Low Energy and Low Cost Freshwater Production by Membrane Distillation

Mohammad Jabled Perves Bappy, Rubina Bahar* and Tasnim Firdaus Ariff
Department of Manufacturing and Materials Engineering
Kulliyyah of Engineering, International Islamic University Malaysia,
Kuala Lumpur-53100, Malaysia
*Corresponding Author Email:<rbahar@iium.edu.my>

Abstract— During the recent dry spell in Malaysia, water rationing was imposed for few months in the first quarter of the year 2014. Besides the meteorological condition, in some states of Peninsular Malaysia the demand and supply for freshwater has reached in vulnerable condition already. The water demand management study revealed applying 3R principle can be of great help and re-use of waste water should lead toward sustainable development in the overall freshwater production. In this study, economic evaluation of one of the emerging low energy and low cost saline water treatment method has been discussed. The process named Membrane Distillation (MD) incorporates membrane and distillation based on the partial pressure difference across a hydrophobic membrane. As an evaporative process, it does not require high heat energy input. The setup is compact and distilled freshwater produced from the system is of superior quality. A comparative energy and cost analysis between MD and the existing water re-use technologies is presented in this paper based on production rates and energy sources. Further improvement of the system has been suggested to improve its economic efficiency using available renewable energy resources.

Keywords—Membrane Distillation, Saline water treatment, Water Economy, Wastewater Treatment, Sustainable Process, Energy.

I. INTRODUCTION

Water everywhere, nor a drop to drink. 97% of all available water on earth is highly salty. In rest 3%, 2% is frozen and only 1% is drinkable [1]. More than 30% of the world population don’t have access to pure drinking water. More than 80 countries around the world is facing serious scarcity of drinking water at this very moment. For last 50 years researchers have been trying to find a cost effective and quick method to produce fresh water from saline water. But the available system used in market are not affordable enough. On the other hand, the demand of freshwater is increasing day by day with the increased number of population all over the world. So to meet up the demand, new technology and improvement need to be invented. Recycling and reuse of water also can be a preventive measurement for now [2]. But for permanent remedy, a cost effective desalination system need to be found. As demands going high, the rate of desalination plant installation is also increasing rapidly. The available major desalting techniques include Reverse Osmosis (RO), Multistage Flash Distillation (MSF) and multiple effect Distillation (MED). RO uses semipermeable membrane to separate waste particles from water under high osmotic pressure [3], While MED and MSF work on the principle of evaporation/boiling of saline water to get the condensate as the freshwater. MSF uses a portion of water and flush it into steam in stage by stage [4]. MED is a special type of multistage distillation system in which every step reuses the energy from its previous step [5]. In the recent years, Membrane Distillation (MD) has emerged with promising outcomes as a desalination process. MD is a purification technology in which a hydrophobic membrane is used to separate pure water in vapor phase from waste or saline water driven by the partial pressure difference of the two sides of the membrane [6]. Most commonly used membrane distillation processes are: Air gap Membrane Distillation (AGMD), Direct Contact Membrane Distillation (DCMD), Vacuum Membrane Distillation (VMD) and Sweep Gas Membrane Distillation (SGMD) [7]. In this study, the energy and cost analysis of various freshwater production processes have been discussed based on the study from some other researches. Based on the study, some improvement also have been suggested to make a cost effective hybrid system using Membrane Distillation in AGMD mode.
II. COSTS OF ELECTRICITY

The electricity cost is a primary cost in freshwater production which depends on per unit cost of electricity of that area. In reverse osmosis process electricity price is a major concern. As the RO needs a high pressure pump to run, so the electricity cost is comparatively higher on RO. If the cost of electricity goes up from $6 K^{-1}Wh^{-1}$ to $10 K^{-1}Wh^{-1}$ then the cost of freshwater production increase almost 12% in RO. On the other hand, AGMD and DCMD needs low amount of energy comparatively because of the ability to work in low pressure and energy. Figure-1 shows the relation between Freshwater production cost and the cost of electricity [8].

![Figure-1: Fresh water cost vs cost of Electricity](image)

III. MEMBRANE COSTS

The quality of waste water largely affects the life of membrane. Low salinity brackish water will cause less rupture of membrane, on the other hand, high salinity seawater causes maximum membrane rupture rate [9]. For calculating membrane replacement costs, first the total cost of membrane is calculated for one year and then divided by the total amount of water produced in one year. Normally the replacement rate varies from 9% to 20% per year.

Membrane cost ($/m^3) =

$$\text{Membrane price ($/m^3) \times Replacement Rate (y^{-1}) \times (1000 \text{ m}^3 / \text{Membrane flux m}^2\text{h}^{-1} \times 8760 \text{ hy}^{-1})} \quad (1)$$

IV. CAPITAL AND MAINTENANCE COSTS

Capital cost means the cost to build a new desalination plant whereas O&M costs is the cost to maintain and routine repair of the plant [10]. Capital cost is one of the key cost of desalination process. Capital and O&M cover upto 60% cost in a destination plant. The capital cost of the plant can be determined as –

$$\text{Capital cost ($/m^3) = \frac{CRF \times \text{Capital Cost ($/y)}}{\text{Plant Capacity (m}^3\text{/y)}}} \quad (2)$$

where, CRF = The plant capacity recovery factor.

The capital cost of various desalination processes shown in table-1.
TABLE-1: CAPITAL COST OF VARIOUS DESALINATION PROCESSES

<table>
<thead>
<tr>
<th>Process</th>
<th>Plant Capacity (m³/day)</th>
<th>Unit-Capital Cost $/(m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>24,000</td>
<td>1,131</td>
</tr>
<tr>
<td>MED</td>
<td>37,850</td>
<td>1,860</td>
</tr>
<tr>
<td>MSF</td>
<td>37,850</td>
<td>1,598</td>
</tr>
<tr>
<td>RO</td>
<td>37,850</td>
<td>1,313</td>
</tr>
</tbody>
</table>

V. TOTAL WATER PRODUCTION COSTS

The total cost of water production can be found by calculating the cost of energy, cost of hardware and equipment and costs of operation & maintenance.

So the total cost -

$$C_{\text{total}} = C_{\text{Energy}} + C_{\text{Hardware}} + C_{\text{Q&M}}$$

(3)

Unit water production cost

$$C_{\text{unit}} = C_{\text{total}} / M$$

(4)

Where, M is the daily capacity of the plant.

TABLE-2: ENERGY REQUIREMENT AND WATER PRODUCTION COST COMPARISON AMONG DIFFERENT FRESHWATER PRODUCTION SYSTEM [6, 11-13]

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy Source</th>
<th>Water cost (/m³)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane Distillation</td>
<td>Normal available energy</td>
<td>1.17</td>
<td>[11]</td>
</tr>
<tr>
<td>Membrane distillation</td>
<td>low grade energy source</td>
<td>0.64</td>
<td>[11]</td>
</tr>
<tr>
<td>Membrane distillation</td>
<td>Industrial waste heat</td>
<td>0.26</td>
<td>[16]</td>
</tr>
<tr>
<td>Nanofiltration + reverse osmosis</td>
<td>With heat recovery device</td>
<td>0.56</td>
<td>[17]</td>
</tr>
<tr>
<td>Nanofiltration + reverse osmosis</td>
<td>Without heat recovery device</td>
<td>0.80</td>
<td>[17]</td>
</tr>
<tr>
<td>Reverse osmosis + membrane distillation</td>
<td>Normal available energy</td>
<td>1.25</td>
<td>[18]</td>
</tr>
</tbody>
</table>

In table-2, the comparative energy requirement and costs of different freshwater production system has been shown. The electricity and heat cost is comparatively low for AGMD system as it works under atmospheric pressure and need no extra high pressure pump to operate. Additionally, MD works under a temperature range of 80°C; hence, the AGMD can use low strength piping and fittings made up of available polymer. So the hardware cost is also low compare to other systems. The rupture of membrane in AGMD is also low and only need to change the membrane for its polarization effect [14]. On the other hand, DCMD has higher rate of membrane rupture as the membrane is kept directly in contact with both feed and cold solution. DCMD’s 50% capital cost comes from membrane cost and 30% capital costs comes from operation and maintenance cost [11]. Reverse osmosis needs relatively high pressure to operate thus increase hardware and electricity cost [15]. The cost of AGMD can even decrease if renewable sources can be used such as solar PV cells or wind turbine.

Table-3 is showing effective water cost of various desalination processes using different heat source from various literatures. From the table it can be seen that MD is more cost effective over RO, RO+NF combo even RO+MD combo when cheap industrial waste heat or low grade heat energy is used. It also shows that heat recovery device can recover 30% to 40% heat energy in reverse osmosis and RO+NF combo.
VI. FUTURE PREDICTION AND RECOMMENDATION

The future prediction on the cost development of various types of large scale desalination processes have been shown by Memstill® in figure-2. It is seen that the cost of Air Gap Membrane Distillation using Memstill® Technology will be around 0.21$/m³ whereas the cost of RO will be around 0.4$/m³ [16]. The cost of MED and MSF will be much higher than that considering large scale operation. The heat recovery system will allow around 50% of heat recovery in both AGMD and RO. The prediction was made considering the seawater desalination capacity of 105,000 m³/d with different process conditions.

![Expected cost Development](image)

Figure-2: Expected development costs of water production over years

The economic efficiency of the system can be improved by using renewable energy sources like solar, wind, geothermal etc. A Hybrid system including two or three different combo of energy sources coupled with Air Gap Membrane distillation can decrease the energy cost thus increasing the cost effectiveness of the overall system [19]. So the improvement of economic efficiency can be achieved by –

1. AGMD with heat recovery (HR)
2. Solar PV with AGMD
3. Wind Turbine with AGMD
4. Geothermal with AGMD
5. Hybrid AGMD-Wind-Solar-Geothermal Combo with HR

Based on this study, a hybrid system can be suggested as the optimum and cost effective system which will consist a full scale AGMD system with heat recovery coupled with solar, wind and geothermal sources. The three different sources will be used to cover the demand of energy all day long. If solar energy is not available in certain
period of time in a day than other two sources can cover up the demand. Same thing goes for other two sources and vice-versa. Figure-3 showing the proposed optimum model of freshwater production system.

![Figure-3: Proposed Hybrid low cost Freshwater production system](image)

**VII. CONCLUSION**

The overall production costs of freshwater is decreasing over the last decades but still a long way to go. From the above study it has been seen that AGMD is a very promising technique which has better cost efficiency than other methods for its ambient pressure requirement, low operation and maintenance costs and less hardware cost. Moreover, the efficiency can increase more by coupling renewable power sources with AGMD. Enabling heat recovery also can increase the thermal efficiency of the system. Thus a hybrid AGMD-Wind-Solar-Geothermal Combo with heat recovery system has been suggested as future recommendation which can be a better choice of freshwater production system in terms of energy and cost effectiveness.

**ACKNOWLEDGEMENTS**

The work was jointly supported by Fundamental Research Grant Scheme (FRGS-14-118-0359) and IIUM Endowment fund (EDW B14-134-1019) by providing necessary financial and technical assistance.

**REFERENCES**


**BIOGRAPHY**

**Dr. Rubina Bahar** is an Assistant Professor in Materials and Manufacturing Engineering Department, International Islamic University Malaysia. She obtained her BSc in Mechanical Engineering from Bangladesh University of Engineering and Technology (BUET) in 2002. After graduation she worked with ABB in Bangladesh. Later she obtained M.Engg (Mechanical) from National University of Singapore (NUS) in 2006 and PhD also from NUS in 2011. Throughout her post graduate studies she was awarded with the research scholarship from NUS. Her main area of research during her stay in NUS was desalination (conversion of saline water to freshwater) using Vapour Compression Distillation process and Membrane Distillation process. She joined International Islamic University Malaysia (IIUM) in 2013. She is currently project leader of two ongoing research project to address the problem of freshwater supply system in the Malaysian households. Her interest also covers thermal management of machining process and energy harvesting from waste/renewable energy resources.