

Evaluation of seasonal performance for single-effect desalination system with solar energy

Hee-youll Kwak¹, Hong-jin Joo², Jeong-bae Kim³ and Won-gee Chun⁴

¹Solar Thermal Research Center, KIER(Korea Institute of Energy Research, Daejeon, Korea, hykwak@kier.re.kr

²Solar Thermal Research Center, KIER(Korea Institute of Energy Research, Daejeon, Korea, joo@inhain.net

³Department of Energy system engineering, Chungju National University, Chungju, Korea, jeongbae_kim@cjnu.ac.kr

⁴Department of Energy engineering, Cheju National University, Cheju, Korea, wgchun@cheju.ac.kr

ABSTRACT: This study was carried out to evaluate the seasonal performance for the decentralized desalination system with the solar thermal system and the photovoltaic power system.

Firstly, the demonstration system was set up at Cheju-island in 2006. These systems were comprised of the desalination unit with daily fresh water capacity designed as 2 m³, a 120 m² evacuated tubular solar collector to supply the heat, a 6 m³ heat storage tank, and a 5kW photovoltaic power generation to supply the electricity of hydraulic pumps for the working fluids.

In spring, solar irradiance daily averaged was measured 392W/m², the daily fresh water yield showed that can be produced about 340liter. In summer, solar irradiance daily averaged was measured 296W/m², the daily fresh water yield showed that can be produced about 328liter. In autumn, solar irradiance daily averaged was measured 349W/m², the daily fresh water yield showed that can be produced about 277liter. Finally, in winter, solar irradiance daily averaged was measured 342W/m², the daily fresh water yield showed that can be produced about 271liter.

Keywords: Desalination system, Evacuated tubular solar collector, Seasonal performance, Single-effect fresh water generator

1. INTRODUCTION

All Reverse osmosis, freezing process, and evaporation methods are often utilized to produce fresh water from seawater. Fresh water generators based on the reverse osmosis method consist of complicated structures, have high manufacturing costs, and are difficult to operate. In purifying seawater, they are not economically feasible

because of their great expense and frequent need to replace membranes due to the impurities and high turbidity of seawater. Regarding the freezing process method, it minimizes the heat transfer between the desalination system and the environment to separate sea water attached to ice. The evaporation method has been widely used on ships to purify waste water because it consists of relatively simple and inexpensive

structures, and the machines are easy to operate.

A low-pressure evaporation method can achieve high levels of performance due to its relatively high evaporation velocity, and can be developed as a small capacity fresh water generator due to the low amount of energy consumed. The low evaporation temperature can be reduced through maintaining the vacuum pressure below atmospheric pressure inside the chamber by operating a vacuum pump or ejector. However, heat is required to make fresh water from sea water. Part of the sea water injected into the generator is evaporated, and then the evaporated steam is condensed into water through a heat transfer process with the cold seawater to obtain freshwater. Non-evaporating brine accumulates in the bottom of the generator and is discharged into the environment using a pump or ejector.

Huyghe et al. [1] observed that low-pressure evaporation phenomena were related to the gas concentration in the water during rapid low-pressure experiments. Bourouni et al. [2] experimentally showed the relationship between the flow rate or temperature of the heat source and the operating conditions of a blower used to deliver the evaporated vapour. They attached two tanks to a bare tube to use as an evaporator and condenser, and sprayed seawater into the tube of the evaporator using a nozzle. The sea water was heated by a heat source and condensed by cold seawater in the condenser. The evaporated vapour was delivered to the condenser using the blower. However, it may be difficult to incorporate the characteristics of a fresh water generation system with a blower in the design of such a system based on plate heat exchangers.

Miyatake et al. [3] examined the transient characteristics and performance of a desalination system based on various heat source conditions and spray flashing. Voropoulos et al. [4] used experimental and theoretical approaches to design a

desalination system based on a solar still that made direct use of a solar thermal collector as the heat source. The basic principles of solar water distillation are simple yet effective because distillation replicates the way nature creates rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is water cleaner than the purest rain water. The still is a passive solar distiller that only requires sunshine to operate and does not have any moving parts.

Joseph et al. [5] designed a single-stage solar desalination system for domestic utilization that could obtain a daily maximum yield of 8.5 L of potable water with a collector area of 2 m². The experimental system consisted of a flat plate collector, a single-stage vacuum pump, an evaporator, and a condenser. Two heat exchangers were separately installed inside two tanks. The input parameters such as the solar irradiance and vacuum pressure in the flash evaporator were varied to determine their influence on the performance output with regard to the system efficiency and yield per day. Moon and Jung [6] used a simulation to determine the performance of a double-effect fresh water generation system with two serial fresh water generators based on the low-pressure evaporation method.

In this study, we used a solar thermal system as heat source of the single-effect fresh water generator with plate-type heat exchangers and a photovoltaic power system as electric source of hydraulic pumps. The demonstration system was designed and installed at Cheju-island in 2006. The system was comprised of the desalination unit with daily fresh water capacity designed as 2 m³, a 120 m² evacuated tubular solar collector to supply the heat, a 6 m³ heat storage tank, and a 5kW photovoltaic power

generation to supply the electricity of hydraulic pumps for the heat medium fluids. Through the operation during about 2 years, this study was analyzed the seasonal performance of the demonstration system for solar energy desalination in Korea.

2. SOLAR ENERGY DESALINATION SYSTEM

The demonstration system was consisted of the solar thermal system to make the heat for the evaporation of sea water, the photovoltaic system to make the electricity, the fresh water generator, and remote control and monitoring system.



Figure 1: Monitoring Screen for the system.



Figure 2: Control screen for the system.

Figs. 1-2 made by LabView showed the monitoring and remote controlling screen of the system. The developed program can also showed the running state of the electric valves and pumps.

The control modes were chosen as two modes including the distributing board (installed in the mechanical room near the system) or the computers. (host computer is used for the data acquisition in the

mechanical room in Cheju, client computer was used for the remote control in Daejeon) When the interruption of electric power was happened during the system were operated under the remote control mode, the control mode was automatically changed into the distributing board mode.

And the remote control and monitoring system was carefully designed and made to accurately measure the temperatures in inlet and outlet of the pipes and flow rate of the fluids (sea water, fresh water, or hot water) that are needed to estimate the solar thermal storage, the supplied heat flow rate into the generator, and the fresh water yield.

In remote control mode by the client computer in Daejeon, the program was consisted of to easily modify the temperature difference control, the heat rejecter control and the anti-freezing control for the solar thermal system, fresh water pump control, and the salinity control of fresh water.

3. RESULTS AND DISCUSSIONS

3.1 Seasonal performance characteristics

Using the solar desalination system normally operated from Sep. 2006, this study was summarized the operating characteristics from Jan. 1. 2007 to Mar. 17. 2008. The daily solar irradiance used in this paper was averaged from sunrise to sunset.

Before the usual operation, this study was tested the system to choose the optimum operating conditions including hot water supply temperature condition. Then, this study showed that temperature of the hot water to the evaporator of fresh water generator would be supplied at 35 and stopped at 50 °C.

Fig. 3 showed the daily averaged solar irradiance and the fresh water yield during the normal operation from Jan. 1. 2007 to May. 30. 2007 and from Mar. 1. 2008 to Mar. 17. 2008 that can be considered as spring season in Korea. This study found that the daily averaged solar irradiance and the fresh water yield were measured 392

W/m^2 and about 340ℓ in those periods being considered as spring, respectively.

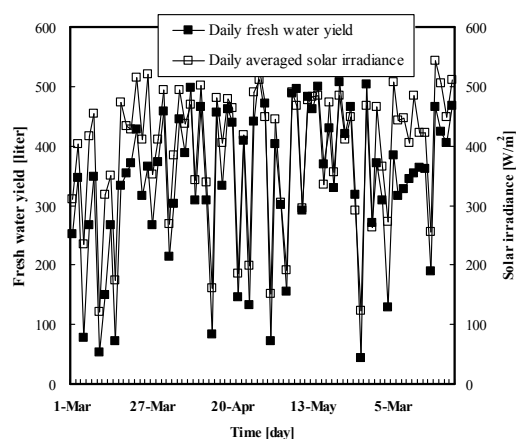


Fig. 3 The operating results in spring

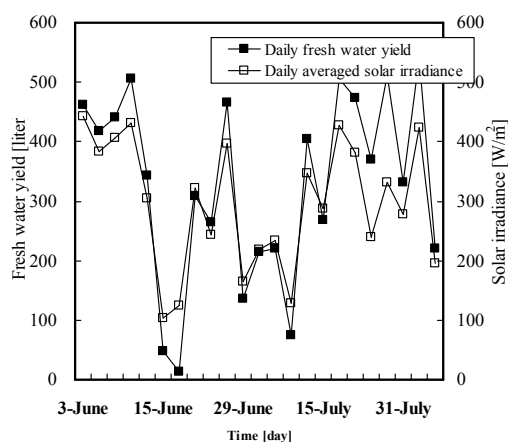


Fig. 4 The operating results in summer

Fig. 4 showed the daily averaged solar irradiance and the fresh water yield during the normal operation from Jun. 1. 2007 to Aug. 30. 2007.

This study found that the daily averaged solar irradiance and the fresh water yield were measured 296 W/m^2 and about 328ℓ in those periods being considered as summer, respectively.

The irradiance of the summer can be considered relatively lower than that of the spring season because of the relatively high-diffuse radiation by humidity and the inclined angle as 35° of solar collector.

Under the daily averaged solar irradiance of 296 W/m^2 , the fresh water yield was measured about 328ℓ. The fresh water yield

in summer was almost similar that in spring in spite of the lower solar irradiance. That can be achieved because of the relatively lower heat loss in the storage tank and the solar collector and higher sea water supply temperature in the summer season.

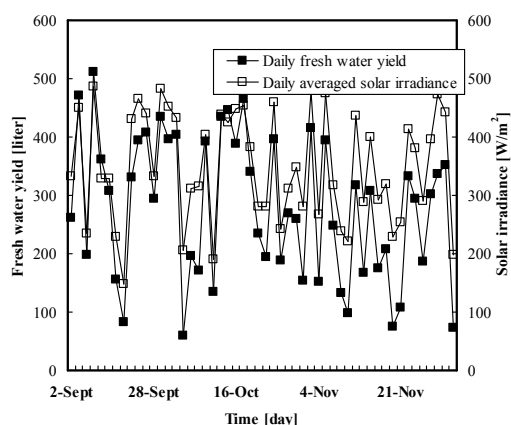


Fig. 5 The operating results in autumn

Fig. 5 showed the daily averaged solar irradiance and the fresh water yield during the normal operation from Sep. 1. 2007 to Nov. 30. 2007 that can be considered as autumn season in Korea. This study found that the daily averaged solar irradiance and the fresh water yield were measured 349 W/m^2 and about 277ℓ in those periods being considered as autumn, respectively. The fresh water yield was decreased because solar irradiance in autumn was measured as lower than that in spring at Cheju-island smaller-than-expected.

Fig. 6 showed the daily averaged solar irradiance and the fresh water yield during the normal operation from Jan. 1. 2007 to Feb. 28. 2007 and from Dec. 1. 2007 to Feb. 29. 2008 that can be considered as winter season in Korea. This study found that the daily averaged solar irradiance and the fresh water yield were measured 342 W/m^2 and about 271ℓ in those periods being considered as winter, respectively.

The solar irradiance in autumn and winter was higher than that in summer but the fresh water yield in autumn and winter was lower than that in summer, because the

heat loss was relatively decreased the according to low ambient temperature in autumn and winter and the sea water temperature was also decreased.

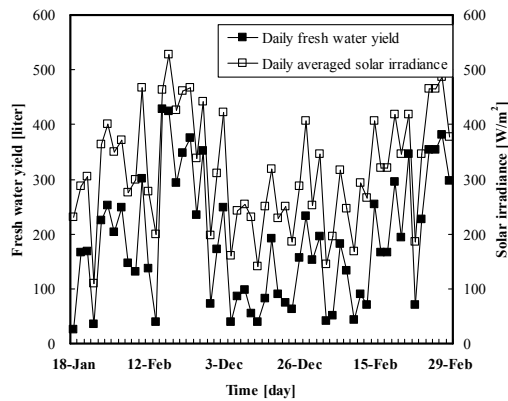


Fig. 6 The operating results in winter

Table I: The relationships between solar irradiance and fresh water yield

Season	Relationships
Spring	$y = 1.062x - 76.81$
Summer	$y = 1.3966x - 86.126$
Autumn	$y = 1.2088x - 144.99$
Winter	$y = 1.0601x - 151.83$

* x : daily averaged solar irradiance, y: fresh water yield

Table II: The fresh water yield for various daily averaged solar irradiance

Season	Daily averaged solar irradiance [W/m^2]			
	200	300	400	500
	Fresh water yield [ℓ]			
Spring	136	242	348	454
Summer	193	333	472	612
Autumn	97	218	339	459
Winter	60	166	272	378

Table I showed the relationships between the seasonal fresh water yield and the solar irradiance. And Table II showed the fresh water yield estimated by various daily averaged solar irradiance with the relationships presented in Table I.

3.2 Annual Performance characteristics

Fig. 7 showed the daily averaged solar irradiance and the fresh water yield during the normal operation from Jan. 1. 2007 to Mar. 17. 2008. As explained earlier, the daily solar irradiance presenting in this paper was averaged from sunrise to sunset.

This study found that the annual averaged solar irradiance and the fresh water yield were measured $355 W/m^2$ and about 312 ℓ in those periods, respectively.

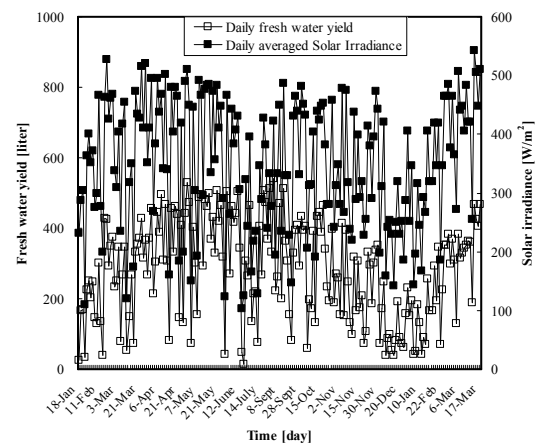


Fig. 6 Annual solar irradiance and fresh water yield

The fresh water yield was lower than the target yield expected in the collector area design of the system because the solar irradiance measured was about 20% lower than at the design condition considered as $500W/m^2$.

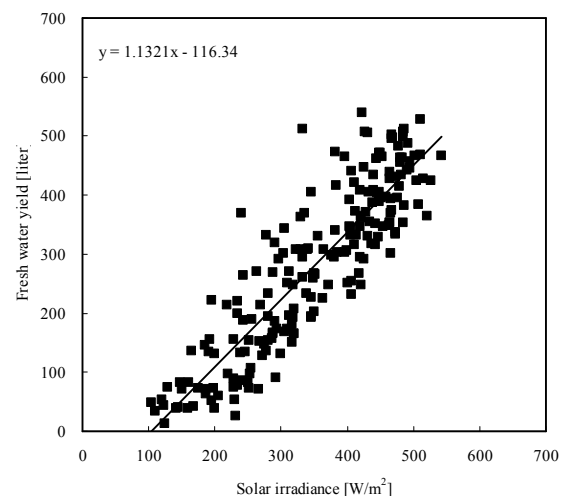


Fig. 8 The relation between solar irradiance and fresh water yield

Fig. 8 presented the relation between the daily averaged solar irradiance and the fresh water yield during the operating periods using the solar energy desalination with single-effect fresh water generator installed.

The relationship between the solar irradiance(x) and fresh water yield(y) was revealed as $y=1.1321x-116.34$. And as expected, the fresh water yield was linearly increased for higher solar irradiance.

Table III showed the solar irradiance and fresh water yield using the relationship presented in the upper paragraph.

Table III: The relation between fresh water yield and Solar irradiance

Solar irradiance [W/m ²]	200	300	400	500
Fresh water yield [ℓ]	136	241	348	450

4. CONCLUSION

This study derived the following conclusions using the independent solar energy desalination system installed the branch of KIER located in Cheju-island and operated until now from Sep. 2006.

- This study found that the annual averaged solar irradiance and the fresh water yield were measured 355 W/m² and about 312ℓ in those periods, respectively.

- The fresh water yield in summer was estimated that could be higher than other seasons because of the higher ambient and sea water supply temperature in spite of the lower solar irradiance due to the rainy season.

- The relationship between the solar irradiance(x) and fresh water yield(y) was revealed as $y=1.1321x-116.34$ for this demonstration system with single-effect fresh water generator.

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