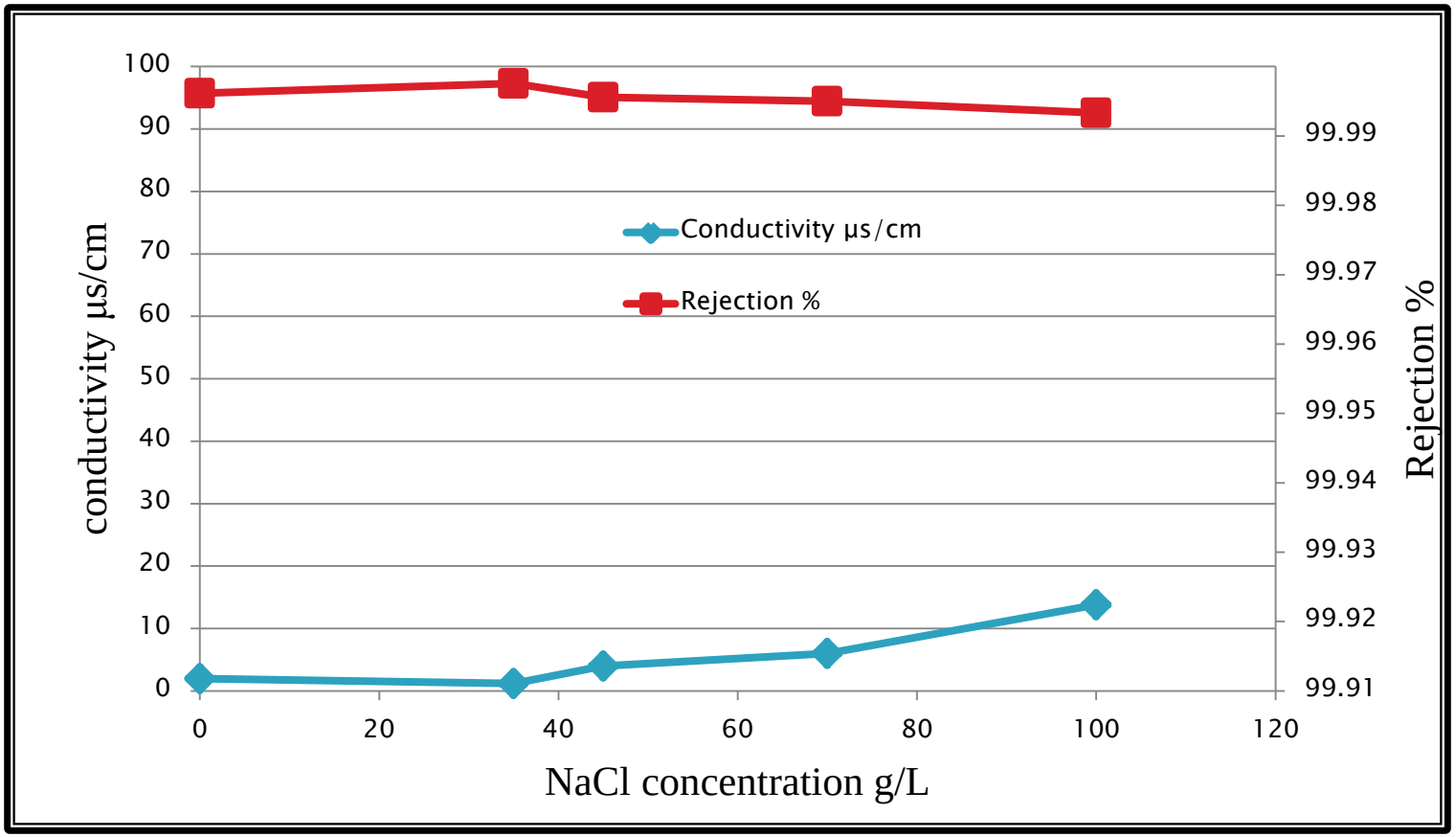
Fig(5)effect of feed concentration at different temperature

❑ Effect of vacuum pressure



Fig(6) effect of vacuum pressure on permeate flux

Conductivity for permeate and salt rejection at different concentration



Variation of temperature with time

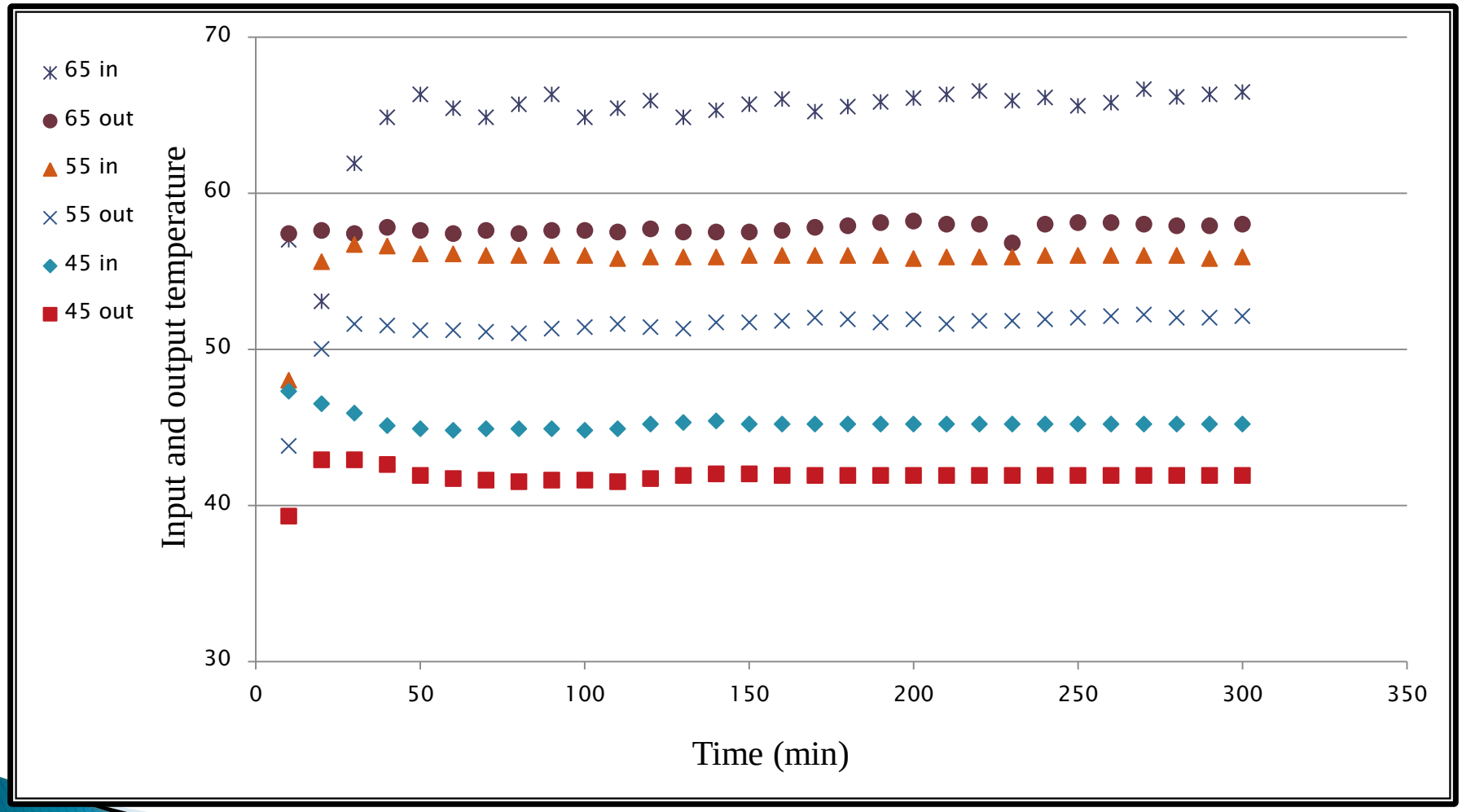


Table Summary of the results achieved in some VMD tests for PP membrane

Ref	membrane material	no of fiber	ID mm	ODmm	thickness µm	length mm	Area m^2	porosity %	average pore size µm	Con. g/L	Temp ° C	flow rate l/min	vacuum pressure(abs) mbar	flux $kg/m^2.h$
1	PP-FS	_	_	_	163	_	$9.1*10^{-4}$	75	0.2	50	55	1.8	130	16.9
2	PP-HF	_	0.33	_	53	800	12.3	_	_	35	55	1.1	83.25	5.4
3	PP-HF	500	0.37	35.4	35	140	0.09	_	0.1	potabe water	75	3	_	32.19
4	IPP-FS	_	_	_	200	_	28 *10^-4	70	0.02-0.2	30	70	0.833	29.61	24.81
5	pp-HF	3	5.5	_	1.5	750	0.039	75	0.2	ethanol	12_32	0.15-1.3	59.226	10_15
6	PP-FS	_	_	_	163	_	9.1*10^ -4	75	0.2	100	25-55	1.8	40-120	14.4
7	PP-FS	_	220	300	0.04	190	0.6	40	0.04	pure water	18-22	0.05	2.961	1.15
8	PP-FS	4	_	_	_	_	180 cm^2	70-75	0.2-0.45	0.0002-0.005 arsinic	20-40	_	10	3-12.5
9	PP-HF	40	1.8	2.6	0.4	470	0.15	70	0.2	20	40-65	_	40	4_19
10	PP-HF	60	0.03	0.04	_	120		60	0.1	20	80	0.0833	236.84	7.8
11	PP-HF	180	330 µm		150µm	_	119 cm^2	65	>0.2	10	85	_	131.58	72
12	PP-HF	300	1.05	0.61	0.22	105	37350	55-65	0.2	pure water	75-88	_	313.25	58
13	PP-HF	40	1.8	2.6	0.8	470	0.1	70	0.2	pure water	65	_	39.484	30.6

Table Summary of the results achieved in some VMD tests for other type of membrane (PTFE-PVDF-Silicon nitrite- alumina)

			membrane properties							operating conditions				
Ref	membrane material	no of fiber	ID mm	OD mm	thickness µm	Lengthm m	Area m^2	porosity %	average pore size µm	conc. g/l	feed Temp.˚C	Flow rate l/min	vacuum pressure(abs) (mbar)	flux $kg/m^2.h$
14	PTFE-HF	_	_	_	_	_	0.8	_	0.2	0	75	1	49.3	9
15	PTFE-FS	_	_	_	175	_	$3.6*10^{-4}$	70	0.22	30	60	0.9	29.613	12
16	PVDF-HF	_	0.8	_	150	90	0.023	85	_	-	75		53.25	17
17	PTFE-FS	_	_	_	_	_	_	_	_	7	60	0.916	9.871	28.34
18	PTFE-HF	40	0.9	2.4	75	390	0.044	63.4	0.46	30	80	0.6	9.871	17.2
19	PTFE-FS	_	_	_	45.2	_	_	38.6	_	DW	70	0.533	20	9.45
20	PVDF-FS	_	_	_	121.4	_	$23.5*10^{-4}$	76.5	_	DW	60	0.5	296.13	9.28
21	silicon nitrite - HF	7	_	_	_	80	_	_	1.6	40	80	1.6	20	28.292
22	alumina - HF	7	2.6	1.6		100	$39.56*10^{-4}$		0.7	40	80		40	42.9
23	PVDF-HF	3			0.23	200	_	70-80	0.32	DW	50	0.1	40	41.78
24	PVDF-FS	_	_	_	0.082	_	26.4*10 ^-4	78	0.49	35	85	0.9	69.09	40
25	PVDF-HF	3	1.4	1.7	170	_	_	71-83	0.15-0.54	DW	50	0.51	20	18
26	PTFE-FS	_	_	_	175	_	$3.6*10^{-4}$	70	0.22	7	60	0.916	14.8	28.34

Table Operating conditions and permeate fluxes in (DCMD- AGMD), as obtained in several studies.

Ref	Configuration	Membrane material	Memb. Thick. mm	porosity %	pore size (μ m)	Feed Temp. ° C	Conc. g/l	Flow rate L/min	Flux kg/m^2. h
26	DCMD	PP-FS	0.025	55	0.064	60	seawater	-	4.24
27	DCMD	PTFE-FS	0.175	_	0.2	70	--	1.5	33.7
28	DCMD	PVDF-FS		_	0.22	80	-	6	51.14
29	DCMD	PVDF-FS	0.045	55.8	0.22	80.5	35	-	47.6
30	AGMD	PTFE-FS	0.175	70	0.22	60	Ground water	0.916	40.48
31	AGMD	PTFE-FS	0.178	80	0.45	71	30	3.05	47.18

membrane material	no of fiber	ID mm	OD mm	thickness µm	length mm	Area m^2	porosity %	average pore size µm	Con. g/L	Temp °C	flow rate l/min	Vacuum pressure(abs) mbar	Flux ($Kg/m^2.h$)
PP-HF	1	1.8	2.7	0.45	180	0.1	70	0.2	35	65	0.6	125	65.8

Conclusion

In this work, seawater and high-NaCl concentration solutions desalination were performed by using VMD process. Influence of the various parameters such as, feed temperature, feed concentration, and feed flow rate, vacuum pressure for sea water at 35000 ppm and high-NaCl concentration up to 100000 ppm on the permeate flux were studied by using PP hollow fiber membrane with a pore size of 0.2 µm. VMD permeation flux increased with increasing of feed temperature, flow rate and vacuum pressure. Whereas, the permeation flux of PP hollow fiber decreased with increasing of NaCl concentration in feed solution. Salt rejection is high in MD process and not affected by salt concentration. Electrical conductivity for permeate was less than 10 µs/cm for salt solution of 35 g/l . The permeation flux obtained in this work 65.8 ($Kg/m^2.h$) for salt solution of 35 g/l, 65 ˚C feed temperature, 0.6 l/min feed flow rate, 665 mmHg vacuum pressure. In this method the permeate flux obtained was higher than that found in the literature for VMD and other configurations. No significant decrease in permeation flux with increase of salt concentration and the flux decline is between 1.75 to 15.65% with increase of salt concentration from 35000 to 100000 ppm at 65 °C

Thank you

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