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Total annual profits estimation for new construction of an SWRO desalination plant in Korea

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ABSTRACT

A seawater reverse osmosis (SWRO) desalination process has become an alternative technology to solve water shortage problem in the world. Although SWRO is an advanced and useful technology for humanity, there is still unsettled cost effective issue. Therefore, the estimation of operation and maintenance (O&M) costs should be significantly considered before a new construction of SWRO desalination plant. The objective of this feasibility study is to estimate total annual profits (TAP) according to O&M for a new construction of SWRO desalination plant at 9 candidate sites along the shoreline in Korea. The cost estimation model was developed and validated with Fujairah SWRO plant operation data in 2005. As a result, TAPs for the 9 candidate sites were estimated and compared with that of Fujairah SWRO plant. The result reflects that the cost estimation model in this study is able to propose a reasonable range of TAP for a new construction project of SWRO desalination plant in Korea.

Keywords: SWRO desalination; Cost estimation; Seawater; Total annual profits, Site-specificity

1. Introduction

A desalination process, which produces fresh water from seawater, has been increasingly applied to resolve worldwide water shortage problem [1]. Typical desalination processes can be categorized with membrane separation (i.e., seawater reverse osmosis (SWRO) membrane process) and thermal separations [i.e., multistage flash desalination (MSF), multi-effect distillation (MED) processes] [2]. Among them, SWRO desalination is the most popular technology which can reduce energy consumption comparing to other desalination technologies. In particular, a large-scale of SWRO desalination plant has been focused on the reduction of production cost, because it is more cost-effective than a small-scale SWRO desalination system and thermal separation processes [3,4]. The production cost reflecting energy consumption of plants has been emerged as a significant factor, before a new construction of SWRO desalination plant. The cost for SWRO desalination plant can be divided into the capital cost and operating and maintenance (O&M) cost [5–8]. Although capital costs mainly consist of construction costs, project engineering services, project development, and project financing costs, O&M costs which include variable and fixed O&M costs, can be reduced by the optimization of operation and maintenance of SWRO desalination plant. Therefore, many studies have been performed to reduce O&M costs and to optimize the process by considering of various operating conditions. Larson and Leitner mentioned that the capital cost estimation should concern

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the electricity cost of reverse osmosis process [8]. Glueckstern studied cost estimation of seawater and brackish water in relation to capital costs (direct/indirect), energy consumption, fixed charge rate, electric power cost, and O&M costs [5]. Also, Wittholz et al. tried to calculate a series of cost correlation using a cost database including the information about production cost of large-scale desalination plants [6]. Recently, the package model was developed by Kim et al., which can simulate the SWRO process performance as well as estimate the operating cost of SWRO desalination plant [4]. In this study, total annual profits (TAP) which calculated by subtracting total expenses (i.e., electricity, membrane, pumps, and energy recovery) from total revenue, was estimated as a practice to find a reasonable range of TAP during an operation of SWRO desalination plant.

The objectives of this feasibility study are to estimate TAP of SWRO desalination plants of 9 candidate sites along the shoreline in Korea using the cost estimation model which was developed and validated with the Fujairah SWRO desalination plant in UAE in 2005, and to propose a reasonable range of TAP for a new construction project of SWRO plant in Korea.

2. Data description

Table 1 shows the operation conditions in Fujairah SWRO desalination plant. Raw seawater intake point is situated at 380 m from the seashore and at 10 m below surface of the sea. The capacity of total water production is 170,500 m^3/d [4,9] and feed temperature and TDS concentration are ranging from 22.7 to 34.5°C and from 34,920 to 39,538 ppm, respectively.

In this study, 6 input data such as feed flow, TDS concentration, pressure, temperature, permeate pressure, and salt rejection of the Fujairah SWRO plant on February (n = 15), May (n = 9), August (n = 26), and November (n = 20) in 2005 (see Table 2), were selected to compare TAPs of 9 candidate sites in Korea for a new construction project of SWRO desalination plant along the shorelines (see Fig. 1). The candidate sites which were chosen by refering to the previous study [10], can be divided into 3 shorelines, that is, Yellow Sea (i.e., Inchoen, Gunsan, and Mokpo), South Sea (i.e., Goheung, Tongyeong, and Pusan), and East Sea (i.e., Ulsan, Pohang, and Sokcho). And C_{Feb}, C_{May}, C_{Aug}, and C_{Nov} in Table 2 denote operating conditions in February, May, August and November, respectively.

TDS concentration and temperature data of 9 candidate sites in Korea (see Fig. 1), which measured in 2008, were obtained from National Fisheries Research Development Institute (NFRDI) and Korea Hydrographic and Oceanographic Administration (KHOA). In Table 3, TDS concentration and temperature data of 9 candidates in 2008 were summarized to compare seasonal characteristics of seawater. Temperature and TDS concentration data from the 9 candidate sites are relatively lower than

Table 1
Description of system configuration and operation conditions of Fujairah SWRO desalination plant in 2005

Intake location	380 m from the seashore, 10 m below the surface	
The capacity of total water production	170,500 m^3/d	
System configuration	7 elements per vessel, 136 vessels per train, and 17 (+1)* trains	
Operating parameters	Feed flow rate (m^3/h)	1,056–1,090
	Feed TDS concentration (ppm)	34,920–39,538
	Feed pressure (bar)	62.5–68.2
	Feed temperature (°C)	22.7–34.5
	Permeate pressure (bar)	6.11–12.20

* (+1) indicates one more train for stand-by operation.

Table 2
Summary of operating data in Fujairah SWRO desalination plant of 4 months in 2005

Parameters	C_{Feb}*	C_{May}	C_{Aug}	C_{Nov}
Feed flow rate (m^3/h)	1,059–1,064	1,061–1,072	1,058–1,073	1,059–1,090
TDS concentration (ppm)	36,585–36,965	36,737–38,143	36,889–38,754	36,737–38,067
Feed pressure (bar)	66.69–67.24	66.81–67.01	66.84–67.62	66.72–67.30
Feed temperature (°C)	22.7–23.4	28.3–31.2	27.4–33.3	25.5–29.8
Permeate pressure (bar)	10.1–11.0	11.2–11.8	8.9–11.4	7.3–8.5
Salt rejection	0.9475–0.9489	0.9514–0.9522	0.9565–0.9590	0.9643–0.9662
The number of data (n)	15	9	26	20

* C_{Feb}, C_{May}, C_{Aug}, and C_{Nov} represent operating conditions in February, May, August and November, respectively.

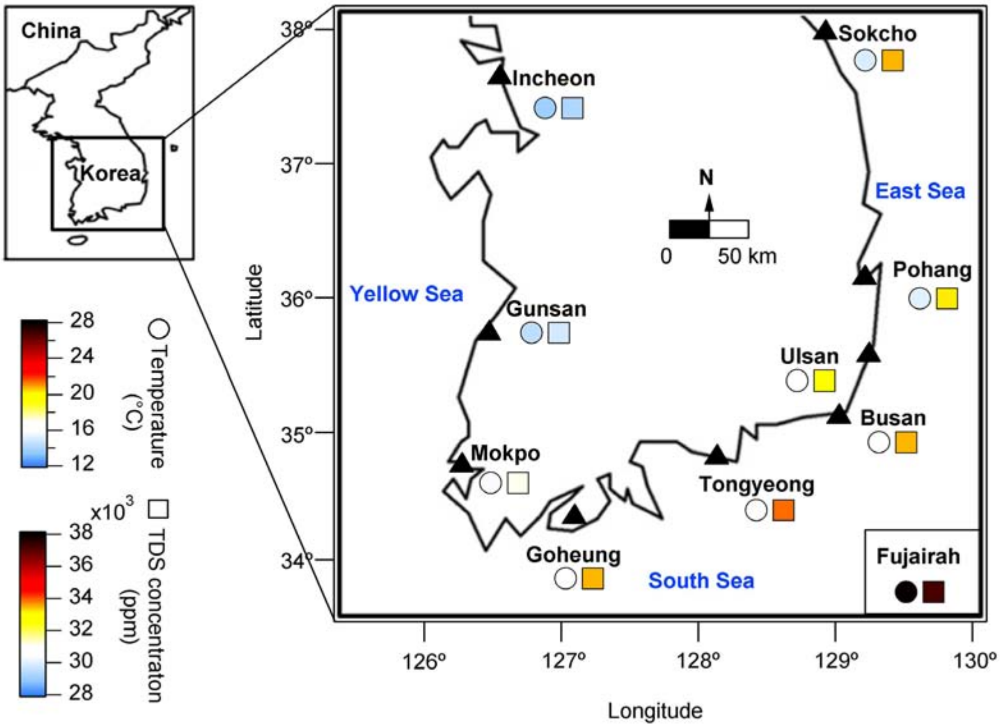

Fig. 1. Annual averages of temperature and TDS concentration at 9 candidate sites along the shoreline in Korea.

Table 3
Description of feed water intake conditions at 9 candidate sites in Korea for 4 months

Sites	Seasonal condition	C_{Feb}		C_{May}		C_{Aug}		C_{Nov}	
		Temperature (°C)	TDS (ppm)	Temperature (°C)	TDS (ppm)	Temperature (°C)	TDS (ppm)	Temperature (°C)	TDS (ppm)
Yellow Sea	Incheon	1.0–2.6 (1.6)*	31,505	13.5–17.5 (15.2)	30,586	23.5–26.0 (24.6)	25,327	10.2–16.6 (13.3)	29,767
	Gunsan	1.8–4.0 (2.8)	29,304	13.8–19.0 (16.0)	29,829	24.0–27.4 (25.7)	29,239	9.6–16.6 (13.1)	30,884
	Mokpo	2.9–4.8 (3.9)	30,850	14.5–19.0 (16.6)	32,622	25.2–28.0 (26.2)	28,313	13.2–18.5 (16.1)	32,795
South Sea	Goheung	4.1–6.2 (4.7)	34,036	16.2–19.5 (17.4)	33,936	25.4–28.9 (26.8)	32,980	11.1–17.2 (14.3)	32,981
	Tongyeong	6.2–7.9 (6.9)	34,211	16.4–19.9 (18.1)	34,637	23.8–26.8 (25.0)	33,335	13.8–18.4 (16.1)	33,132
	Pusan	9.2–10.5 (9.8)	34,084	15.1–17.2 (16.1)	33,172	19.1–26.6 (23.0)	33,228	14.9–18.7 (16.8)	33,375
East Sea	Ulsan	8.9–10.8 (10.0)	33,360	14.6–17.3 (15.9)	33,460	18.0–27.1 (23.1)	32,341	12.5–16.5 (14.9)	32,504
	Pohang	5.5–8.4 (7.1)	33,669	14.5-18.4 (16.1)	33,605	20.5–27.3 (24.6)	32,722	10.2–14.5 (12.8)	32,717
	Sokcho	7.2–9.0 (8.0)	33,430	11.1–15.7 (15.2)	33,950	22.3–25.4 (23.8)	32,941	10.7–15.8 (13.3)	33,520

*The number in parentheses indicates average temperature of each site and month.

those of Fujairah of 4 months in 2005. Among the 9 candidate sites from Korea, data in Incheon show the lowest values in both TDS concentration and temperature. Especially, the decrease of TDS concentration of Incheon and Mokpo in August is prominent as compared with that of other sites.

3. A practice of total annual profit estimation and profit ratio

A package model for calculating the TAP of a SWRO desalination plant in Korea consists of 3 sub-models, that is, RO membrane model, RO module model, and cost estimation model. Firstly, input data such as operating data (i.e, feed flow rate, feed TDS concentration, feed pressure, and feed temeprature, permeate pressure, and salt rejection), system configuration (i.e., 7 elements per vessel, 136 vessels per train, and total 17 trains), and process parameters (i.e., physicochemical properties) are applied to calculate the process performances (i.e., flow rate and permeate concentration). Then, both total cost and TAP of the process are estimated, considering the operating cost of pump and energy recovery device (ERD). A more detailed model description and methodology can be found elsewhere [4]. In this paper, profit ratio (PR) which is defined by the ratio of potential TAP of one of 9 candidate sites to that of Fujairah SWRO plant, is introduced to examine a reasonable TAP range for a new construction project of SWRO desalination plant in Korea. For a control value of comparison, the identical water price in Fujairah is applied to the 9 candidate sites for estimating TAP with respect to a site-specific change of feed water condition (i.e., temperature and salinity).

4. Results and discussion

The cost estimation package model used in this study was already developed base on the experimental data from 2003 to 2007 of the Fujairah plant in the literature [4]. The model including empirical values (i.e., *A* and *B* that reflect membrane property) showed high accuracy for simulating the performance of Fujairah SWRO plant. Therefore, the cost estimation model with the estimated empirical values (A and B) in the literature was applied to calculate the TAP for 9 candidate sites along shoreline in Korea. Data in four months (i.e., February, May, August,

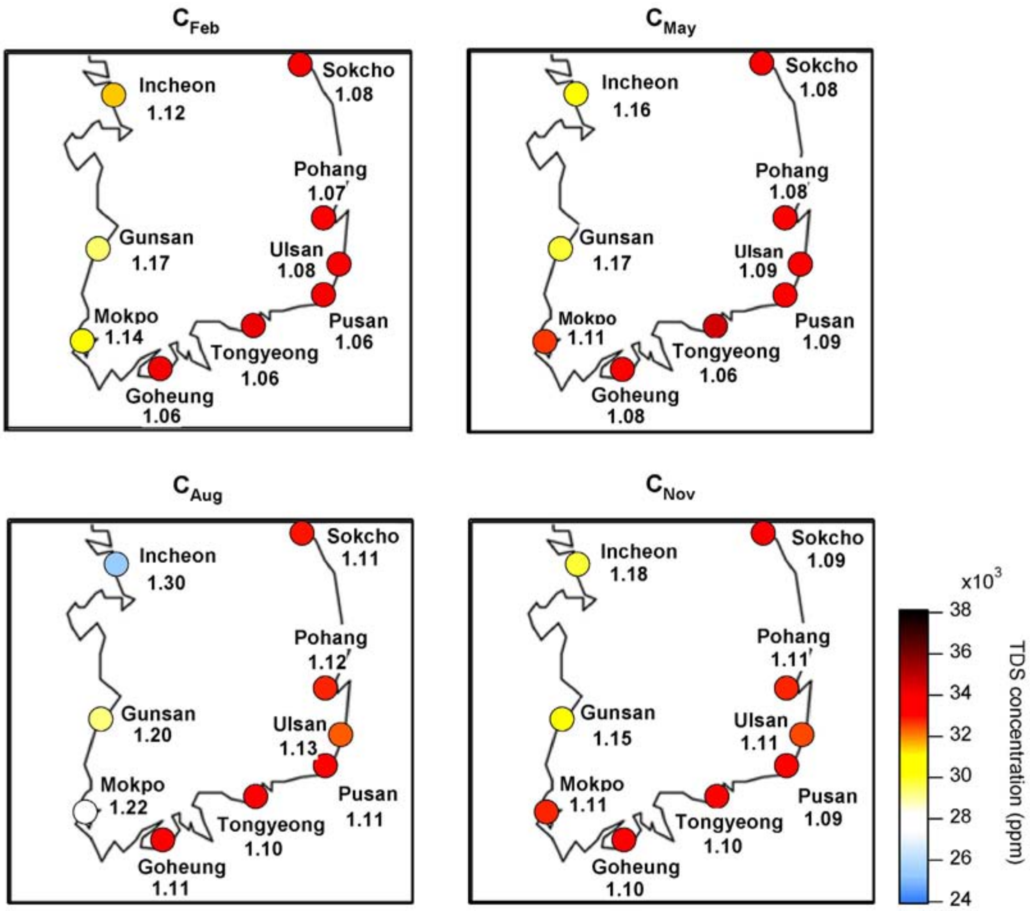

Fig. 2. Seasonal difference of profit ratio of 9 candidate sites in Korea. Here, pretreatment cost for 9 candidate sites in Korea was assumed to be identical with that of Fujairah plant.

and November) collected from the operating data of Fujairah SWRO plant in 2005 were used for comparing with data of 9 candidate sites. In this study, it is considered that each month is assumed to be a representative season, i.e., February for winter; May for spring; August for summer; November for autumn.

For the results in Fig. 2, PRs in four different operating conditions (i.e., C_{Feb}, C_{May}, C_{Aug}, and C_{Nov}) were calculated. It is shown that the change of PR adjacent to Yellow Sea (i.e., Inchoen, Gunsan, and Mokpo) was fluctuated according to the seasonal variation. On the other hand, the PRs of other candidate sites would not be significantly influenced by seasonal variation. PRs at Inchoen, Gunsan, and Mokpo on August are relatively higher than other months because of high temperature and low TDS concentration. It can be explained by an influence of storm water runoff from inland watershed during the monsoon season in summer (i.e., August). Especially, the PR of Inchoen was considerably high comparing to other sites during this monsoon season. It implies that considerable amount of freshwater usually flowed from the Han River watershed during the rainy season, resulting in dilution of salty water in Incheon which is located near the river mouth.

Table 4 shows average PR of 9 candidate sites in Korea compared with Fujairah SWRO plant. 9 candidate sites have 10–20% higher PR than Fujairah SWRO plant indicating positive possibility of economic advantage, and especially the candidate sites adjacent to Yellow Sea (i.e., Inchoen, Gunsan, and Mokpo) have relatively higher PR than other sites. Based on the results, Incheon might be recommended as a best site for a new construction project of SWRO desalination plant in Korea. However, there are several limitations in this study as follows; Firstly, the TAP was calculated without considering other seawater properties (e.g., pH, turbidity) and it was done only considering temperature and salinity. Turbidity of the candidate sites along the shoreline of Yellow sea is usually higher than that of other shorelines in Korea; Next, since this study did not consider the site-specific variation of pretreatment cost (i.e., Pretreatment cost for 9 candidate sites in Korea was assumed to be identical with that of Fujairah plant), it is ideally considered that the sites in Yellow Sea, where salinity is relatively low, might have high potential TAP than other sites.

Table 4
Average profit ratio of 9 candidate sites in Korea compared with Fujairah SWRO plant

Sites		PR
Fujairah		1.00
Yellow Sea	Incheon[a]	1.21[b]
	Gunsan	1.17
	Mokpo	1.15
South Sea	Goheung	1.09
	Tongyoeng	1.08
	Pusan	1.09
East Sea	Ulsan	1.10
	Pohang	1.10
	Sokcho	1.09

[a]Pretreatment cost for 9 candidate sites in Korea was assumed to be identical with that of Fujairah plant.
[b]Profit Ratio (PR) represents the ratio of potential TAP of one of 9 candidate sites to that of Fujairah SWRO plant.

5. Conclusions

Total annual profits (TAP) estimation of SWRO desalination plant was performed to examine a feasibility of 9 candidate sites in Korea, based on TAP estimation of Fujairah SWRO plant. It has been studies that the TAP of 9 candidate sites is significantly related to the regional seawater characteristics, especially to TDS concentration and temperature. Therefore, the result in this paper reflects that an adopting the methodology as well as a practice of the cost estimation model can open a way to propose a reasonable range of TAP for a new construction project of SWRO desalination plant in Korea. The framework in this study, however, should be upgraded to build more accurate cost estimation model considering more system factors affecting total cost (e.g., seawater compositions, fouling rates, electricity rates, etc) for analyzing TAP of SWRO plant systematically.

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References

[1] S.A. Kalogirou, Seawater desalination using renewable energy source, Progr. Energy Combust. Sci., 31 (2005) 241–281.
[2] B.Van der Bruggen and C.Vandecasteele, Distillation vs. membrane filtration: Overview of process evolutions in seawater desalination. Desalination, 143 (2002) 207–218.
[3] S. Kim, D. Cho, M.S. Lee, B.S. Oh, J.H. Kim and I.S. Kim, SEAHERO R&D program and key strategies for the scale-up of a seawater reverse osmosis (SWRO) system, Desalination, 238 (2009) 1–9.
[4] Y.M. Kim, S.J. Kim, Y.S. Kim, S. Lee, I.S. Kim and J.H. Kim, Overview of systems engineering approaches for large scale seawater desalination plant with reverse osmosis network, Desalination, 238 (2009) 312–332.

[5] P. Glueckstern, Cost estimation of large RO systems, Desalination, 81 (1991) 49–56.
[6] M.K. Wittholz, B.K. O'Neill, C.B. Colby and D. Lewis, Estimating the cost of desalination plants using a cost database, Desalination, 229 (2008) 10–20.
[7] M. Wilf, ed., The Guidebook to Membrane Desalination Technology. Elsevier, The Netherlands, 2007.
[8] T.J. Larson and G. Leitner, Desalting seawater and brackish water: A cost update, Desalination, 30 (1979) 525–539.
[9] M.A. Sanz, V. Bonnelye and G. Cremer, Fujairah reverse osmosis plant: 2 years of operation. Desalination, 203 (2007) 91–99.
[10] S.J. Kim, Y.G. Lee, K.H. Cho, Y.M. Kim, S. Choi, I.S. Kim, D.R. Yang and J.H. Kim, Site-specific raw seawater quality impact study on SWRO process for optimizing operation of the pressurized step, Desalination, 238 (2009) 140–157.