**Journal of Engineering**
journal homepage: www.joe.uobaghdad.edu.iq
Number 11 Volume 25 November 2019

*Chemical, Petroleum and Environmental Engineering*

# A Comparison Study of Brine Desalination using Direct Contact and Air Gap Membrane Distillation

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## ABSTRACT

Membrane distillation (MD) is a hopeful desalination technique for brine (salty) water. In this research, Direct Contact Membrane Distillation (DCMD) and Air Gap Membrane Distillation (AGMD) will be used. The sample used is from Shat Al –Arab water (TDS=2430 mg/l). A polyvinylidene fluoride (PVDF) flat sheet membrane was used as a flat sheet form with a plate and frame cell. Several parameters were studied, such as; operation time, feed temperature, permeate temperature, feed flow rate. The results showed that with time, the flux decreases because of the accumulated fouling and scaling on the membrane surface. Feed temperature and feed flow rate had a positive effect on the permeate flux, while permeate temperature had a reverse effect on permeate flux. It is noticeable that the flux in DCMD is greater than AGMD, at the same conditions. The flux in DCMD is 10.95LMH, and that in AGMD is 7.14 LMH. In AGMD, the air gap layer made a high resistance. Here the temperature transport reduces in the permeate side of AGMD due to the air gap resistance. The heat needed for AGMD is lower than DCMD, this leads to low permeate flux because the temperature difference between the two sides is very small, so the driving force (vapor pressure) is low.

**Keywords**:membranedistillation,direct contact membrane distillation, air gap membrane distillation, desalination.

# دراسة مقارنة في تحلية الماء المالح باستخدام التقطير بواسطة الاغشية ذات الاتصال المباشر والفجوة الهوائية

## الخلاصة

ان هذه الدراسة تعتبر مقارنة بين طريقتين للتحلية, تعتبر تقنية التقطير بواسطة الاغشية تقنية واعدة لتحلية المياه المالحة. في هذا البحث تم استخدام نوعين من تقنيات التحلية بواسطة الاغشيةDCMD و AGMD . تم استخدام مياه شط العرب(قيمة الاملاح الذائبة الكلية = 2430 ملغم/لتر) كلقيم.الغشاء المستخدم من نوع PVDF على شكل غشاء ورق مسطح موضوع داخل خلية من نوع اللوح والاطار.تمت دراسة عدة عوامل مثل: زمن التشغيل وحرارة اللقيم وحرارة الماء المقطر ومعدل جريان اللقيم. بينت النتائج انه بمرور الزمن يقل تدفق الناتج بسبب تراكم المواد على سطح الغشاء. حرارة اللقيم ومعدل جريانه لها

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2019.11.04

Article received: 20/11/2018
Article accepted: 13/1/2019
Article published: 1/11/2019

تأثير ايجابي على معدل التدفق, بينما حرارة الناتج لها تأثير عكسي على معدل التدفق. من الملاحظ ان تدفق الناتج في الDCMD هو اكثر من الAGMD حيث ان تدفق الناتج في الDCMD هو 10.95 لتر لكل متر مربع في الساعة بينما تدفق الناتج في الAGMD ولنفس الظروف هو 7.14 لتر لكل متر مربع في الساعة .في ال AGMD طبقة الفجوة الهوائية تصنع مقاومة عالية, هنا انتقال الحرارة يقل في جانب الماء المقطر للAGMD بسبب المقاومة العالية (الفجوة الهوائية), لذلك الحرارة المطلوبة في الAGMD هي أقل من الحرارة المطلوبة في ال DCMD وهذا يؤدي الى ان تدفق الناتج القليل بسبب ان اختلاف الحرارة بين جانبي الغشاء جدا قليل وبالتالي القوة المحركة (ضغط البخار) قليلة.

**الكلمات الرئيسية:** التقطير بالأغشية، أغشية التقطير ذات الاتصال المباشر , وأغشية التقطير ذات الفجوة الهوائية ,تحلية المياه المالحة.

## 1. INTRODUCTION

Water covers 71% of the Earth's surface and plays a vital role in sustaining life on earth. Around 96.5% of the planet's water is found in seas and oceans while the rest is in groundwater, glaciers and the ice caps of north and south poles around 0.001 % is detected as vapor in the air. Only 2.5% of the total water content in the earth is considered as freshwater, and around 98.8% of the fresh water is in ice form. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, **Gleick, 1993**. The water resources in the Middle East represent less than 1% of the total fresh water in the world, and the difficulty to access these resources indicates how poor is the region. Middle East region has a specialty if it is compared to the other areas around the world. This is due to several reasons, such as; 6% of the total world’s population lives in the region, the high rate of population growth in the world, the scarceness of natural water resources lack in the natural water resources, and the high water consumption rates across the globe. The biggest and poorest region in the Middle East is Gulf countries, this region has low freshwater resources(rivers, lakes, and even low rain rainfall average) so desalination plants is the main source for the pure and drinkable water in this region, **Fard & Manawi, 2014**. The southern region in Iraq faces a drinkable and pure water crisis, the primary water source (especially in Basra) is Shat al–Arab river which suffers from high salinity rates, the salinity averages are not equal. It differs from time to time and from region to another due to natural or human-made factors. It is becoming more demanding to provide new and more affordable water clarification technologies. As such, further research into this field of water desalination is becoming of significant importance to overcome this overgrowing dire need and provide more stable and affordable water desalination techniques.

**Desalination** is a separation process that removes the salt from the aqueous solutions; its main objective is to produce pure water that is suitable for human use from brine water, **Alkhudhiri, 2012**. There are several technologies used for desalination, but usually, the region that suffers from lack of water in developing countries cannot provide highly cost desalination technologies, so the necessity for a cost-effective desalination process in which producing pure and drinkable water leads to the study of Membrane distillation (MD).

**Membrane distillation** (MD) is a separation process in which the temperature difference is the driving force (vapor pressure difference). The vapor transports through the hydrophobic membrane from the hot side and condensate at the cold side, **Cerneaux et al., 2009**. The most common membrane distillation configurations are:

1- Direct Contact membrane distillation (DCMD)
2- Air Gap membrane distillation (AGMD)
3- Vacuum membrane distillation (VMD)
4- Sweeping Gas membrane distillation (SWGMD)

This study is a comparison between membrane distillation configurations temperature, feed flow rate, and effect of time. Here, two bench scale of MD configurations will be used DCMD and AGMD. The feed used here is Shat-AL-Arab water (TDS=2430 mg/l).

## 2. EXPERIMENTAL WORK

### 2.1 Experiment System Contents

A bench scale unit of flat sheet DCMD process for the PVDF membrane is shown in the **Fig.1**. It illustrates a schematic diagram for the system Membrane cell in the labrotary of a Teflon plate and frame module. DCMD unit consists of (1) membrane cell, (2) reservoir tanks, (3) pumps for both streams, (4) hot (feed), and (5) cold (permeate) water streams, and (6) temperature and pressure sensors. Four thermometers (with a range from -50°C to 70°C) are installed in the inlet and outlet for each stream to measure the temperature at the membrane cell streams. Conductivity meter(Model:cond7110) is installed at the outlet of the cold (permeate) stream from the MD.

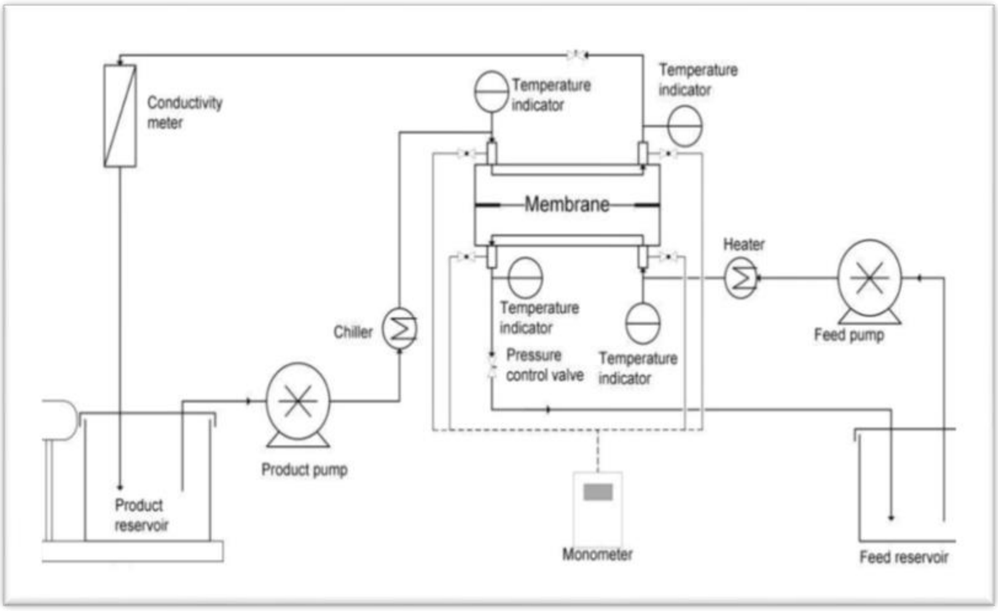
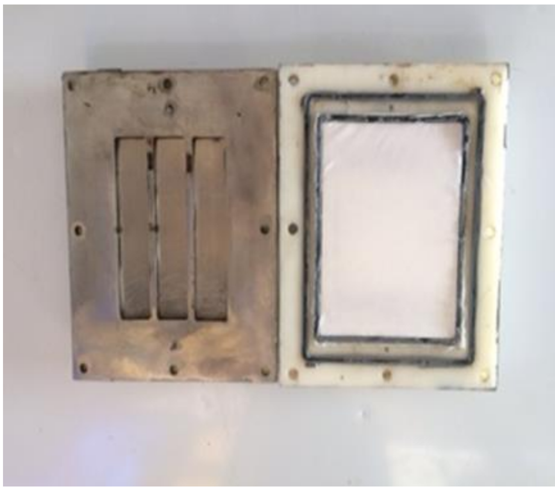



**Figure 1.** Schematic diagrams of the employed DCMD process.

A coil heated water in the feed tank. Hot water was pumped from the feed tank by using a feed pump to the membrane distillation cell and recycled back to the feed tank. Similarly, cold water was pumped using a centrifugal pump from the permeate tank to the MD cell and recycled to the same tank. Chiller cools the permeate. A balance used for measuring the flux of permeate by measuring the initial weight of water and the increasing weight of water with time each half hour.

AGMD system is similar to DCMD, but in DCMD a thin PVDF membrane is between the cold and hot streams in the cell. In AGMD, there is an air gap added to the membrane 5mm (10 to 100 times the membrane thickness), **Khayet et al., 2008**, which is a spacer and membrane support made of stainless steel, added to this a condensation plate as shown in **Fig. 2**.



**A.** AGMD cell.

**B.** DCMD cell.

**Figure 2**. Images of the using membrane distillation cells.

### 2.2 Operating Conditions

The new membrane was installed for every MD configuration, 10 wt.% acetic acid used to remove accumulated materials (fouling and scaling) from the feed side. 50, 60, and 70˚C is feed temperatures (TF), while 17˚C used as permeate temperature (TP), feed flow rate (QF) was 60 l/h and permeate flow rate (QP) was 50 l/h, with co-current flow the pressure in feed side was less than 0.1 bar while in permeate side was almost atmospheric pressure. Operation conditions were kept to be constant at all experiment time.

### 2.3 Feed and Permeate Solutions Properties

The feed solution used in experiments was Shatt Al-Arab water with total dissolved salts (TDS) of 2430 mg/l, and the other properties are shown in **Table 1.** Permeate solution was distilled water which was prepared from one step laboratory distillation device; the distilled water has a TDS range (1-4) mg/l.

**Table 1**. **Shat Al Arab Properties.**

| Parameter | Value mg/l |
|---|---|
| **TDS** | 2430 |
| **Sulphate ($SO_4$)** | 624 |
| **Total Hardness** | 836 |
| **Sodium (Na)** | 540 |
| **Potassium(k)** | 11 |
| **Magnesium (Mg)** | 97 |
| **Chloride (Cl)** | 845 |
| **Alkalinity** | 166 |

### 2.4 The Measured Parameters

The measured parameters were the temperature at the feed and permeate streams, the temperature inside the module for both sides, TDS for permeate side stream and fluxes. Results were measured every 30min, with 180 min as operating time, also through all the time of experiment random TDS test was done by portable and bench type TDS meter for permeate to be sure there was no penetration for feed solution through the membrane.

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Feed Temperature

The driving force in all membrane distillation configurations is the difference of vapor pressure, which depends on the temperature difference from the bulk liquids to the membrane surface (source). For both configurations, the increase in feed temperature increases the permeate flux. **Fig. 3** shows the flux increases with temperature, and the flux in DCMD is greater than DCMD. In DCMD when the feed temperature increase from (50°C to 60°C) for Shat Al-Arab water, the flux increase from 7.61LMH to 10.95 LMH this increase continues when the temperature increases more 10˚C (from 60˚C to 70˚C) to reach 14.85LMH. In AGMD, the flux increase from 5.42 LMH to 7.85 LMH for the first 10˚C increasing in temperature, also with increasing the temperature from 60˚C to 70˚C, the flux increases from 7.85 LMH to 11.85 LMH. The flux in AGMD is less than DCMD, in AGMD the air gap layer made a high resistance**, Alklaibi & Lior, 2005.** Here the temperature transport reduced in the permeate side of AGMD due to the air gap resistance, so the needed heat for AGMD is lower than DCMD, that leads to low permeate flux because the temperature difference between the two sides is very small**, Adham, Samer, & Altaf Hussain, 2013**.

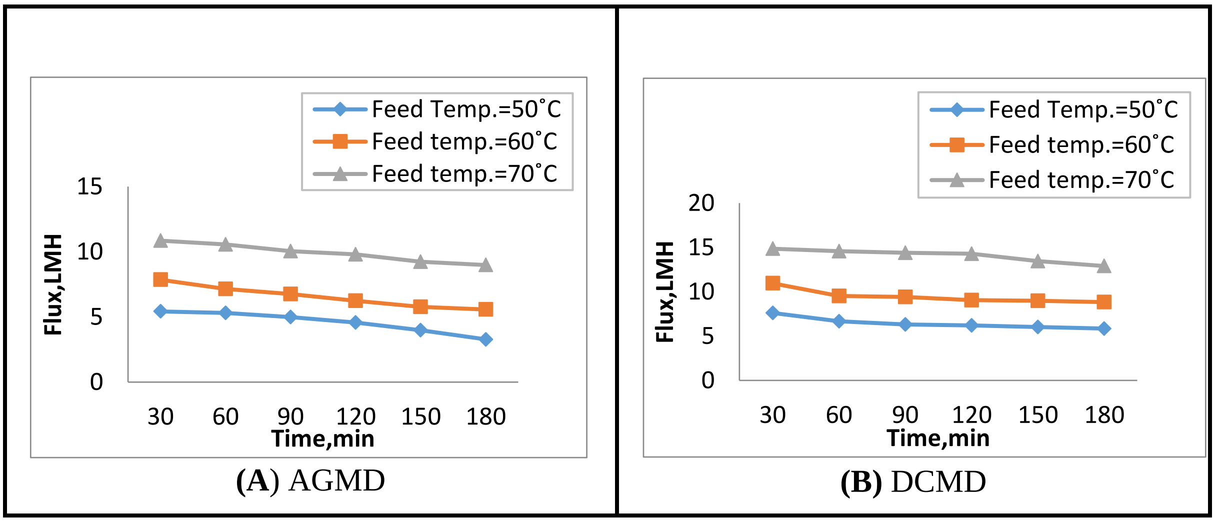



**Figure 3.** Effect of Feed Temperature. on Average Flux Amount ($Q_F$=60 l/h, $Q_P$=50 l/h, $T_P$=17˚C)**.**

### 3.2 Effect of Time

The results of the experiments showed that with increasing time, there is an infrequent decreasing in the amount of flux, and this behavior was for both configurations. The main reason for flux decreasing with time passage was the clogging due to fouling and scaling, **Asim et al., 2013**. For the membrane pore, the main reason for fouling is the precipitation of salts particles on the membrane. Scaling is caused by the formation of crystals on the membrane.

The experiment time was 180 minutes, and the results were calculated every 30 minutes. For DCMD the flux decreased with time passage from 7.61LMH (at the first 30 minutes) to 6.55 LMH (after 180 minutes). For AGMD, the flux decreased from 5.42LMH at the first 30 minutes to 3.28LMH after 180 minutes, as shown in **Fig. 4**. There is a noticeable difference in the amount of fluxes between DCMD and AGMD; the flux in AGMD was less than DCMD due to the high resistance in AGMD. The air gap used in AGMD laboratory cell is 5 mm, which is 10 to 100 times the membrane thickness, **Qtaishat et al., 2010**.

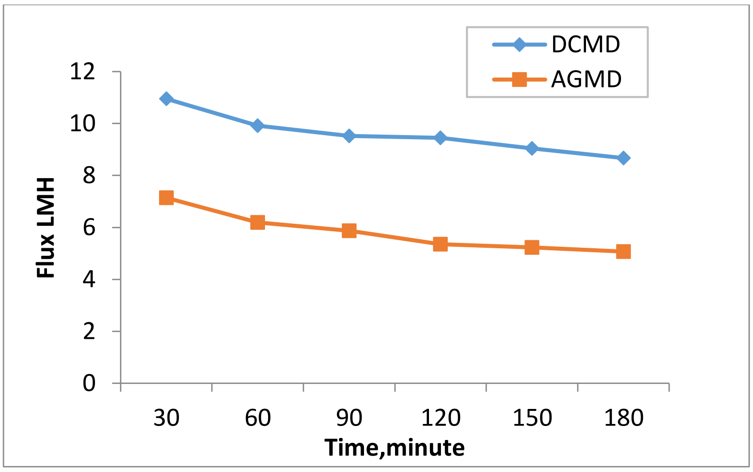
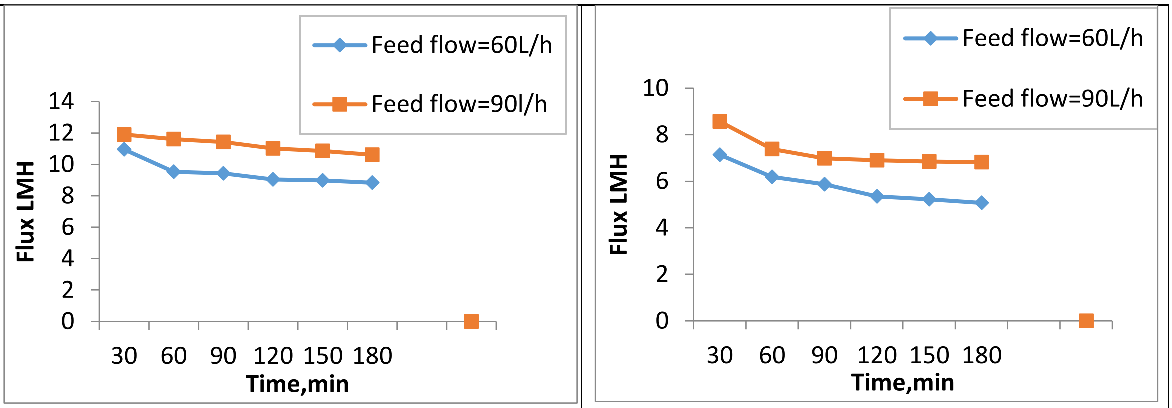



**Figure 4.** Flux vs. operation time for DCMD and AGMD ($Q_F$= 60 l/hr., $Q_P$= 50 l/hr., $T_F$= 60°C, $T_P$= 17°C, $P_F$= 0.1 bar, Shat Al Arab, TDS=2430, co-current flow).

### 3.3 Feed Flow Rate Effect

Feed flow rate is an essential parameter due to its proportional relation to the mass flux in membrane distillation configurations (DCMD and AGMD). As the permeate flux increases with the increasing feed flow rate, this parameter is related to the feed velocity where permeate flux increases with increasing the velocity of feed. Higher flow increases the flux, which results in reducing the boundary layer caused by temperature polarization and increases the heat transfer coefficient. Another factor is high flow rate creates a turbulent flow which lowers the temperature polarization influence; two different rates are taken for DCMD and AGMD at the same conditions ($T_f$ =60ºC,$T_P$ =17 ºC, Shat AL-Arab, PF=0.1 bar). In DCMD, when the feed flow rate increases from (60 l/h to 90 l/h) the flux increased from 10.95LMH to 11.90 LMH. In AGMD when the feed flow rate increased from (60 l/h to 90 l/h) the flux increased from 7.14LMH to 8.57LMH, it's the flux increase with increasing feed flow rate, and the flux in AGMD is less than DCMD.




**A)** DCMD. **B)** AGMD.

**Figure 5**. Flux vs. Feed Flow rate for PVDF Membrane (QP= 60l/hr, TF= 60°C, Tp=17°C).

### 3.4 Permeate TDS Value

Results showing that desalting using DCMD and AGMD are effective processes with an efficiency reaching 99.9% of salts removed. Permeate TDS value was measured every 15 minutes.

## 4. CONCLUSIONS

**1.** At the same conditions for DCMD and AGMD, it is noticeable that the permeate flux in DCMD is higher than AGMD due to the high resistance of the air gap AGMD.

**2.**. The temperature transport is reduced in the permeate side of AGMD due to the air gap resistance, so the heat needed for AGMD is lower than DCMD.

**3.** For DCMD and AGMD, the salt rejection was 99.9% according to the results of the experiment (TDS tests).

**4.** The flux decreasing over time occurred due to several factors like fouling and scaling formation.

**5.** The effect of feed flow rate on the permeate flux was positive in both configurations of DCMD and AGMD.

**6.** The result of feed temperature on the permeate flux was positive in both configurations of DCMD and AGMD.

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**NOMENCLATURE**

| | |
|---|---|
| DCMD Direct | Contact Membrane Distillation |
| AGMD | Air Gap Membrane Distillation |
| VMD | Vacuum Membrane Distillation |
| SGMD | Sweeping Gas Membrane Distillation |
| QF | Feed flow rate, l/h |
| QP | Permeate flow rate, l/h |
| TDS | Total dissolved solids, mg/l |
| TF | Feed temperature, ˚C |
| TP | Permeate temperature, ˚C |
| LMH | Liter per square meter per hour |
| MD | Membrane distillation |
| PVDF | Polyvinylidenediflouride |