A Feasibility Study of Optimal Nuclear Desalination Process for Industrial Water Supply in Korea

Hyun-Chul Park, Ki-In Han
KEPCO International Nuclear Graduate School, Ulsan, Republic of Korea
Corresponding author: *ptmaster@kepco.co.kr*

1. Introduction

A severe shortage of fresh water is an important factor in inhibiting regional economic development. Continued shortages resulting from exhaustion and/or pollution of existing water supplies could lead to a general decline in the quality of life and development of local industries. Seawater Desalination can be an alternative technology for water production based on salt separation from seawater. Seawater desalination can produce freshwater with necessary quality by choosing an appropriate desalination process and post-treatment methods of the product water. The commercial seawater desalination processes which are proven and reliable for large scale freshwater production are MSF and MED for evaporative desalination and RO for membrane desalination. Vapor compression plants based on thermal and mechanical compression are also employed for the small and medium capacity ranges.

The aim of this study is to compare the characteristics and cost of each process methods and suggest the most efficient and effective method of desalination for an industrial water supply to the National Industrial Complex nearby Nuclear Power Plant.

2. The Characteristics of Desalination Process

Traditionally, the use of multi-stage flash(MSF), multi-effect distillation (MED), electrodialysis(ED), and reverse osmosis (RO) process has received significant attention to improve the reliability and the performance of freshwater production processes. A wide variety of desalination technologies effectively remove salts from salty water (or extract fresh water from salty water), producing a water stream with a low concentration of salt and another with a high concentration of remaining salts.

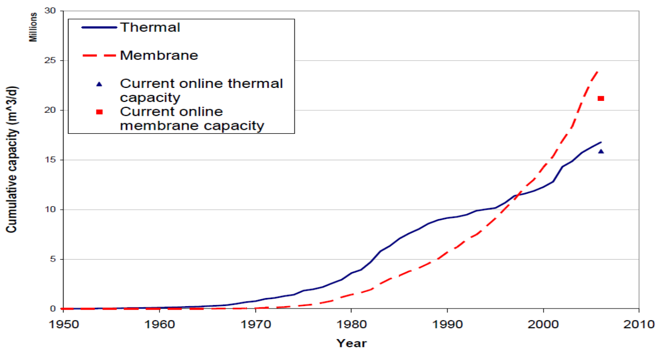


Fig1. The comparison of power generation capacity of Distillation & RO method[4]

Comparing with distillation process, Fig1 shows RO process is rapidly increasing due to lower energy consumption and environmentally friendly management. The comparison of the characteristics of each process is shown in Table 1[2]. At this table, electrodialysis(ED) is not considered to apply seawater to the desalination process by table 2,3[2]

Table 1. Summary of characteristics of major desalination technologies

Characteristics	Reverse osmosis (RO)	Multistage flash (MSF)	Multiple-effect distillation (MED)
Energy cost	Moderate	High	Very high
Energy/Salinity	Increases with salinity	Independent of salinity	Independent of salinity
Applicable to	All water types	Seawater -brine	Seawater - brine
Plant size	Modular	Large	Large
Bacterial contamination	Possible	Unlikely	Unlikely
Final product salinity	On demand	Can be <10 mg/L TDS	Can be <10 mg/L TDS
Complexity	Easy to operate; small footprint	Only large complex plants	Only large complex plants
Susceptibility to scaling	High	Low	Low
Recovery	30–50% (seawater) up to 90% for brackish water	Poor (10–25%)	Low but better than MSF

Table2.water concentration & operating temp of each sea water desalination process

Desalination type	Concentration (TDS ㎎/ℓ)	Operating temp (℃)
Distillation	30,000 ~ 500,000	35 ~ 120
Reverse osmosis (RO)	500 ~ 50,000	0 ~ 40
Electrodialysis(ED)	500 ~ 3,000	0 ~ 65

Table3. Applied Sea water Desalination Method of each water quality

Desalination type	Brackish water		Sea water (35,000 ppm)	Condensed waste water (Brine)
	0-3,000(ppm)	3,000-10,000(ppm)		
Distillation	V	△	○	○
Electrodialysis	○	△	V	○
Reverse osmosis	○	○	○	△
Ion exchanged	○	-	-	-

* ○ : Prior application, △ : applicable, V : applicable, but non-economical

2. Methodology

The economic evaluation of desalination process is shown, comparing the unit cost of each desalination process by using each Nuclear Power Plant's (Kori, Wolsung, Youngkwang, Uljin) water usage, initial investment and O&M cost data. And The DEEP computer model developed by IAEA is also used to calculate the cost including the various technical and economic outputs. The status of water usage of nuclear power plants in Korea is shown in Table 4. [2]

Table2. The status of water usage of Nuclear Power Plant in Korea

(Unit : m³/day)

Nuclear Power Plant		Capacity (MW)	Water (Power Generation)	Water (Non Power Generation)	Others	Total
Kori Unit(1~4)	Average(Day)	3,140	1,588	2,361	1,019	4,968
	Maximum(Day)		4,389	4,313	2,800	11,502
Uljin Unit(1~4)	Average(Day)	3,950	2,679	1,274	961	4,914
	Maximum(Day)		6,057	2,238	1,806	10,101
Wolsung Unit(1~4)	Average(Day)	2,805	1,308	376	2,568	4,252
Youngkwang Unit(1~4)	Average(Day)	3,920	1,959	2,862	1,137	5,958

4. Results

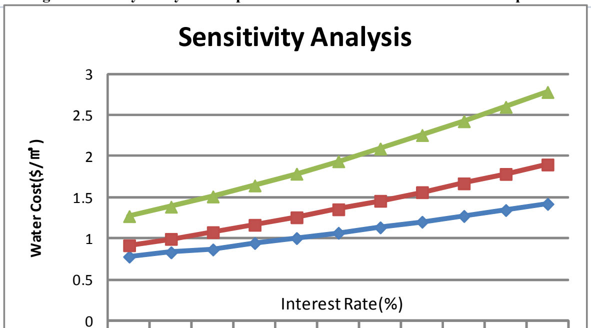
As shown in Table 5[2], RO process is the more economical than distillation process. As for the water usage of reservoir or river nearby nuclear power plants, the economic feasibility is low with a high level of water charge during 30 years of operation. And also, in comparison with the cost of sea water desalination equipment, it doesn't have a big difference. However, a stable industrial water supply will be difficult by a bad weather condition with the water shortage. For RO process, it can overload pure water treatment equipment a little bit with a lot of ion, In terms of equipment and operation costs, RO has a good economical advantage. For desalination equipment, distillation's cost is lower than that of RO process. However it should make excessive electric power costs, so its economic feasibility is low. Fig2 shows the comparison of the cost of each process by using DEEP program, in terms of O&M and total water cost. In this model, IR(5%) is applied and total water costs are derived .

Fig2. The comparison of O&M, operating and total water cost of each process

Operating Costs of Desalination Plant	MSF	RO	Total (M$)	Specific ($/m3)	Share
Energy Costs					
Heat cost	-		-	-	0%
Backup heat cost	-		-	-	0%
Electricity cost	-	0.5	0.5	0.16	32%
Purchased electricity cost	-	0.1	0.1	0.03	5%
Total Energy Costs	-	1	1	0.19	37%
Operation and Maintenance Costs				-	0%
Management cost	-	-	0.13	0.04	8%
Labour cost	-	-	0.27	0.08	16%
Material cost	-	0.58	0.6	0.18	35%
Insurance cost	-	0.07	0.1	0.02	4%
Total O&M cost	-	1	1	0.32	63%
Total Operating Costs	-	1	2	0.50	
Total annual cost				2.56	M$
Water production cost				0.780	$/m³
Water Transport costs				-	$/m³
Total water cost				**0.780**	**$/m³**

Operating Costs of Desalination Plant	MSF		Total (M$)	Specific ($/m3)	Share
Energy Costs					
Heat cost	2		2	0.60	62%
Backup heat cost	-		-	-	0%
Electricity cost	0.4	-	0.4	0.12	12%
Purchased electricity cost	-	-	-	-	0%
Total Energy Costs	2	-	2	0.72	74%
Operation and Maintenance Costs				-	0%
Management cost	-	-	0.13	0.04	5%
Labour cost	-	-	0.27	0.09	9%
Material cost	0.3	-	0.3	0.09	9%
Insurance cost	0.1	-	0.1	0.02	2%
Total O&M cost	0	-	1	0.25	26%
Total Operating Costs	2	-	3	0.96	
Total annual cost				3.76	M$
Water production cost				1.271	$/m³
Water Transport costs				-	$/m³
Total water cost				**1.271**	**$/m³**

Fig3. Sensitivity Analysis Comparison between IR & Water Cost of each process



	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
RO	0.78	0.832	0.866	0.944	1.005	1.069	1.135	1.203	1.274	1.346	1.421
MED	0.917	0.994	1.077	1.165	1.258	1.355	1.457	1.562	1.671	1.784	1.9
MSF	1.271	1.386	1.511	1.645	1.787	1.937	2.093	2.256	2.424	2.599	2.78

Fig3 shows the sensitivity analysis between interest rate (%) & water cost ($/m^3) of each process. From the result of the sensitivity analysis, an interest rate is shown to be the influential factor to the water cost. When an interest rate is increased, we can find out that the water cost between RO and MSF have a big difference especially range from 10% to 15%.

Table5. The economic feasibility comparison of industrial water of each process (for 30 years)

(Unit : Half billion won)

classification		River (Reservoir)	Distillation (A type)	Distillation (B type)	RO (A company)	RO (B company)
Capacity(m³/day)		10,000	10,000	10,000	10,000	10,000
Initial investment cost	Industrial water supply equipment	38.4	-	-	-	
	Raw water treatment equipment	12	-	-	-	
	pure water treatment equipment	75.6	53.1	52.9	75.6	75.6
	construction cost of water treatment equipment	82	82	82	82	82
	Desalination equipment	-	359	127	202.8	172.2
	Waste water treatment equipment		8.3	8.3	13.9	13.9
	Sea water supplier	-	5.6	5.6	5.6	5.6
	Sea water reservoir	-	2.1	2.1	2.1	2.1
	Sea water filtering tank	-	1	1	1	1
	Sea water piping		9.9	9.9	9.9	9.9
Total initial investment cost		208	520.9	288.9	362.3	392.9
Water charge		270.8	-	-	-	-
Electric power cost		266.7	231.1	351.7	116.9	116.9
Labor cost		24.3	24.3	24.3	24.3	24.3
O&M		57.2	125.2	125.2	171.3	171.3
Chemical agent cost		87.1	116.8	116.8	147.4	147.4
Waste water cost		31.7	56.2	56.2	94.4	94.4
Total economic feasibility cost		945.8	1,072.00	960.3	915.5	946.1

* 1. Estimated the annual cost based on water cost data by K-water in 2007
2. Estimated the annual labor cost (1 work / 4 men power)

5. Conclusion

The costs associated with desalination depend on many factors such as capital, energy, labor, chemicals that are specific to the location, plant capacity, product salinity pre-treatment necessities, and other site-related costs for land, plant and brine disposal. A detailed analysis of each situation is thus required to estimate desalination costs. It could be stated that RO cost is lower than distillation one in energy and environmental terms. The optimal capacity(10,000 m³/day) was decided to analyze the estimated water usage in nuclear power plants. And then compared the availability of each process, energy consumption, O&M and economic aspects. In terms of economic feasibility study, RO is the most recommendable process in nuclear power plants in Korea.

Reference

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[3] "Aly Karameldin", Atomic Energy Authority of Egypt, "Nuclear Technology and Water Desalination"

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