Proceedings of the 2nd World Congress on Mechanical, Chemical, and Material Engineering (MCM'16)
Budapest, Hungary – August 22 – 23, 2016
Paper No. HTFF 149
DOI: 10.11159/htff16.149

A Novel Desalination System with Evacuated Tube Solar Collector

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Abstract – Drinking water is one of the most significant needs for sustaining human life like air. Water consumption are continuously increasing due to the rapid industrialization and growth of the world population. Clean water sources, therefore, have started to become insufficient. Especially, clean water shortages in countries with arid climate are in larger sizes. Many countries located in arid climatic zones are in contact with the sea. But salty sea water is not suitable for drinking and agricultural purposes. By desalination, sea water can be used for these purposes. The considerable part of drinking water demands can be met by this way. The history of desalination is based on very old civilization. There are various methods for obtaining drinking water from sea water by desalination. In the application of these methods, different energy resources can be used. In this study, solar energy is used as the energy source and evacuated tube solar collector is used for obtaining drinking water by a new design greenhouse type desalination system. The novel desalination system is well defined in detail in the paper. The results show that the amount of clean water obtained increases when the solar radiation increases. The maximum amount of clean water is obtained as 467 ml in one-hour period for 944,32 W/m^2 solar radiation and 27 ºC ambient temperature.

***Keywords*:** Sea water, Desalination, Greenhouse type, Solar energy, Evacuated tube

1. Introduction

The demand of fresh water is increasing day by day in the world. This demand is very important issue all over the world, especially in arid regions. Increasing depletion and contamination of existing water resources makes finding or creating new clean water sources essential. Therefore, people have utilized various methods and techniques for obtaining clean water. Desalination of sea water is one of the earliest methods and it is still a popular method throughout the world today [1]. The processes in which salt is removed from salty water to obtain fresh water for the use of drinking and irrigation purposes are called desalination [2]. Desalination technology is still evolving with different technologies and integrated with various energy sources.

Desalination processes can be driven by different energy sources. In the present desalination technique, the salt in sea water is removed by the evaporation of water and a heat source is therefore required. Intensive consumption of fossil fuels and the use of hazardous gases have resulted in fatal outcomes such as ozone layer depletion, climate change, global warming, air pollution. Fossil fuels also have high costs and difficulties in producing. Therefore, renewable energy sources should be used for both economical and environmental concerns. In this study, a novel greenhouse type desalination system assisted by solar energy is used to obtain drinking water from sea water. Sea water is heated and evaporated by using evacuated tube solar collector. The novelties in this system are the use of evacuated tube type solar collector rather than flat plate type, and the manufacturing of the main tank of the system with PVC based composite material that has high resistance to corrosion, and the application of a black colour spongy material on the bottom of the main tank to make easy to remove brine and to get more solar radiation by black surface.

2. Material and Methods

Desalination systems are generally classified in two groups as membrane and thermal methods [3]. In thermal methods, desalination system requires an energy source that can be composed of fossil fuels or renewable energy. Desalination systems using solar energy are quite common recently [4]. Solar radiation is collected by an evacuated tube solar collector and is used to evaporate the sea water in this study. In addition to the solar collector, a main tank that allows a certain amount of sea water at the bottom level to evaporate. Evaporated sea water is condensed on the glass cover of the main tank and the clean water produced is collected in a different tank. This type of desalination system is called the greenhouse type desalination system [5,6].

The main elements of novel greenhouse type desalination system are evacuated tube solar collector, main tank, sea water feed tank, clean water tank, brine tank, circulation pump and electrical heater. A certain amount of sea water is taken into the main tank in such a way that the sea water level does not exceed a certain value (about 3 cm) in order to decrease the product time of clean water. There is no need for a circulation pump in this line because circulation is provided by natural circulation due to the high level of the sea water feed tank. A capacitive sensing is applied to keep the sea water level inside the main tank constant. The solar system used in this system is a closed type heating system and thus the water heated by the solar collector rejects its heat to the sea water inside the main tank. The black spongy cover at the bottom of the main tank absorbs an additional solar radiation. The sea water inside the tank then evaporates and the vapour is lifted upward and is condensed on the cold glass cover. The condensed water moves downward due to the slope of the glass cover and collected in the chamber in front of the main tank and stored in the clean water tank. The glass cover is well joined with the main tank to prevent vapour to leak. The clean water obtained can directly be used by means of a tap located on the clean water tank. When solar radiation is insufficient, electrical heaters can be used as an auxiliary unit to evaporate for instant requirements. Brine water is collected in the brine tank and this tank is discharged if necessary. All the tanks are connected to each other with pipes. The main tank is insulated to decrease the heat losses from the edges. The main tank is made of PVC based composite material (Forex). The water passing through the solar heating system is circulating by using a circulation pump. The novel greenhouse type desalination system assisted by the evacuated tube solar collector design is shown schematically in Figure 1.

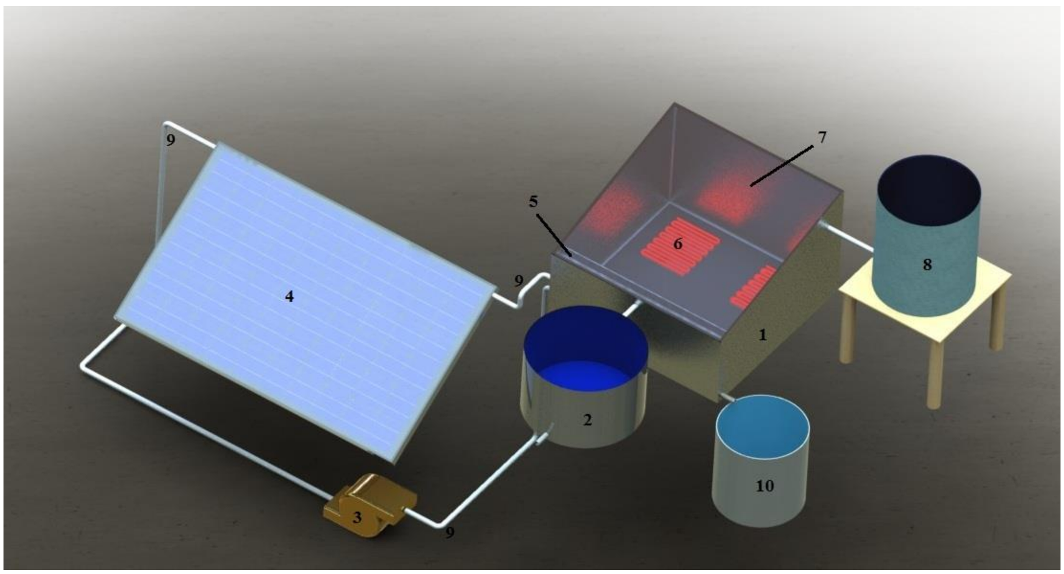

Fig. 1: Schematic of greenhouse type desalination system.

1. Main tank	6. Electric heater
2. Clean water tank	7. Glass cover
3. Circulation pump	8. Sea water feed tank
4. Evacuated tube solar collector	9. Piping
5. The condensed clean water chamber	10. Brine tank

Evaporation process reduces the level of the sea water in the main tank. Capacitive sensor can both supplies sea water to the main tank automatically and removes the water inside the main tank if the tank is overcharged. The reason for the remove of the sea water is that if the sea water in the main tank is too much, the evaporation process and production rate cannot be performed as fast as desired. Therefore, the amount of clean water obtained will be considerably reduced.

The brine in the main tank increases over time. The main tank must therefore be cleaned periodically to take away the brine from the main tank. If the brine isn't taken out from the main tank, system efficiency and tank life reduces due to corrosion. Therefore, the main tank is made of corrosion-resistant material.

The slope of glass cover must be chosen properly. If the slope is chosen so small, condensed water droplets cannot be collected in the clean water chamber. On the other hand, if this slope is chosen so high, some solar radiation can't reach to the bottom of the main tank. The slope of the glass cover is therefore chosen as 20^{o} in this study.

3. Results

A series of experiments were performed to test the experimental setup. Some views from the setup and experiments are shown in Figure 2. Measurements were made for three different days in May 2016 in an open area outside the Department of Mechanical Engineering of Akdeniz University in Antalya, Turkey. Clear weather conditions were experienced for all measurement days and solar radiation were recorded between 827 W/m^2 and 944 W/m^2. The amount of clean water obtained for one-hour periods were measured and recorded. The volume of clean water was measured by a volumetric flask with high accuracy. The measurement results are shown in Tables 1, 2 and 3 for three days seperately.

(a) (b)

Fig. 2: Experimental setup a) An overview from the experimental setup; b) A view from the experiments (Evaporation and condensation processes in the main tank).

Table 1: Measurement results for the first day (May 18, 2015).

Time Range	Hourly Solar Radiation on Sloped Surface (W/m^2)	Ambient Temperature (˚C)	Amount of the Clean Water (ml)
11:00 – 12:00	842,52	25	397
12:00 – 13:00	915,34	26	421
13:00 – 14:00	923,17	27	433
		TOTAL	1251

Table 2: Measurement results for the second day (May 21, 2015).

Time Range	Hourly Solar Radiation on Sloped Surface (W/m^2)	Ambient Temperature (˚C)	Amount of the Clean Water (ml)
11:00 – 12:00	872,55	26	406
12:00 – 13:00	922,01	26	432
13:00 – 14:00	944,32	27	467
		TOTAL	1305

Table 3: Measurement results for the third day (May 27, 2015).

Time Range	Hourly Solar Radiation on Sloped Surface (W/m^2)	Ambient Temperature (˚C)	Amount of the Clean Water (ml)
11:00 – 12:00	827,65	24	379
12:00 – 13:00	874,92	25	410
13:00 – 14:00	913,41	26	417
		TOTAL	1206

As seen from the tables above, the amount of clean water obtained is varied between 379 ml and 467 ml while solar radiation varies between 827 W/m^2 and 944 W/m^2. Ambient temperature does not change significantly during the experiments. Daily average total amount of clean water measured between hours 11:00-14:00 for three days is determined as 1254 ml. Hourly average amount of clean water is obtained as 418 ml. It can also be concluded from the tables that solar radiation has an effect on the production amount. This effect are graphically demonstrated in Figure 3. As seen from the figure, the production amount of clean water increases when the solar radiation increases. This is mainly due to the increase in the heat transfer to the sea water and hence increase in the evaporation and condensation rates for higher values of solar radiation.

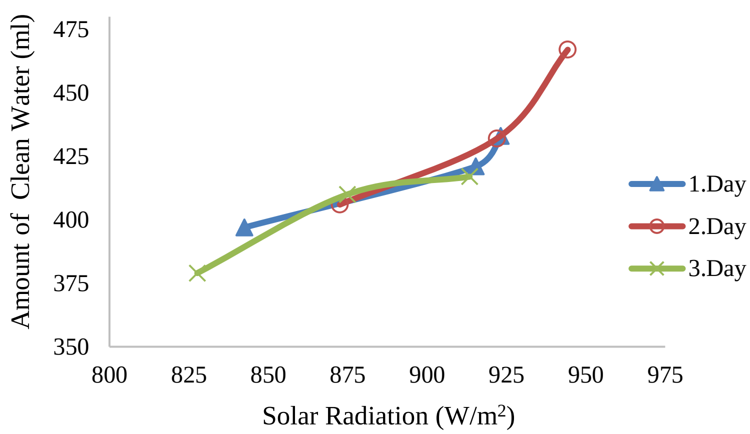

Fig. 3: The effect of solar radiation on clean water production amount.

4. Uncertainty Analysis

In this experimental study, the weather was partly cloudy and windy and convective heat losses were in significant amounts. The weather condition is therefore one of the most important factors that influences the system performance. Additionally, the main tank was not insulated and this increased the thermal losses. The results are negatively affected for this reasons.

The measurement results have a certain uncertainty depending on the sensitivity of the measuring device used in the experiments. A mercury-in-glass thermometer was used to measure the temperature of the water in the main tank and ambient temperature. SP-Lite2 Silicon Pyranometer was used for measuring the global solar radiation. The pyranometer was oriented to the south with a 35^o tilt angle similar to the solar collectors. The accuracy of the measurement devices and the other measurement errors are listed in Table 4.

The uncertainty can be expressed by the following equation [7]:

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{1/2} \quad (1)$$

Table 4: Measurement errors of the desalination system.

Errors of temperature measurement	
Errors due to design of the glass thermometer	$W_{Tt}=\pm 0,5\ ^{o}C$
Errors due to reading a temperature value	$W_{Tr}=\pm 0,1\ ^{o}C$
Errors due to determine ambient temperature	$W_{Ta}=\pm 0,5\ ^{o}C$
Errors of solar radiation measurement	
Errors due to measuring the solar radiation	$W_{Ih}=\pm 2\%\ W/m^2$

In Eqn. 1, *R* represents the function of the independent variable and *W* represents the uncertainty of the independent variable. The total error for the temperature measurement on the main tank can be defined as follows:

$$W_R = [(W_{Tt})^2 + (W_{Tr})^2]^{1/2}$$

$$W_R = [(0,5)^2 + (0,1)^2]^{1/2}$$

$$W_R = \pm 0,5099\ ^{o}C$$

5. Conclusion

Desalination methods used for producing clean water from the sea water are developing day by day. Energy consumptions in membrane and heat driven desalination systems are very high if renewable energy sources are not applied. Cost effective techniques must be applied to meet the clean water needs of water poor countries especially in arid areas with a seashore. High energy consumption problem can be overcome with the integration of renewable energy sources to the desalination systems. The important advantage of this type system is the use of clean and unlimited energy sources such as solar energy. In this study, regarding this advantage of solar energy, a new design greenhouse type desalination system with an evacuated tube solar collector is used. Turkey is a peninsula surrounded on three sides by the sea and have a large potential of solar energy. So, countries such as Turkey are very suitable areas for the application of the proposed system. Considerable part of the drinking water need can be met by using this technique.

Results show that the amount of clean water obtained is varied between 379 ml and 467 ml while solar radiation varies between 827 W/m^2 and 944 W/m^2. Hourly average amount of clean water is obtained as 418 ml. Results also show that the production amount of clean water increases when the solar radiation increases.

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