Membrane and Water Treatment, *Vol. 12, No. 4 (2021) 177-185*
https://doi.org/10.12989/mwt.2021.12.4.177

Cost analysis and scheduling of the desalination vessel using reverse osmosis technology

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(Received April 29, 2021, Revised June 22, 2021, Accepted June 30, 2021)

Abstract. Water scarcity issue becomes severe due to climate change and increase of water needs, globally. In order to provide fresh water in islands, small-scale desalination plants (< 100 m^3/day) had been installed using reverse osmosis technology. To decrease high desalination cost of small-scale SWRO plants in islands in Republic of Korea, the desalination vessel having RO system (300 m^3/day) was recently suggested. The desalination costs of the small-scale SWRO plants in islands and desalination vessel which can provide desalinated water to several islands were analyzed and were compared. The operational schedule of the desalination vessel in Shinan-gun, Republic of Korea was suggested considering the water demands, velocity and water storage of the desalination vessel, and distances between target islands. It was found that the water production cost could be saved when the desalination vessel was applied in Shinan-gun, Republic of Korea.

Keywords: cost analysis; desalination vessel; reverse osmosis (RO); small-scale desalination; vessel routes

1. Introduction

The climate change occurring has been caused the water scarcity globally. In Republic of Korea, the water shortage has been happened severely for the coastal areas and islands (Park *et al.* 1997) because precipitation could be the only possible water source and water storage system is not sufficient (Yang *et al.* 2020). The southeastern islands group (Sinan-gun) in Republic of Korea have been experienced severe drought these years (The KoreaTimes 2017) and the government had to provide the bottled drinking water to the islands by helicopter or ferry for emergency. As an alternative water source in islands, submarine pipeline to transport tap water and small-scale desalination process based on the reverse osmosis (RO) have been applied in Republic of Korea. The RO process is the cheapest and the most commonly applied (112 plants out of 331 desalination plants in the world) desalination technology among the thermal (multi-stage flash (MSF) and multi effect distillation (MED)) or membrane (seawater RO (SWRO) and brackish water RO (BWRO)) desalination technologies (Shemer and Semiat 2017, Wittholz *et al*. 2008). However, only near islands (up to several km distance from the mainland) have been connected with the submarine pipeline due to its high cost of the construction and small-scale desalination process required high cost due to frequent maintenance and membrane replacement resulted from intermittent operation. The fouled RO membrane could be cleaned or reused in other membrane purposes to decrease the replacement cost (Ng *et al*. 2020, Jung *et al*. 2021).

A mobile floating desalination system (vessel having desalination plant on it) has been employed to provide the drinking water for people in the isolated islands. It was utilized as a temporary water supplying solution in Saudi Arabia in 2009, Cypriot in 2008 and Thailand in 2006 at the meantime of the permanent land-based desalination plants were under construction (Kokubun 2014). In addition, a fully seagoing desalination vessel carrying two 1,250 m^3/day multi-stage flash (MSF) distiller was implemented to provide water for the towns along the coast and on the islands in Abu Dhabi Emirate (Fadel *et al*. 1983). 120,000 m3 per day desalinated water were produced on the mobile desalination vessels on Algeria to provide the fresh water to the human living at the ports and towns on the shores of arid areas and deserts with hot and dry climatic weather. Similarly, a mobile floating desalination plant (Preussag conversion system, PCS) of 50,000 m^3/day was implemented to provide potable water to the arid coastal regions in Germany (Lampe *et al*. 1997). The mobile plant employed SWRO (20,000 m^3/day) to supply potable water to Limassol city and surroundings in Moni, Cyprus (Gasia-Bruch *et al*. 2011).

The desalination vessel can provide the water flexibly to the various water demanders in the isolated islands because the vessel can produce water during its locating or moving then deliver water to the islands upon request as well as move to escape the disasters like hurricane and immediate come back to supply water. In addition, a desalination vessel shows some advantages in comparison to the conventional land-based installations on each site, such as

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ISSN: 2005-8624 (Print), 2092-7037 (Online)

Appendix

Table S1 Collected capital costs of the SWRO system

Name of the component	Spec.	Unit price ($)	No. of required component or equation for cost according to the desalination capacities (m^3/day)							Price source
			10	30	50	100	200	300	500	
RO element	SWRO 4 (inch) × 40 (inch), water production: 7 m^3/day/element	500	2	6	8	16	32	45	72	Dow, USA
RO vessel for 2 elements	1,000 Psi vessel	500	1	0	0	0	0	0	0	Pentair Codeline, USA
RO vessel for 3 elements	1,000 Psi vessel	600	0	2	0	0	0	15	0	
RO vessel for 4 elements	1,000 Psi vessel	700	0	0	2	4	8	0	18	
RO skid (small)	SUS316L	450	1	1	0	0	0	0	0	Quotation from domestic company, Korea
RO skid (big)	SUS316L	900	0	0	1	2	4	5	9	
High pressure pump	Flow rate: 5.6 m^3/hr	15,000	1	1	1	2	4	5	9	Grundfos, Denmark
Monitoring devices - electrical conductivity meter	Seawater	1,300	3	3	3	3	3	3	3	Horiba, Japan
Monitoring devices - pressure gauge	Seawater	700	2	2	2	2	2	2	2	Newark Electronics, USA
Monitoring devices - flowmeter	Seawater	500	3	3	3	3	3	3	3	Flowtech, India
Cartridge filter	Flow rate: 8 m^3/hr	1,600	1	1	1	2	4	5	9	Quotation from domestic company, Korea
Chemical units - chemical pump	Chemical	600	3	3	3	6	12	15	27	Marco, USA
Chemical units - chemical tank	Chemical	100	3	3	3	6	12	15	27	Enduramaxx, UK
Tank	1 m^3	150	2	0	0	0	0	0	0	Dezhou Huili Environmental Tech., China
	2 m^3	150	2	2	0	0	0	0	0	Hengshui Jinghua Trading Company, China
	5 m^3	600	0	2	2	0	0	0	0	Hebei Dongding Chemical Trade Company, China
	10 m^3	1,000	0	0	2	2	0	0	0	Qingdao Dejun Environment Tech., China
	20 m^3	2,000	0	0	0	2	2	0	0	
	30 m^3	3,000	0	0	0	0	0	2	0	
	40 m^3	4,000	0	0	0	0	2	0	0	
	50 m^3	5,000	0	0	0	0	0	0	2	
	60 m^3	4,800	0	0	0	0	0	2	0	
	100 m^3	8,000	0	0	0	0	0	0	2	
Pipes and angles	SUS316L	19,000	1	1	1	2	4	5	9	Quotation from domestic company, Korea
Pre-treatment - media filtration	10-30 m^3/day	5,000	1	1	0	0	0	0	0	
Pre-treatment - media filtration	50 m^3/day	5,200	0	0	1	2	4	5	9	
Post - treatment	Cost ($) = 75 ($/m^3/day) × desalination capacity (m^3/day)									Birnhack *et al*. 2011
Brine disposal	Cost ($) = 0.175 ($/m^3) × produced brine (desalination capacity (m^3/day) × 365 (day))									Panagopoulos *et al*. 2019
Infra - structure	Cost ($) = 1.55 ($/m^3/day) × desalination capacity (m^3/day)									Hafez and El-Manharawy, 2002
Professional and financing	Cost ($) = 0.28 ($/m^3/day) × desalination capacity (m^3/day)									Hafez and El-Manharawy, 2002
Intake	Cost ($) = 130 ($/m^3/day) × desalination capacity (m^3/day)									WRA, 2012