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Technical and Economical Evaluation of Desalination Processes for Potable Water from Seawater

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Abstract: At low pressure and temperature, water is easily vaporized under partial vacuum pressure. Desalination of seawater as source of potable water is globally considered as an applied reliable technology. At low temperature and pressure, the heat transfer process yield is higher than any normal process. Therefore, the rate of vaporization of seawater is much higher than any usual processes. The partial vacuum was generated by the steam passing through steam ejector. Multi effect desalination (MED) evaporators were employed and the vaporized mass steam from the seawater was used as steam for the next evaporator. In this process, for each kg of stream utilized about 2kg of pure condensate drinking water was obtained. Multi stage flash (MSF) desalination technology is the dominant technology in Persian Gulf area. Advanced technologies are applied for industrial use of water. Reverse osmosis (RO) is a membrane separation process operated at high pressure. Another membrane process is electro-dialysis (ED) which is used for desalination purposes. Total dissolved salts concentrations in seawater at inlet seawater and outlet stream of the desalination plant were 38 and 57 g/L, respectively. The concentrated brine solution can be separated from seawater for salt production. The market value for salt product from seawater is $30 per ton; that may assist to reduce the price of potable water to $0.44/m^3$. The purpose of present work was to investigate the estimated costs of potable water per m^3; for several existing technologies with the aim of energy conservation for small, medium and large scale desalination plants to deliver potable water. The lowest price of $0.35/m^3$ of drinking water may be projected for the water obtained from RO or freezing processes.

Key words: Desalination · Multi effect evaporator · Multi stage flash · Potable water Seawater

INTRODUCTION

Water is precious for life, civilization and development. About 70% of our earth's surface is covered by water. More than 95% of the water sources available are sea and oceans. About the remaining 5% of the world's water supply is considered as drinking water. The salinity of seawater is defined as total dissolved salts (TDS) estimated to be 35-40g/l [1-3]. As world population gradually increases, demand for potable water is growing. Desalination of seawater is a predominant technology used for water supply in coastal regions. The availability of drinking for the new settlements in most of Iranian islands especially in Persian Gulf area is vital. Desalination plants are the promising technologies to supply the needs for potable water in past few decades.

In terms of application of advance technologies, Iran's existing desalination plants use a combination of thermal processes and RO for high yield and economic reasons. MSF is the most dominant technology widely used in Persian Gulf islands. RO processes are often used for industrial plants. The thermal technologies mostly benefited from advanced technologies such as multi effect distillation (MED) and vapor compression (VC) processes. Among the world 100 largest desalination plants, Iran has an operating plant in Bandar Imam with daily production capacity of 92000 meter cubes [4]. In fact, the largest desalination plant is devoted to Mahshar Petrochemical plant. Iranian Petrochemical Company projected the need for water supply would be 131,000 -149,000m^3/d of water. A reverse osmoses (RO) plant producing 140,300m^3/d of water already in operation and serves Fajr Petrochemical plant [5].

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Technology development for desalination plants are progressing and worldwide dominated in many neighbor countries in Persian Gulf area. The valid question may exist is about the cost effectiveness and application of any specific modern technology and the plant size for delivered cost of $1000m^3$ of potable water. More than 40% of Middle East desalination plants in operation have daily production capacity in the range of $20\text{-}100m^3$ [6]. This means, the plant size by manufacturers are depends on technology applied in desalination units. The most common desalination plants are dominated with evaporators often designated as flash distillation, multistage flash (MSF) and multi effect distillation (MED). However, recent technologies focused on application of membrane separation processes combined with other separation technologies.

The purpose of present work is to investigate on technologies dominated in Iranian desalination plants and find out challenges, limitations and cost analysis for the production of drinking water in Persian Gulf islands.

Desalination Technologies: In new millennium, membrane technology such as RO which is a reliable technology and relatively new process has been commercially developed and dominated in industrial scale for the water supply in Persian Gulf area. The selected technologies in this work are based on availability of desalination plants in southern part of Iran.

Membrane desalination processes are reverse osmosis and electrodialysis (ED). The thermal processes are known as MSF, MED and vapor compression distillation (VCD) [7]. Alternative desalination processes are combination of renewable energy which is powered conventional distillation units. Solar humidification, freezing and membrane distillation processes are required special attention to make them more efficient for effective and large scale applications [8].

Generally, large scale desalination plant has great potential to reduce operation costs due to application of modern membrane separation modules [9]. Ashkelon is the world's largest desalination plant operated with reverse osmosis (RO) membrane technology has drinking water capacity of 330 000 m^3/d. The estimated cost of Ashkelon plant is estimated to be $\$0.527/m^3$ [2]. Large RO desalination plants has reduced the finishing potable water costs [10]. Turek [1] has conducted cost analysis for drinking water obtained in a hybrid system of electrodialysis and multi stage flash evaporation plant. He has estimated the cost of additional by-product salt $30 per ton; then the estimated cost of drinking water is $\$0.44/m^3$.

Bouchekima [8] has investigated on application of solar energy to distill saline or brackish water. The radiation of sun on solar collectors evaporated water inside a chamber at a temperature higher than ambient. This research claimed high thermal efficiency for single stage flash evaporator; unfortunately there were no cost figures available in terms delivered portable water price.

Kim *et al*. [10] have applied a hybrid system of RO, ultra filtration (UF) membrane along with thermal energy recovery [11]. They have reduced the operation costs by 40% of desalination plant in large scale operation. Zidouri [3] has utilized four RO system with 94 DuPont B-10-6845 T (hollow-fine fibre) RO modules arranged in two stages. He has found about 45% of the seawater recovered as potable water and the remaining 55% was brine solution. Since desalination plant size was small; the cost of drinking water higher than reported values.

The next technology has not been revealed yet would be Sliepcevich process. Civan and Sliepcevich have developed a novel technology at the University of Oklahoma (Norman, Okla., USA) the freezing process [12]. When crystals of ice formed in an aqueous phase, the solute is practically rejected from ice crystals. This is the basis of separation of pure water from brine solution via freezing process. The ice crystal is pure water, the remaining salts trapped in the boundaries of the solid cubes of ice. The polycrystalline ice has to be removed from the remaining brine solution. Heat is removed by evaporation of refrigerant in direct contact with brine solution; the refrigerant may be water itself or an immiscible refrigerant with water called secondary refrigerant. The heat required for melting is obtained from condensation of the refrigerant as a result liquid refrigerant and water both products are obtained. This process is carried out under vacuum freezing vapor. The power required is estimated to be $0.1kWh/m^3$. The lowest price for pure water is obtained. Table 1 summarized several technologies with averaged plant capacities and percentage of contributions to deliver potable water.

Table 2 compares the estimated costs of produced water with various dominated technologies. Table 3 summarizes the capacity of Iranian desalination plants operated in various locations in Persian Gulf area with multi effect distillation (MED) technology.

Table 1: Desalination Plants with Various Technologies

Desalination Process	Type	No. of Plant	Plant Capacity (MGD)	Capacity (%)
Single Stage Flash distillation	SF	49	6.6	2.7
Multi-stage Flash distillation	MSF	196	158.4	64.9
Vertical Tube Evaporator	VTE	102	30.5	12.3
Submerged Tube Evaporator	ST	293	33.5	13.7
Vapor Compression Evaporator	VC	22	2.9	1.2
Electrodialysis equipped with Membrane,	ED	44	12.2	5.0
Reverse Osmosis with Membrane Modules	RO	3	0.2	0.1
Vacuum Freezing Vapor Compression	VFVC	3	0.3	0.1

Table 2: Costs analysis for potable water produced in desalination processes

Desalination process	Estimated costs per m^3 potable water, $	Reference
Electrodialysis- Multi stage Flash (EDMSF)	0.44	[1]
Membrane Technology (MT)	0.53	[2]
Multi Stage Flash (MSF)	0.52	[14]
Vertical Tube Evaporation (VTE)	0.45	[14]
Reverse Osmosis (RO)	0.45	[4]
Vapor Compression Evaporation (VCE)	0.39	[15]
Secondary Refrigeration Freezing (SRF)	0.35	[16]

Table 3: Iranian desalination plants in operation*

Company	Location	Capacity, m^3/d	Water quality, TDS	Operation started
Kharg Petrochemical	Kharg Island	1000	<10ppm	1998
Iranian Offshore Oil	Sirri Island	1000	<10ppm	1999
Hormozgan Power	Bandar Abbas	2400	<5ppm	2000
Mobin Petrochemical	Assaluye	5800	<10ppm	2002
Iranian Offshore Oil	Lavan Island	1200	<10ppm	2003
Agip Enl Iran	South Pars Gas field	1500	<10ppm	2004
Iranian Offshore Oil	Lavan Island	1200	<10ppm	2004

*Multi Effect Desalination (MED) plant technology was commissioned by Fan Niroo Company Feb. 2012

Table 4: Advantages and disadvantages of various desalination plants

Desalination Process	Capital Intensive	Plant Utilities	High Pressure pump Costs	Operation Costs
Multi-stage Flash Distillation	High	High	Low	High
Multi Effect Desalination	High	High	Low	High
Vertical Tube Evaporator	High	Medium	Medium	High
Vapor Compression Evaporator	High	High	High	Medium
Reverse Osmosis with Membrane Modules	High	Low	High	Low
Vacuum Freezing Vapor Compression	Medium	Medium	High	Low

There are many small scale units may be benefited from advance technologies with use of solar cells; since the rate of potable water productions are not significant; therefore, the detail descriptions of the above technologies and units are eliminated [13]. Advantages and disadvantages of various desalination plants in terms of capital, operation, utilities and highly technical equipments are summarized in Table 4.

CONCLUSION

The desalination plant was based on energy and heat conservations for sustainable and secured potable water used in Persian Gluf area. Several low costs developed technologies have been evaluated. The costs for finished product were compared. Most of the desalination processes have great potential to be commercialized in Middle East region.

This paper presents economical and technical advantages of several desalination plants. In fact the unit cost of water produced from membrane process such as RO may be lower than the thermal or evaporative desalination plants. Economic analysis showed that RO may be more competitive than the thermal process. It is clear that RO has bright future for development of low cost membrane and high process performance in cost reduction of water for domestic and industrial usages.

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