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Cost-benefit Analysis of Water Production with Seawater Reverse Osmosis System: A Case study for Mersin Free Zone and International Port

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ABSTRACT

In this study, calculation of sea water reverse osmosis system cost has been used to determine local cost of the system and recycling time of investment. Local area owner and investor of the system are accepted as Mersin Free Zone and Mersin International port due to common water usage areas, and real connection road is named as "corridor." The local cost of the system was calculated as 0.49 $/m^3$ for 1000 m^3/day capacity. Both companies take and use water which has a cost of approximately 0.75$/m^3$ from Mersin Metropolitan Municipality. The most important factors are determined as the sales volume and price of water for ships due to earnings from ships significantly decreased the recycling period of the system. The calculation of the system cost showed that the recycling time of the capital is <2 years, and after approximately 10 years, system which is assumed as 30 years lifetime would be completely free for the companies.

Keywords: Reverse Osmosis, Water Production, Cost-benefit, Economy
JEL Classifications: D61, Q25

1. INTRODUCTION

In the new global life, the decline of water resources and the high costs of water production are one of the potential problems to be solved. Therefore, water production from sea water, groundwater and waste waters have been studied by many researchers using different methods since today.

International ports (IP) and free zones (FZ) have a wide range of potential in world trade areas due to international transport and ships are the main key factor of this trade. Ships and facilities inside of the IP or the FZ pay money for taking water, and the aim of this case study is to find establishment of seawater reverse osmosis (SWRO) system is beneficial or not as an investment for Mersin, Turkey.

Requirement of fresh water (FW) on ships are mostly supplied by own desalinators but, if consumption rates are higher than production amounts, ships will need to receive FW from the port facilities. Particularly long-term waiting in port or anchorage positions have negative influences on water production for ships in that the ships navigating in the sea mostly prefer to use the waste heat energy of the engine for desalination (Shu et al., 2013).

The reduction of FW resources in the ground and development of technology could canalize the facilities and ports SWRO system for a possible cheaper production of FW from SW. These facilities in Turkey mostly use city water supply and sell the FW to the ships with different profit percentages. Most of the FW plants used around the world are preferred as RO system due to lower energy consumption when compared with the other thermal process plants (Shenvi et al., 2015). However, different studies indicate that performance and compatibility of the SWRO can be affected of many parameters such as feed water quality, electrical cost, taxes, interest rates and other local variables (Judd, 2017; Wilf and Bartels, 2005; Wilf and Klinko, 1998, 1994; Zhou et al., 2006; Ziolkowska, 2015). Wilf and Bartels (2005) evaluated the economic effect of the SWRO system supply recovery rates and determined that SWRO system, for recovery rate exceeding 55%, can be useful especially in case of low feed salinity and low electricity cost. There are many studies on the RO subject but water sale in FZ or IP and system appliance with capital return time have not been calculated yet. Water sale prices in FZ or IP are different from normal city prices in Turkey because of the distribution responsibility of the water to facilities and ships. Throughout the last two decades, many studies calculated the cost of FW production from SW at different capacities with reverse osmosis technology and found the minimum cost 0.50 $\$/m^3$ (Dore, 2005; G.G. Pique, 2002; Karagiannis and Soldatos, 2008). Thus, it can be claimed that this price can be decreased with long life membranes and chemicals, hybrid systems, lower maintenance cost, lower electrical power prices and other technological developments (Atikol and Aybar, 2005; Ghaffour et al., 2013; Gökçek and Gökçek, 2016; Gude, 2016; Reddy and Ghaffour, 2007). Atikol and Aybar (Atikol and Aybar, 2005) estimated the cost of SWRO system and found 0.68 $/m3 in Northern Cyprus, and the real cost was approximately 0.7 $\$/m^3$ in operation, which meant that estimation had with an error of ±2.9%. According to Dore (Dore, 2005), using ultrafiltration system, renewable energy and government policies on electric prices had decline effect on prices of SWRO system up to 0.49 $\$/m^3$. Gokcek and Gokcek (Gökçek and Gökçek, 2016) evaluated the cost effectiveness of wind powered SWRO system in Gokceada Island, Izmir and determined that water cost of the system was between 2.962 and 6.457 $\$/m^3$. In this paper, Mersin FZ (MFZ Founder and Operator Inc.) and Mersin IP (MIP) are assumed as the potential investors; therefore, they will be evaluated in terms of system cost and profits to establish a SWRO plant which has 1000 m^3/day capacity. The reason of the assumption is that there is a close connection and a common business area between MFZ and MIP. This connection named "corridor" has a property in that it is specific for Turkey ports(Location specifications of the MIP, 2018). SWRO system aims to eliminate the external dependence of the FW for both companies with more profit by producing the FW less cost.

As can be seen from the literature, a considerable amount of papers has been published about water production methods and also very few of studies have been written about how economic benefits or costs could be evaluated for IP or FZ with water production from sea water. In this study, the major objectivity is to investigate SWRO system compatibility by calculating installation cost and profitability for the case study of MFZ and IP consumption values.

2. MATERIALS AND METHODS

There are two kind of water production methods which are distillation and reverse osmosis. The main differences between them is the production capacity which is more in SWRO systems. In this study, SWRO system was chosen and a schematic diagram of sea water reverse osmosis system is given in the Figure 1.

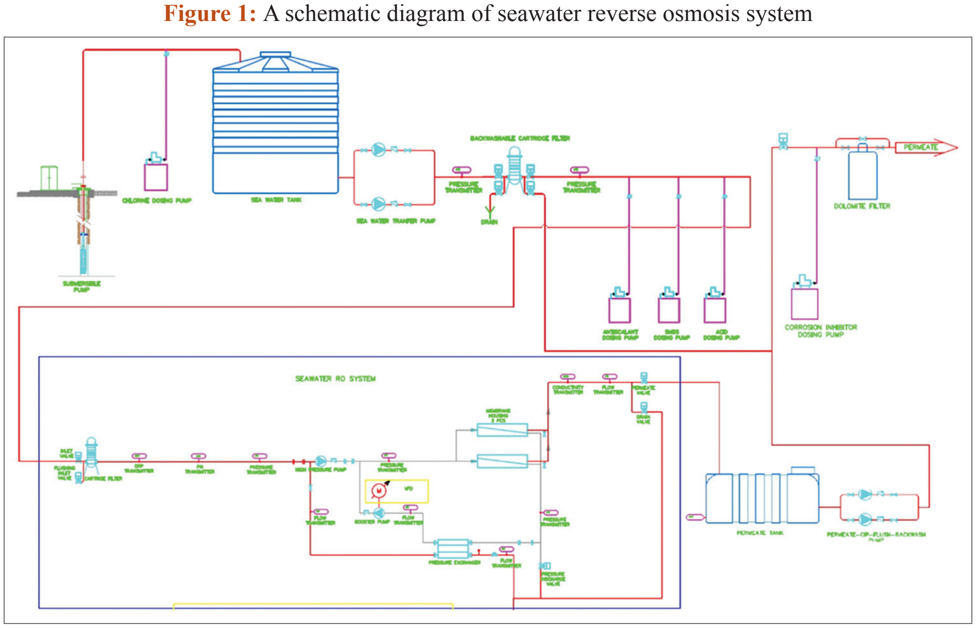
There are various factors which affect capital cost particularly because of the fact that capital consists of land cost, process equipment, structures, membranes, disposal cost, well supply and auxiliary equipment. In this study, the FW production cost of a SWRO plant was calculated in units and this methodology was used as an important method of calculation in the literature (Al-Wazzan et al., 2002; Atikol and Aybar, 2005; Avlonitis et al., 2003; El-Dessouky and Ettouney, 2002; Widiasa and Yoshi, 2016). The sensitivity of the calculation technique has been demonstrated in a study by Atikol and Aybar (Atikol and Aybar, 2005).

$$A_{total}\ (\$/m^3) = A_1+A_2+A_3+\ldots\ldots\ldots+A_n \quad (1)$$

where A_n is the unit cost component for each variable n. A_{total} was calculated as separate units for the system assuming 30 years life time and 10,800,000 m^3 water production capacity. The units were named as follows:

$$A_{total}\ (\$/m^3) = A_{capital}+A_{maintenance}+A_{membrane}+A_{electric}+A_{chemicals}+A_{pretreatment}+A_{manpower}+A_{interest}$$

Figure 1: A schematic diagram of seawater reverse osmosis system



$$A_{capital}\left(Capital\ Cost\ Effect\right)=\frac{D_{capital}}{V_L} \quad (2)$$

V_L is the total volume of water produced (10,800,000 m^3) during the lifetime (30 years) of the system. $D_{capital}$ is the main capital cost for establishment of the system.

$$A_{maintenance}\left(Maintenance\ cost\right)=\frac{M}{V_L} \quad (3)$$

M is the maintenance cost of the system.

$$A_{membrane}\left(Membrane\ cost\right)=\frac{S_{membran}xYearsxl}{V_L} \quad (4)$$

S_{memb} is the membrane cost and □ is a value between 0.05 and 0.2 (El-Dessouky and Ettouney, 2002), depending on the salinity and the quality of water.

$$A_{electric}\left(Electric\ cost\right)=\frac{E_{pumps}xL}{V_L} \quad (5)$$

E_{pumps} is hourly cost of pumps ($/h) and L is total life time of the system in hours (259.200 h).

$$A_{chemicals}\left(Chemical\ cost\right)=\frac{F_{chemical}}{V_L} \quad (6)$$

$F_{chemical}$ is the total chemical cost of the system.

$$A_{pretreatment}\left(Pretreatment\ cost\right)=\frac{T_{pretrt}}{V_L} \quad (7)$$

T_{pretrt} is the total pretreatment cost of the system.

$$A_{manpower}\left(Manpower\ cost\right)=\frac{W_{manpwr}}{V_L} \quad (8)$$

W_{manpwr} is the total manpower cost of the system.

$$A_{interest}\left(Interest\ rate\right)=\frac{D_{capital}xax\ years}{V_L} \quad (9)$$

$$Where\ a=\frac{i(1+i)^{years}}{(1+i)^{years}-1}\left(amortization\ factor\right)$$

SWRO plant construction cost was calculated and evaluated for compatibility for future profit feasibility. Local prices for 2018 were used for calculation and future estimation of all parameters. Gross profit percentage was evaluated based on MFZ's and MIP's 2016-2017 water consumptions and 2017 water prices. The profit was not evaluated as net profit due to expenditures of the MFZ and MIP, like waterline maintenance, labor costs and other operating costs of MFZ and MIP. These percentages were calculated using the following formulas, which not only include the cost of SWRO plant and city water but also sale prices of water to facilities and vessels.

Cost of the SWRO plant water: A_{total} *($/m^3)*

Cost of water taken from the city: *C ($/m^3)*

Sale price of water to facilities: *F ($/m^3)*

Sale price of water to ships: *S ($/m^3)*

$$Gross\ profit\ percentage\ from\ facilities\ with\ city\ water=\frac{F-C}{C} \quad (10)$$

$$Gross\ profit\ percentage\ from\ ships\ with\ city\ water=\frac{S-C}{C} \quad (11)$$

$$Gross\ profit\ percentage\ from\ facilities\ with\ SWRO\ plant\ water=\frac{F-A_{total}}{A_{total}} \quad (12)$$

$$Gross\ profit\ percentage\ from\ facilities\ with\ SWRO\ plant\ water=\frac{S-A_{total}}{A_{total}} \quad (13)$$

Also, net profit value (NPV) (Widiasa and Yoshi, 2016), was calculated for the system and investment return time could be determined with a formula which is illustrated as follows:

$$NPV=A0+\frac{A_1}{(1+i)^1}+\frac{A_2}{(1+i)^2}+\dots+\frac{A_n}{(1+i)^n}(\$) \quad (14)$$

If NPV>0, SWRO plant is profitable.

Where: A_o = Cost of SWRO system (negative) ($),
$A_{1,2,n}$ = Money generated from water sell ($) in year 1.2, until n
i = Interest rate was accepted %5 in all calculations of the methodology.

3. RESULTS AND DISCUSSION

In this study, the cost benefit analysis of SWRO system was studied with applying of Mersin FZ and IP. The analysis of sea water inside the Mersin port is illustrated in Table 1.

MFZ has totally 728 local and foreign investor facilities which are using water, and approximately 250 ships are annually approaching to

Table 1: Sea Water Analysis Results (Mersin Container Port Project, 2009)

Parameter	Unit	Measurement result
pH	-	7.75
Suspended solid	mg/L	28.8
Nickel	mg/L	<0.1
Lead	mg/L	<0.1
T. Chrome	mg/L	<0.03
Zinc	mg/L	<0.2
Copper	mg/L	<0.01
Dissolved Oxygen	mg/L	8.3
Arsenic	mg/L	<1
Phenol	mg/L	<0.1
Mercury	mg/L	<1
Cadmium	mg/L	<0.1
Ammonia	mg/L	0.04

private dock (Trade volume and statistics MFZ, 2017). Moreover, MIP is the one of the leading ports of Turkey and the East Mediterranean region (Location specifications of the MIP, 2018). Nowadays, MIP and MFZ take water from city and pays approximately 0.75 $/m^3$ to Mersin Metropolitan Municipality (Water tariff and fees of MESKI, 2017). Therefore, according to the calculations, MFZ and MIP have respectively %72 and %700 gross profit percentage from water sale to facilities and ships. If these calculations are made for SWRO plant water, gross profit percentages will be doubled nearly. MIP does not have any income from facilities; therefore, only the sales made by MFZ to facilities were used in the calculations.

If SWRO plant, which has 1000 m^3/day capacity, is decided to be established in MFZ, it will cost company 0.49 $/m^3$ (Local price values of SWRO system, 2017) with in all factors. All factors are identified by units in Table 2.

MFZ and MIP water sale volumes (m^3) for 2016 and 2017 have been illustrated in Figures 2 and 3. Moreover, total sales volumes

Table 2: SWRO system local prices of all factors and total for MFZ and MIP (Local price values of SWRO system, 2017)

Unit cost of factors	Local prices ($/m³)
$A_{capital}$	0.067
$A_{maintenance}$	0.013
$A_{membrane}$	0.035
$A_{electric}$	0.15
$A_{chemicals}$	0.08
$A_{pretreatment}$	0.008
$A_{manpower}$	0.007
$A_{interest}$	0.13
A_{total}	0.49

SWRO: Seawater reverse osmosis, MFZ: Mersin free zones, MIP: Mersin International ports

have been illustrated in Figure 4, and sales acceptance volumes were derived from these values. The figures indicate that volume of water sales of both companies showed a steady distribution between the years 2016 and 2017. This steady distribution allowed an approximate sale volume acceptance annually. In this study, approximate sale volumes have been accepted as 190.000 m^3 for the facilities and 60.000 m^3 for the ships. These values were officially requested from MIP and MFZ headquarters and used for the study (MFZ water consumption statistics, 2017; MIP water consumption statistics for ships, 2017). Furthermore, water sale prices of MFZ and MIP to ships and facilities have been illustrated in Table 3 (Water tariff and fees of MFZ, 2017; Water tariff and fees of MIP, 2017). Since MFZ has not recorded the volume of water given to the vessels, the total volume of MFZ sale was accepted as 500 m^3 per month and added to monthly MIP water sale afterwards.

When the annual sale volume averages are accepted as 190.000 m^3 for the facilities and 60.000 m^3 for the ships, MFZ and MIP could receive 245.100$ from the facilities and 360.000$ from the ships annually. Even though it was assumed that water prices would not change throughout the following three decades, the same interest value, accepted as %5, NPV result would be more than 3.5 million dollars. SWRO system capital investment return time has been found under 2 years, and it could compensate all expenditures (A_{total} for 10.800.000 m^3) in approximately 10 years which meant 20 years completely free usage of the system.

4. CONCLUSION

In this study, SWRO system cost analysis, for the FZ and IP, has been calculated for the first time in Turkey via using a methodology which has a wide perspective in the literature. SWRO systems

Figure 2: Mersin free zones (MFZ) and Mersin International ports (MIP) Water Sales volumes for 2016 (MFZ water consumption statistics, 2017; MIP water consumption statistics for ships, 2017)

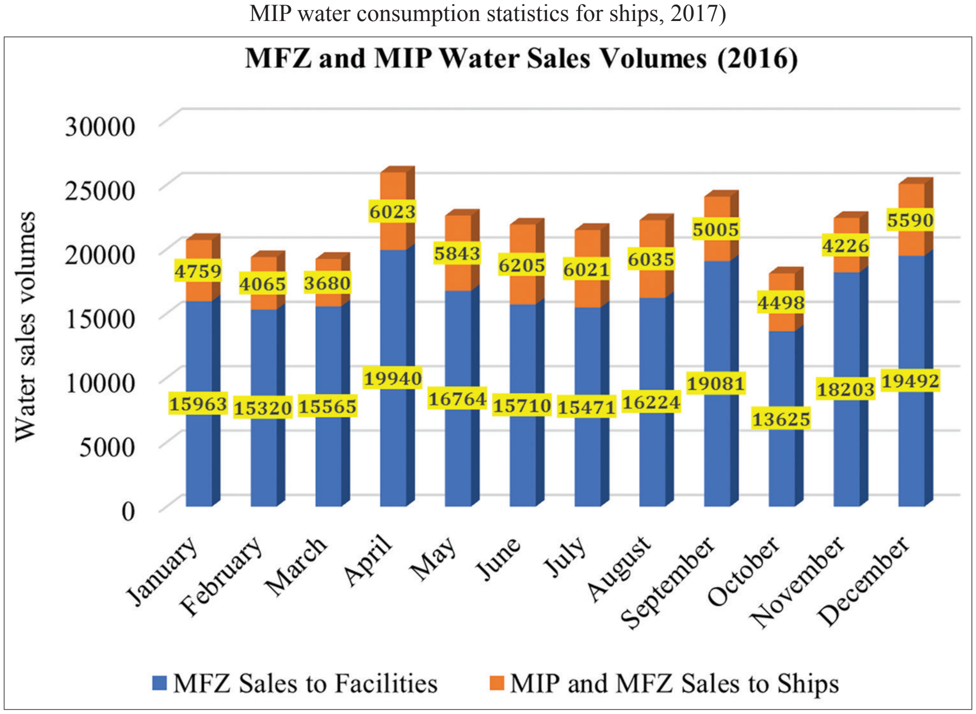


Figure 3: Mersin free zones (MFZ) and Mersin International ports (MIP) Water Sales volumes for 2017 (MFZ water consumption statistics, 2017; MIP water consumption statistics for ships, 2017)

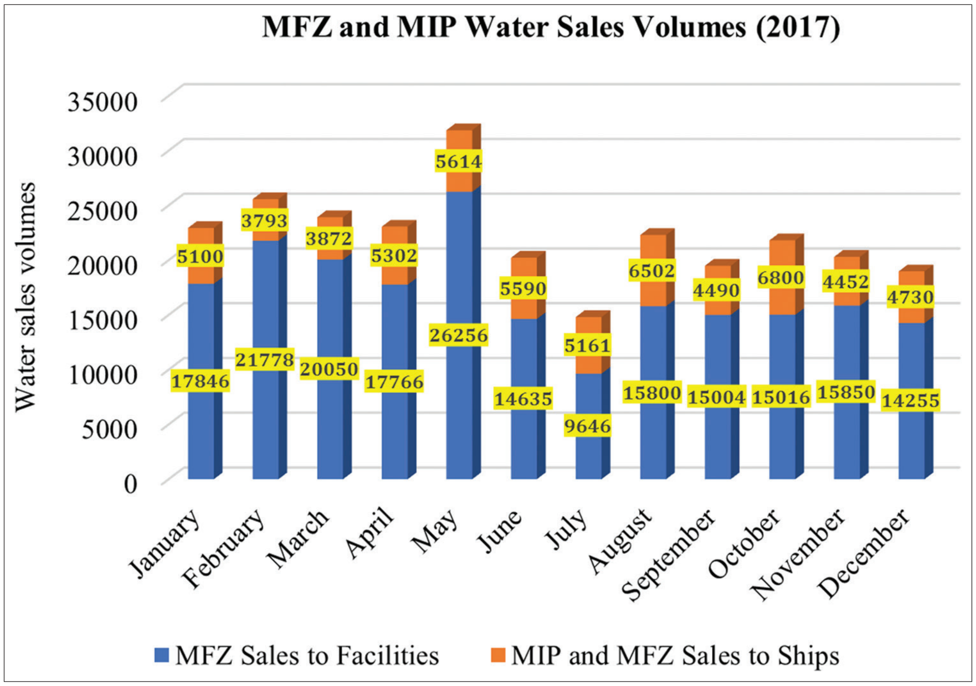


Figure 4: Mersin free zones (MFZ) and Mersin International ports (MIP) total water sales volumes for 2016-2017 (MFZ water consumption statistics, 2017; MIP water consumption statistics for ships, 2017)

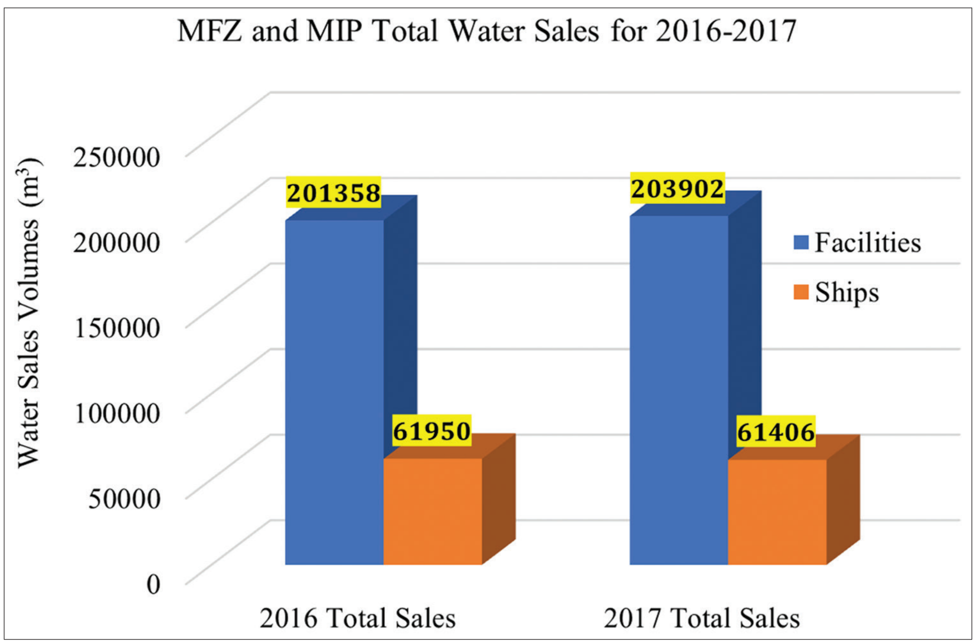


Table 3: Water Sale Prices of MFZ and MIP (Water tariff and fees of MFZ, 2017; Water tariff and fees of MIP, 2017)

Water sale prices of MFZ and MIP	($/m³)
Ships	6 ($/m³) (from shore)
Facilities	1,29 ($/m³)

SWRO: Seawater reverse osmosis, MFZ: Mersin free zones, MIP: Mersin International ports

have been already used as a practical and an applicable solution for the water supply problems throughout the world. Although the system establishment has a serious investment cost, the water supply issue might be inevitable for the future of the companies like FZ and IP due to growing climate problems and possible reduction of natural water supplies. SWRO system cost is related to various factors and working conditions that can also affect this cost. Growing technological improvement and government support could be identified as major contributing factors for the decline of SWRO system cost. Practically, capital expenditures in the initial establishment, and after that the reduction of electricity consumption in operation of the system have had significant influences in cost. A reasonable approach to tackle this issue could be to support governments with reducing land and electric cost of companies. In this study, the results indicated that system return time and NPVs are logical for SWRO system establishment. In particular, proportion of sales to the ships was found important for system profitability and return time. In a nutshell, it can be said that, capital investments could be decreased with partnership and common use of FW like this study.

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