University of Thi -Qar Journal for Engineering Sciences ISSN :2664- 5572 (online)
http://www.doi.org/10.31663/tqujes13.1.436(2023) ISSN:2664-5564 (print)
Vol13.1(January2023) Available at http://jeng.utq.edu.iq
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Review: Water Desalination Cost

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ABSTRACT

The desalination process is one of the most important ways to obtain water suitable for human use. Several techniques are used for the purpose of water desalination. The most important and most common and most widely used techniques are reverse osmosis (RO) membrane processes and multi-stage flash evaporation (MSF) processes.Several models are used for the purpose of estimating the cost of producing desalinated water. A number of factors that affect costs are included, the most important of which are the technology used and energy, in addition to the properties of raw water.The reverse osmosis (RO) membrane technology is considered the lowest operating cost in terms of energy relative to the multi-stage flash evaporation (MSF) plants, as it requires only electrical energy in all stages of operation, while the thermal plants need fuel and energy for the purpose of operation.Reverse osmosis (RO) membrane processes are more sensitive to salinity compared to thermal plants, as the production and efficiency of membrane plants decrease when the salinity of the desalinated raw water changes high.

Keywords: Desalination, reverse osmosis, multi-stage flash evaporation

1.Introduction

Water is a very important and indispensable resource for human use, likewise the majority of water is salty, and fresh water is a small percentage **[1]**. The lack of fresh water (2.5%) compared to salt water (97.5%), which is not suitable for human use. The increase in human use, industrial progress, and rapid economic growth prevented access to a constant source of fresh water. It has been necessary to desalinate salt water and use it as fresh water **[2].**

Water desalination processes are either classified according to energy sources or according to the operational process **[3]**. The main idea of choosing the optimal desalination system, to choose the appropriate process and energy, to provide abundant quantities of fresh water for a long time, and the economic cost is also very important **[4]**.

The cost, in its two parts, the construction and operation cost, is the main factor in choosing the appropriate technology for water desalination. In this study, we review the factors affecting the cost of desalination and review previous studies that estimated this cost in several regions of the world **[1]**.

2. Water Desalination

The process of removing or reducing salts from feed water is called a desalination process. Two streams are result from the desalination process, a stream of fresh water, and a stream of concentrated salts and unwanted impurities **[5,6]**.

In the later decades, many desalination technologies have been used including membrane desalination techniques and thermal desalination techniques. However, multi-stage flash (MSF) and

Reverse Osmosis (R.O) processes were the most widely used among desalination technologies as shown in the **Figure (1) [7]**.

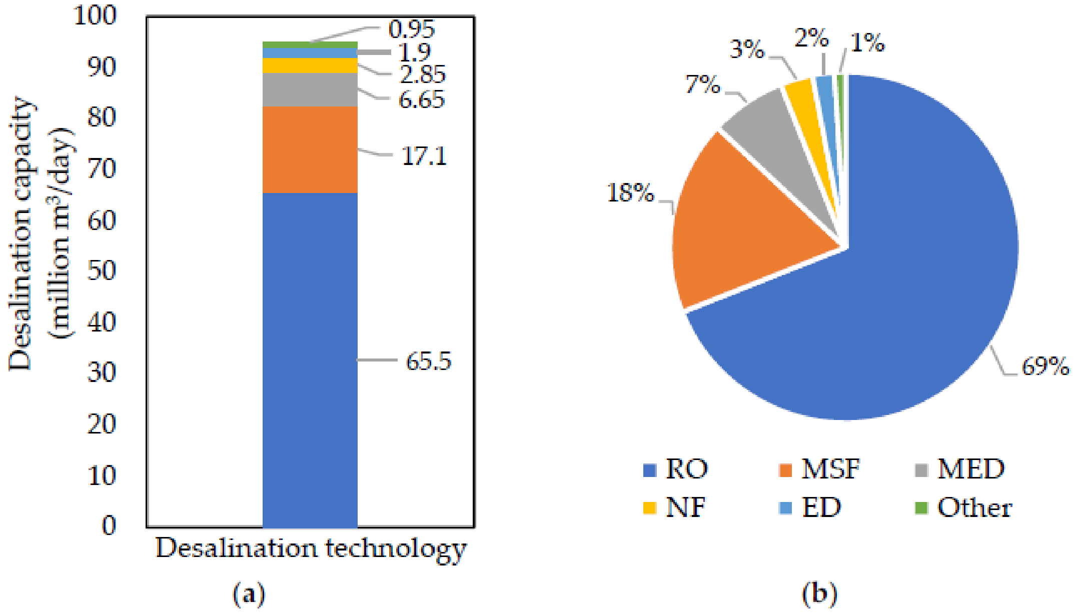

Fig. 1 Desalination technology distribution **[8]**

3. Desalination Cost

The economic cost of desalination plants is divided into two main parts. The capital cost is the construction cost of all the operational units and supporting units in the desalination plant. Operational cost, which includes all operations, maintenance, replacement, etc. **[9, 11, 12]**

3.1 Capital Cost

Capital cost, the acronym CAPEX is often used to express the Capital Expenditures of desalination plants **[10]** . The capital expenditures include construction the infrastructure, operational units and energy supply. The capital cost also includes the inputs to the feed water and the outputs of the saline wastes and the treated fresh water. The main operational units and the supporting units as well as the pre-treatment units are included in the capital cost which include pumps, membranes, filters and all accessories **[9, 11]**.

3.2 Operating Cost

Operating costs OPEX , is the cost that relates to operating, maintaining and replacing parts in desalination plants. Also, the operational cost includes the annual cost of labor, maintenance of units and replacement of damaged parts such as filter membranes, chemicals in pretreatment units. In addition to the periodic cost of monitoring and analysis units **[9,12]**.

3.3 Total Cost to Desalinate Water

The total cost includes all operational and capital expenditures. Thus, the total cost is on an annual basis for each cubic meter or gallon of water produced from the desalination plant

4. Major Impacts on Desalination Cost

There are several factors that affect the cost of water desalination, some of which have a simple effect, such as the cost of replacing membranes and maintaining

units. While, the impact of capital costs and energy sources is directly affected the desalination process **[13]**.
The cost and choice of technology used in the desalination system depends on two main factors that available energy and the type of raw water (brackish or seawater).

4.1 Desalination technology cost

There is a noticeable increase in desalination processes around the world with a growth rate of 7.5% annually. Membrane desalination was the dominant 66% of the total use of desalination processes **[14,15]**. Although the operational expenses of reverse osmosis operations are relatively low compared to desalination processes using thermal energy, the capital cost is relatively high due to the cost of membrane filters and their short operating life **[16]**.

Operational and capital costs are differed among desalination operations as shown in Table **(1)** **[17]**. It is clear that the capital costs and energy sources are the most economical costs and in turn it directly affect water desalination processes. Other costs are less impact on the cost of desalination techniques **[18].**

Table 1 Typical costs of the conventional seawater desalination (USD/m3.day) **[17]**.

Cost	MSF	MED	RO
capital investment costs	1,700–2,900	1,700–2,700	1,300–2,500
Operational costs	0.65–1.25	0.67–0.96	0.58–0.88
Total annualized cost	0.84-1.6	1.21-1.59	1.06–1.36

4.2 Energy Cost

The energy used in desalination is an important component of operating costs. Thermal desalination plants use high energy in evaporators. Desalination plants using membrane filters do not use thermal energy, but use electrical energy in all their units. In reverse osmosis plants, electrical energy is mainly used to drive pumps **[19]**.
In thermal desalination plants, thermal energy is the mainstay in the operations for evaporating salt water in boilers. While the electrical energy is secondary energy for the pumps
Although thermal plants are more efficient in removing salts from saline feed water compared to desalination using membranes. However, the cost in thermal plants is more expensive than reverse osmosis filters **[19]**. (as shown in **Figure (2**)).

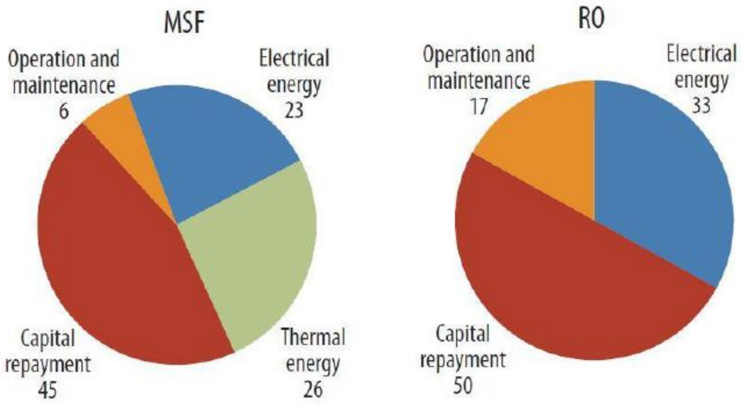

Fig. 2 The main desalination processes and the total annual cost **[20, 21]**

The countries of the Arabian Peninsula prefer to use MSF, due to the availability of operational thermal energy from crude oil as well as the high efficiency in removing salts from sea water. Reverse Osmosis consumes relatively less energy and does not need thermal energy, therefore European countries use reverse osmosis **[3]**.

Energy cost is an important factor affecting the total cost. There is a real need to reduce the cost of desalination, and the need has emerged to use less expensive energies in the production of fresh water. Therefore, many studies have been conducted into the cost of water desalination **[22, 18]**. **Table 2** shows a comparison among several desalination techniques. It is clear that the cost of operational energy for the reverse osmosis process is the most appropriate, but the production cost is almost similar to the production cost of other desalination techniques. This is due to replacement costs and periodic maintenance **[18]**.

	Thermal Technology				Membrane Technology	
	MSF	**MED**	**MVC**	**TVC**	**ED**	**RO**
Water type	Seawater, Brackish	Seawater, Brackish	Seawater, Brackish	Seawater, Brackish	Brackish	Seawater, Brackish
Operation temperature (°C)	90–110	70	70–100	63–70	Ambient	Ambient
Typical unit size (m^3/day)	50,000–70,000	5000–15,000	100–3000	10,000–30,000	2–145,000	24,000
Electrical energy consumption (kWh/m^3)	4–6	1.5–2.5	7–12	1.8–1.6	2.6–5.5	5–9
Thermal energy consumption (KJ/kg)	190–390	230–390	none	145–390	none	none
Electrical equivalent for thermal energy (kWh/m^3)	9.5–19.5	5–8.5	none	9.5–25.5	none	none
Total electric equivalent (kWh/m^3)	13.5–25.5	6.5–11	7–12	11–28	2.6–5.5	5–9
Unit product cost (USD/m^3)	0.52–1.75	0.52–1.01	2–2.6	0.827	0.6–1.05	0.52–0.56

Table 2 Comparison of desalination energy cost **[18,22]**

4.3 Raw water quality

There are many factors that can affect the total cost of desalination plants. The most important of these factors is the quality of the water and the amount of dissolved salts in it. There is a strong relationship between water salinity and operational cost. The higher the amount of total dissolved solids TDS, is the higher the operational cost in thermal desalination plants and reverse osmosis desalination plants **[23]**.

The salinity of the feed water directly affects the annual cost of the reverse osmosis plants. The National Academy of Sciences, 2008 found an increase in the production cost of fresh water used sea water by about 110% as the relative annual cost per the cubic meter, while the relative annual cost per cubic meter was about 40% of the fresh water which used brackish water as feed water as shown in **Figure (3)**. When the cost of operation, maintenance and replacement are all fixed and the only variable is the salinity of the feed water. The operational cost is relatively cheap whenever the feed water is less saline and the cost increases with increasing salinity in membrane desalination plants. However, the operational cost of thermal desalination plants is not affected by the salinity of the water, and therefore thermal plants are always used to desalinate saline water and seldom for slightly salty water **[24]**.

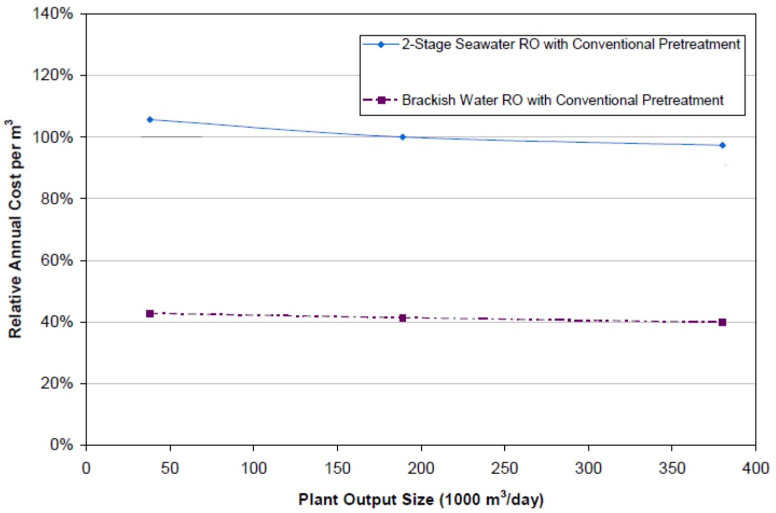

Fig. 3 Effect of facility size, water source, and pretreatment process on relative annual costs per cubic meter for RO plants.

The effect of raw water and desalination plant capacity on the desalination cost are reported on the water production costs in **[25]**. cubic meters per day for popular desalination techniques as shown in **table (3)**

Table 3 Average Water Production Costs of the Main Desalination Processes **[18]**

Type of Process	Type of Water	Cost of Water (U.S. $/m^3)
MSF		
23,000–528,000 m^3/day	Seawater	0.56–1.75
MED		
91,000–320,000 m^3/day	Seawater	0.52–1.01
12,000–55,000 m^3/day		0.95–1.5
Less than 100 m^3/day		2.0–8.0
VC		
30,000 m^3/day	Seawater	0.87–0.95
1,000 m^3/day		2.0–2.6
RO		
100,000–320,000 m^3/day	Seawater	0.45–0.66
15,000–60,000 m^3/day		0.48–1.62
1,000–4,800 m^3/day		0.7–1.72
RO		
Large capacity: 40,000 m^3/day	Brackish water	0.26–0.54
Medium: 20–1,200 m^3/day		0.78–1.33
Very small: few m^3/day		0.56–12.99
ED		
Large capacity	Brackish water	0.6
Small capacity		1.05

5.Estimation model of desalination cost

At least one of the following approaches is used in the cost estimation process including **[9]**:

1- Cost provided on the basis of experience and prior knowledge of the costs of desalination plants. In most cases, it is astonishingly precise. it is called “swag”

2- Empirical Cost Models – Using the references data of previous desalination plants, where the data is analyzed statistically and curves are created to match it with the production capacity of the new plants.

Several studies have used this model in order to predict the cost of setting up a salt water desalination plant. Many researchers have progressed empirical cost models, and one of the most important models developed by Watson et al. **[26]**. This model offers many curves used in various filter systems. It also displays reference cost data and curves for thermal desalination plants and osmosis plants that use saline water as feed water.

3- Parametric Cost Models – The parametric cost model exceeds the one-variable method, not as is the case with the empirical model. The parametric model works using several variables, for the purpose of reaching special case of the different desalination techniques

4- Factored Cost Models – This model is the most widely used model and is used in a wide field in water operations as well as in the oil industry. The capital cost of the basic units is calculated, then some adjustments are added to calculate the cost of the supporting units. In most cases, offers are required to be submitted by investors.

6. Examples of Desalination Facility Costs

Planning for the establishment of a desalination plant may need to know the production cost or perhaps the capital cost. Therefore, knowing the costs of desalination plants in different countries or cities may give an adequate perception of the costs. The **Table (4)** shows a comparison in the costs of desalination plants using the reverse osmosis system in different countries. Whereas, the production cost of desalination water by using thermal desalination units Multistage Flash MSF is compared in the **Table (5)** for diverse countries.

Table 4 Sea water RO plants cost located in various locations

Region:	USA [24]	Arabian Gulf [25]	Australia [26]	Florida[20]
Project name:	Carlsbad Desalination	Fujairah F1 Extension SWRO	Gold Coast Desalination Plant	Tampa Bay SWRO
construction date:	2014	2013	2009	2008
Plant capacity m3/d (MGD):	189,000 (50)	136,000 (30)	133,000 (35.1)	95,000
Raw water salinity (ppm):	36,000	45,000	38,000	26,000
Total installed cost (US$):	$692,000,000	$200,000,000	$943,000,000	$32,000,000
OPEX (US$/year):	$53,100,000	$26,900,000	$32,000,000	4,161,0000
Unit production cost, (US$/$m^3$-day):	$1.86	< $0.60	$1.63	$ 0.83

Table 5 Multistage Flash Distillation Desalination Plants production cost **[30]**

Plant Name	Location	Operation Year	Size (MLD)	Capital Cost total (USD mil)	O&M Total (USD mil)	O&M per MLD	Cost of water (USD/m3)
Arzew	Algeria	2002	88.9	199	9.9	0.11	1.74
Taweelah A1	UAE	2003	146	356	16.6	0.11	1.67
Sohar	Oman	2007	150	472	23.9	0.16	1.55
Ras Laffan 2b	Qatar	2008	272	682	31.3	0.12	1.49
Shuweihat S1	UAE	2004	378	808	35.2	0.09	1.44
Shuweihat S2	UAE	2011	459.1	963	40.5	0.09	1.36
Yanbu Ph3	KSA	2016	550	1000	52.2	0.09	1.28
Shuaibah 3	KSA	2010	880	1640	68.9	0.08	1.02

MLD* million Litter/day

Conclusion

The desalination process is one of the effective options in providing fresh water suitable for human use and developing an integrated environment in communities that suffer from scarcity of fresh water.
Among the most important and widely used desalination methods are membrane and thermal desalination technologies, namely multi-stage flash (MSF) and reverse osmosis (R.O) processes.
Considering the cost of the desalination process is also important. The desalination process can be very expensive. Therefore, it is necessary to conduct a careful study of the quality of the water to be desalinated, in addition to the available capabilities for the purpose of establishing a station with a moderate cost and good efficiency.
The cost and choice of technology used in a desalination system depends on two main factors: the available energy and the type of raw water (brackish or seawater). It is clear that capital costs and energy resources are the most economical costs and therefore directly affect the desalination processes. Other costs are less impact on the cost of desalination technologies. Energy cost is an important factor affecting the total cost. There is a real need to reduce the cost of desalination, and the need to use less expensive energies in the production of fresh water has emerged. As for water quality and the amount of dissolved salts in it, there is a strong relationship between water salinity and operational cost. The higher the amount of total dissolved solids, the higher the operating cost in thermal desalination plants and reverse osmosis desalination plants
Several methods are used in the cost estimation process, including: Estimated cost based on previous experience and knowledge of desalination plant costs. In addition to empirical cost models that use reference data from previous desalination plants and standard cost models that rely on the single variable method. A common model is the fixed cost model, where you calculate the cost of capital for the base units and then some adjustments are added to calculate the cost of the supporting units.

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