Assessment of Thermal and Membrane Seawater Desalination Technologies for Tourism Activities: An Economic comparison

Salah Al-Hengari
The Libyan Academy, School of Applied Science and Engineering, Chemical and Petroleum Engineering Department Tripoli – Libya salah.alhengari@academy.edu.ly

Mohamed El-Bousiffi
Libyan Petroleum Institute Tripoli

Walid El-Moudir
HTC Purenergy Ing., 001 2305 Victoria Avenue, Regina, SK, S4P 0S7 Canada

Abstract Tourism activities are considered as a main supporting sector for many nations economies. These activities are supported by many infrastructure utilities such as electricity, water, and communication systems. In some regions, water is not readily available in quantity and quality required for human consumptions and utilizations.

In fact, water exists in form of high saline water (i.e. brackish water or Seawater) and may contain pollutants and microorganisms that should be eliminated or treated by appropriate methods. To overcome shortage of water, desalination processes are the most feasible approach that can be used to secure acceptable quality and quantity of water. In this paper, opportunities of using different desalination processes for supplying water to tourism activities are explored in term of economics for a small coastal tourism town at three different scenarios of tourists populations: 250, 500 and 1000 persons, economic analysis is focused on estimating the cost of one cubic meter of water produced using four different types of desalination processes namely Multi Stage Flash, Multi Effect Evaporation, Mechanical Vapor Compression, and Reverse Osmosis. Results, conclusions, and recommendations driven from this study are presented.

Index Terms: Desalination for Tourism Activities; Thermal Desalination Processes; Membrane Desalination Processes ; Product Cost Components; Economic analysis.

I. INTRODUCTION

Water is the main utility should be available for any sort of industrial and investment activities. Unfortunately, fresh water is not available every where or is not ready for human consumption. Unusual methods are the solution used such as desalination.

Desalination is defined as water treatment to remove salts and contaminations from water. Desalination processes has many applications such as; pharmaceutical, electronics, bio/medical, mining, power, petroleum, tourism and pulp/paper industries. Desalination becomes an accepted approach of production of water and a price-competitive option around the global. The cost of desalination is decreasing to levels matching that of conventional methods to supply water (i.e. dams or wells). Tourism activities are very essentials for many countries economic. Some country depends entirely on this sector to provide hard currency for the state economic. In this paper, desalination utilization has been investigated on basis of cost-effective method for a virtual coastal tourism activity.

II. DESALINATION PROCESSES

Desalination processes available commercially are divided into two categories; thermal processes which utilize thermal energy source (i.e. steam) and non-thermal processes such as membranes which are utilize non-thermal energy sources (i.e. electricity). Figure. 1 shows the main commercialized desalination processes.
Thermal desalination process depends on the evaporation and condensation of water to remove their salt content. Steam is the tool of heating for Multi Stage Flashing (MSF) and Multi Effect Evaporation (MEE). Non-thermal processes are based on two types; the first non-thermal, Reverse Osmosis (RO) process depends on inverse the osmosis pressure of water and permeability of membrane to allow water only pass with little of salts spillage and reject the brine. The second process is Electro dialyses in which an electrical current is applied to remove ions that cause high salinity from water [1].

Desalination processes can handle different type of feed water and this depends on the type of process. All thermal processes (distillation) and Seawater Reverse Osmosis can be used to handle any type of water. The expected product quality in term of salinity is shown in Figure 2.

As can be seen, thermal processes produce distillate water (i.e. very small salinity content, 10 ppm) which is undrinkable and need to be stabilized for its pH and corrosion tendency by post-chemical treatment.

General schematic of the desalination plant is presented in Figure 3. The raw water is first screened, filtered and disinfected to remove suspended solids and any sand. This includes removal of dissolved air and CO₂. The removal of CO₂ for thermal desalination plants is achieved through acidic treatment to prevent the scale formation. After that the feed water is pumped to desalination process where evaporation takes place. The out streams from this stage are
desalinated water, brine blowdown and non-condensable gases. The last stage is the stabilizing stage where water is stabilized to be non-corrosive. This stage might include making water applicable for human consumptions by potabilization.

In every desalination plant, energy is needed for evaporation or separation. For thermal desalination processes, a performance ratio is used and it means the mass of desalination water produced (kg) per unit of energy input consumed (kg/MJ).

III. DESALINATION ECONOMIC ANALYSIS

Desalination economics analysis is done to estimate unit product cost, $/m³ of desalinated water. A convenient method, mentioned by El-Dessouky and Ettouney [1], for estimating the cost of desalted water is used. Moreover, the analysis explains why the estimation of accurate water cost is quite difficult.

The economic analysis is based on a desalination plant stand alone to produce water only (e.g. not dual purpose plants to generate electricity and produce water, see Figure 4).

The desalinated water cost depends on a number of designing and operational factors as illustrated in Table 1.
Table 1. Factors Influence Desalinated Water Cost [2]

<table>
<thead>
<tr>
<th></th>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quality of feed water</td>
<td>Lower salinity allows for higher productivities, less chemicals consumptions for treatment and less shutdown due to scale problems.</td>
</tr>
<tr>
<td>2</td>
<td>Plant capacity</td>
<td>Larger plant capacity provides water at lower cost although they need large investments.</td>
</tr>
<tr>
<td>3</td>
<td>Site conditions</td>
<td>Building a new desalination facility close to the operating plants reduce investments cost considerably. Also, installation near the feed water is preferred such as near coastal for seawater desalination units.</td>
</tr>
<tr>
<td>4</td>
<td>Qualified labor</td>
<td>Presence of high skilled personal for operation and management improve plant availability and operability.</td>
</tr>
<tr>
<td>5</td>
<td>Energy cost</td>
<td>Availability of energy sources with inexpensive fuels and electricity are cost-effective method to reduce water cost.</td>
</tr>
<tr>
<td>6</td>
<td>Plant life &amp; amortization</td>
<td>Product capital cost can be reduced through increasing life of the plant.</td>
</tr>
<tr>
<td>7</td>
<td>Plant Factor (PF)</td>
<td>It is a combined factor from the availability and productivity factors. Forced and planned outage of a unit for maintenance reduces its availability for production on annual basis. The operating load influences the annual productivity of plant.</td>
</tr>
</tbody>
</table>

Water cost is a combined value between fixed costs and operating costs (Eqn. 1). Costs are usually calculated on annual basis, (Figure. 5).

\[
\text{Unit Product Cost} = \text{Fixed Costs} + \text{Operating Costs} \tag{1}
\]
1- Annual Fixed Costs: Direct and Indirect Charges

Fixed charges are consisting mainly from amortization and interest to recover the installed cost of the plant, i.e. the capital cost of the plant is a fixed cost to be paid annually for repayment of the loan required for financing the project. The amount of these payments will depend on the total cost of the installation, the applicable interest rate and amortization period. The capital Recovery factor \( f_r \) can be calculated from Eqn. 2. Where \( r \) is the interest rate.

The second term in the Eqn. 2 is the sinking fund depreciation factor and \( N \) is the amortization period which equals to number of annual payments. The sinking fund depreciation takes into account the timing of returned money by including the interest rate. If the installed cost for the plant is \( I \), then the annual capital cost would be \( I \times f_r \) ($ / yr). The other fixed costs are due to charges for property taxes and insurance. These are usually 1 or 2 % of the installed cost of the plant [2, 3]. Fixed charges are paid whether the plant is operating or out of operation.

As rule of thumb, the plant installed cost can be estimated by the specific investment cost (SIC) of desalination units (Table 2) and the target plant capacity. Generally speaking, specific investment costs for RO and MEE plants are lower than MSF plant. However, the estimation method mentioned above is mainly covering some items of direct costs. Therefore and alternatively, the most reliably estimation method for covering the whole fixed charges is the cost graphs (Figures 6a, b, c and d) provided by the report of USA desalination research and development program [4].

Table 2 Specific Investment Cost (SIC) of Desalination Units

<table>
<thead>
<tr>
<th>Year</th>
<th>MSF</th>
<th>MEE with/out VC</th>
<th>RO</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIC, $/(m³/day) [2]</td>
<td>1990s</td>
<td>1500-2269</td>
<td>1562-2100</td>
</tr>
</tbody>
</table>

Figure 6a the Total Construction Costs for MSF Processes [4]
Figure 6b the Total Construction Costs for MEE/MEE-TVC Process [4]

Figure 6c the Total Construction Costs for MEE-MVC Process [4]
These costs are applicable for equipments from USA [4] and they are overestimated comparing to equipments that can be based on European Union or elsewhere.

The graphs (Figure. 6) cover main package of a desalination plant shown in Figure. 3 and the cost estimated include desalination unit, intake system (except RO process), in-plant piping, pumps, motors, controls, pretreatment, post-treatment, building, cleaning system, electrical distribution, and finally indirect costs. To complete the investment estimation, it is essential to estimate cost of construction of intake system (for RO process only), disposal of brine, boilers (for thermal processes), site development, and storage facility (see appendix for further details, Figure. 11). General comment, before start using cost graphs, it should be mentioned that these graphs are based on 1999 and 2000. Inflation in these costs should be considered; however, in this paper, it is ignored.

The sum of these graphs prediction is called the Total Capital Investment Cost. The total capital investment cost of plant constitutes of purchased cost, delivered cost, and cost of installation within reference manufacturing place which is USA for these graphs. To consider delivering and installation costs elsewhere, location factor should be used. It is multiplied by a location factor > 1.0 depends on the plant location (a reference is 1.0 for the eastern USA coast). For Libya, it can be considered 1.3 comparing with Tunisia (1.2).

IV. OPERATING COSTS

4.1 Labor costs: Labor costs include desalination plant operators and management staff. This cost can be varied from place to another and for local or overseas labor. It can be taken as $1,000/man.month for Libyans. Number of staffs operate in the desalination plant is subject to plant capacity (i.e. 14 personals for 4,000 m³/day plant [4]).

4.2 Chemicals costs: All desalination plants are usually designed to operate on an antiscalent program to prevent scale formation along with periodic acid cleaning. Fig. 7 shows typical costs of chemicals consumption in four types of desalination processes.
4.3 Power cost: power consumption depends on the size of the plant and mode of desalination. MEE plants consume less power than MSF plants which require higher power consumption for recycle pumps. On the other hand, MED-TVC units consume much less power than MEE-MVC units; the later are power intensive process. In fact, power may cost less especially on-site generation. Generally speaking, for estimation purpose power cost can be taken as $0.04-0.09/kWh [2] and average value can be taken $0.07/kWh for Libya. Estimated of annual power costs are given in Figure. 8.
Figure 8a Annual Electricity Costs for MSF Processes [4]

Figure 8b Annual Electricity Costs for MEE/MEE-TVC Processes [4]
4.4 Maintenance & Repairs (M&R) Costs: including spare parts and manpower for non routine maintenance are usually estimated on the basis of the labor experience, plant size and age, and location. Generally speaking, this can be considered as a fixed cost amounting yearly to 1-1.5 % of the total installed cost of the medium plant size (4500 m$^3$/day) [5]. For accurate estimation, Figure. 9 is recommended to be used.
Figure 9a: Maintenance Cost for MSF [4]

Figure 9b: Maintenance Cost for MED [4]
4.5 Energy costs as fuel (for thermal process only): The cost of fuel per product water varies directly with price of fuel and inversely with performance ratio (PR). Low PR means high steam consumption and hence high fuel consumption. Figure 10 can be used to estimate the energy cost.

4.6 Overhead costs: These figures are used in order to fulfill any money flow shortage for a project. If this item is not available for calculations it can be taken as 100% of labour cost [6].
V. CASE STUDY FOR TOURISM TOWN

In this work, a tourism town case study is considered with the characteristics shown in Table 3. Three tourist populations’ scenarios are considered: 250, 500, and 1000 persons. According to the international resources and for area of water shortage like middle east, the standard amount of water for normal man consumption to cover all his needs for living is given as 500 m³/yr (1.37 m³/day) [8]. If we consider presence of site operators and service personals, the quantity of water would be raised much further and to consider any over capacity might be needed. The target production capacity is 2 (consider 100% extra capacity) multiply by number tourists. Therefore, the normal target for three scenarios should be 500, 1000, 2000 m³/day. The desalination plant proposed to be built has the general feature configuration shown in Figure. 3.

![Figure 10 Annual Steam Cost for Single Purpose Plants (1999/2000) [4]](image)

Table 3. Coastal Tourism Town: Supporting Sheet

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Supplying water to a coastal tourism town with 1,000 population of tourists</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Quality, Plant Factor and Performance Ratio</td>
<td>drinkable water, 90%, &amp; 3.44 kg/MJ (7 kg/kg)</td>
</tr>
<tr>
<td>Water feed</td>
<td>Seawater is supplied from intake point deep in seawater and has salinity 38,000 ppm (Mediterranean seawater)</td>
</tr>
<tr>
<td>Facility required</td>
<td>1- Seawater intake; 2- pretreatment; 3- desalinating process; 4- steam supply (for thermal desalination only); 5- post-treatment; 6- delivery to storage facility and distribution system</td>
</tr>
<tr>
<td>Amortization</td>
<td>Life of the plant is 20 years &amp; interest rate is 7%</td>
</tr>
</tbody>
</table>

VI. RESULTS

The costs’ graphs were used to estimate the water product cost components. Four type of desalination processes (they are MSF, MEE, MVC, and RO) were examined at three production scenarios as shown as follows. Location factor for Libya of 1.3 is considered; although, this factor might be much higher. Table 4 summaries results of the four cases.
One can analyze that the smaller the plant, the less expensive investment that is required. This is true but the product cost is the most expensive. Table 4 demonstrates this simple economy principle, the larger the plant capacity, the cheaper product can achieved [7,8,9].

As can be seen in Table 4, the most optimum choice for desalination plant for three production scenarios is RO plant. It provides cheaper choice comparing to other desalination plants. For example, desalinated water can be produced at $2.5/m³ using RO plant capacity of 500 m³/day while it is very high for other processes (MSF, MEE, and MVC). It should be noticed that MSF and MEE are not recommended at all to provide water for such capacity. Their high cost is due to need for extra installation components (i.e. boiler package).

CONCLUSIONS AND RECOMMENDATIONS

1. Seawater desalination processes can be used to provide fresh water for tourism activities as an example of virtual coastal tourism town in Libya,
2. All thermal desalination processes are capable to handle high saline water such as seawater; however, only some non-thermal processes can be used for this (Seawater Reverse Osmosis, SWRO),
3. Thermal processes economically are expensive choice for small capacity plants, therefore, it is recommended to consider them only at medium and higher production capacity in order for them to become competitive,
4. SWRO is the optimum choice for the tourism activity due to low product cost ($2.5/m³ - $1.5/m³), and don’t need long time to start-up, less pollutants, disposal and has less corrosion problems since it is operating at room temperature, flexibility to utilize electricity power and 30% or more of this power can be recovered.

5. SWRO can be run at different loads (0 – 100% of design capacity) and it is easy to be upgrade by only adding extra space for RO cells.

REFERENCES

6. www.unep.or.jp/ietc/publications/techpublications/techpublication.desalination.as
APPENDIX

a. Boilers for Single-Purpose Plant

b. Site Development for Distillation Processes

c. Disposal System for Distillation Processes

d. Site Development for Membrane Processes

e. Intake System for Membrane Processes

f. Storage for one day (Steel Tank)

Figure 11. Other Construction Costs for Thermal and Non-Thermal Processes [4]