Performance Evaluation of a Solar Desalination System Integrated with a Fresnel Lens Concentrator

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Abstract- The purpose of this research work is to develop a water desalination unit that could efficiently produce potable water by evaporation and condensation; integrated with a Fresnel lens solar concentrator. The experimental setup consists of a heater tank powered with a Fresnel lens concentrator for pre-heating the water and a desalination unit. The objective of the work is to evaluate the enhancement in the performance of the system and was compared with the existing desalination unit. The study shows that Fresnel lens concentrator alone as pre-heating device can improve the yield of the desalination system up to 30.8 liters with an efficiency of 55%.

Keywords: Fresnel lens; desalination; solar concentrator; potable water; pre-heating; yield.

1. Introduction

Adequate quality and reliability of drinking water supply are fundamental needs. Without fresh water, human life is not possible. Water is one of the most abundant natural resources on earth, covering about three-fourths of its surface. Unfortunately, ninety-seven percent of the water on the earth's surface is saline in nature. The remaining small percentage of freshwater is available in the ground water, lakes and rivers, which are used to satisfy the needs of living beings. Oceans are the infinite sources of saline water. Salinity can be eliminated by the process of desalination. The separation of salts from sea water requires a huge amount of energy by burning of fossil fuels and can cause harm to the environment. This pollution can be avoided to a large extent by the use of environmental friendly techniques for desalinating the seawater [1]. In conventional process, desalination used fossil fuel as the thermal source for heating but due to rapid decrease in the fuel availability it is necessary to go with the renewable energy for desalination process [2]. There are many parts of the world that are arid and semi- arid areas where plenty of underground water is available but it is of highly saline in nature. The saline water contains 35000 ppm impurities and the acceptable salt content in fresh water for human consumption is only 500 ppm, thus desalination of sea water is important. The solar desalination system operates similar to the natural hydrologic cycle of evaporation and condensation [3].

An excellent review on the use of renewable energy in various types of desalination systems and applications were presented by Sumit M. Kamble *et.al.*[4]. The author highlights the use of solar energy as a best option over conventional systems, as solar solar energy is available in abundant quantity and the technical feasibility of extracting solar thermal energy is relatively simple. Ahamed M. *et.al.*[5] performed experiments to improve efficiency by minimizing thermal losses, that is, by reducing operating temperature of whole system it is possible to reduce heat loss and increase efficiency. Bilal A. Akash *et.al.*[6] performed experiment in Jordan using a solar still with various cover tilt angles of 15, 25, 35, 45 and 55. An optimum tilt angle for water production was found to be 35. Salt was added to study the effect of the salinity of water on solar distillation and it was observed that the salinity of water affects the distillate production even for lower concentration. M. Boukar *et.al*.[7] have performed a comparative study on the performance of a simple basin solar still and a similar one coupled to a flat plate solar collector and it was concluded that the coupled system has better performance than basin solar still. Hitesh N. Panchal *et.al*.[8] in his work used three identical size solar stills having three different thicknesses of glass cover of 4 mm, 8 mm and 12 mm and it was inferred that lower glass thickness gives higher distillate output. Here, Dunkle model is used for comparison of various heat transfer coefficients of solar stills. A.S.Nafty*et.al*.[9] used black rubber or black gravel material within a single sloped solar still as storage medium to increase the productivity. Most recent work by Dr. Omar El-Hadad [10] is the investigation of new desalination technique using lenses to increase the rate of evaporation.

As the above literature review shows, the studies on the detailed investigation on solar desalination using Fresnel lens are scarce. As a result, direct active desalination system using solar heater tank combined with distillation tank has put forward to increase the yield of desalination unit.

2. Experimental Setup

The heating unit is made up of mild steel base. The box is painted black for better absorptivity. Copper sheet was used at the bottom of box. A schematic diagram of the setup is shown in the Fig.1. The six edges are welded together and the edges are stuck together using silica gel and m-seal for sealing off leaks. The heater tank is covered using a glass cover plate, on the top. The Fresnel lens is placed over the heater tank to increase the amount of radiation falling onto glass cover. Two holes are drilled on one side of the tank, one below the other. Two pipes are connected to these holes and this allows the hot water to flow to the distillation tank from heater tank.

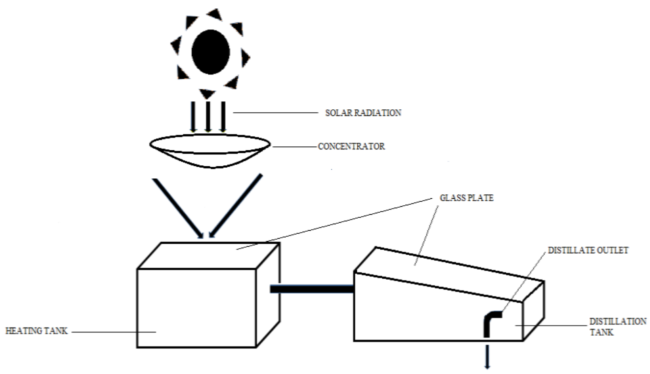

Fig. 1. Schematic of the experimental setup

The distillation unit is also constructed using mild steel. Again the edges are welded together and secured for sealing off leaks. The distillation unit is split into two halves: the evaporation tank and the collection tank. It has an opening at the top, which deviates at an angle from the horizontal plane. The evaporation tank has holes on one of its side, one below the other to which the set of pipes from the heater tank was connected. The distillation unit was also covered with glass. The two compartments are separated using a mild steel sheet as shown in the figure.

The design consists of two major parts: (i) the water heating and (ii) distillation unit. The water heating unit consists of a black coated tank with glass cover on top, which is used to collect and preheat the water before supplying it to the desalination unit. Fresnel lens is combined with the heating tank, so as to concentrate more amount of solar radiation onto the glass cover. The bottom of the tank is coated black to absorb maximum energy. During the day time, solar radiation is trapped inside the tank by greenhouse effect and is utilized for heating process. The heater tank is combined with the distillation unit and the heat energy is continuously transferred as convection current through water which acts as the medium.

The distillation tank is split up into two parts; the evaporation tank and the collection tank. Hot water is continuously supplied to the distillation tank from the heater tank. The water in the distillation tank undergoes evaporation. During evaporation, the impurities present in water are left out in the distillation tank. The water vapor gets condensed inside the glass cover on the top of the tank. As the glass sheet is in a slanted position, the condensed droplets would not trickle until it reaches the collection tank. The heater and distillation units were connected to each other by a set of pipes. The pipes allow the convection currents to help in heating the water.

3. Performance Evaluation

The water desalination unit using Fresnel lens solar concentrator is tested for full load and maximum efficiency conditions to evaluate its performance. Thermocouple is used to measure the temperature of outlet water of the water heater tank. A lux meter is used to measure instantaneous solar irradiation on the surface of Fresnel lens. All measurements were taken during the period of 9:00 AM to 4:00 PM. Maximum efficiency test is carried out to estimate the optimum load to give the maximum distillation yield. In testing process, the water heater tank is loaded to its full capacity of 72 liters.

4. Efficiency

Efficiency calculations are based on the average value of solar irradiation obtained. Maximum value of obtained results (temperature and distilled water volume) is used in each case to determine the efficiency.

4.1.Solar Water Heater Efficiency

Efficiency of the solar water heater tank is defined as the ratio of amount of heat stored in the tank till evening to the total solar input received by the Fresnel lens over the same period.

$$Water\ heater\ efficiency = \frac{mc_p\left(T_o - T_i\right)}{IA\Delta t} \quad (1)$$

Where,

m = mass of water in storage tank, kg

c_p= specific heat of water, kJ/kg°C

I = solar irradiance, W/m^2
A = aperture area, m^2
Δt = time interval, s
T_i = water inlet temperature, ^{0}C
T_o= water outlet temperature from heating tank, ^{0}C

4.2. Solar Distillation Unit Efficiency

Solar distillation efficiency is defined as

$$Distillation\,Tank\ efficiency = \frac{Q_e}{I} \tag{2}$$

Where,

Q_e = Amount of Energy utilized in the still, J/ m^2 .day

$$Q_e = M_e \times f \tag{3}$$

M_e = Daily output of distilled water, kg/m^2 .day

f = latent heat of vaporization of water, J/kg

5. Results and Discussion

The developed desalination unit was tested for its feasibility and the following results are obtained. .

5.1. Full Load Performance

The testing was done for two replications. During the testing, temperature of water and solar irradiation were measured. Maximum solar energy was available at 1:00 PM. After 1:00 PM, there was gradual drop in the incident solar radiation. With the increase in the solar irradiation, the temperature of water increased. From average data of full load test, it was found that the average temperature at 9:00 AM at outlet and storage was 28^{0}C when solar irradiation was 536 W/m^2 and ambient temperature was 27^{0}C. It was obtained that maximum outlet temperature of hot water was 64^{0}C at 4:00 PM when solar irradiation was 212 W/m^2. The maximum solar irradiation obtained was 916 W/m^2 at 1:00 PM and the average solar irradiation obtained for the day was 751 W/m^2. The output of the distillation unit was measured in the subsequent morning. The maximum volume of distilled water obtained was 1.2 liters. The efficiency of the distillation tank was found out to be 24.0 % at an average yield of 7.00*l/m^2 day*.

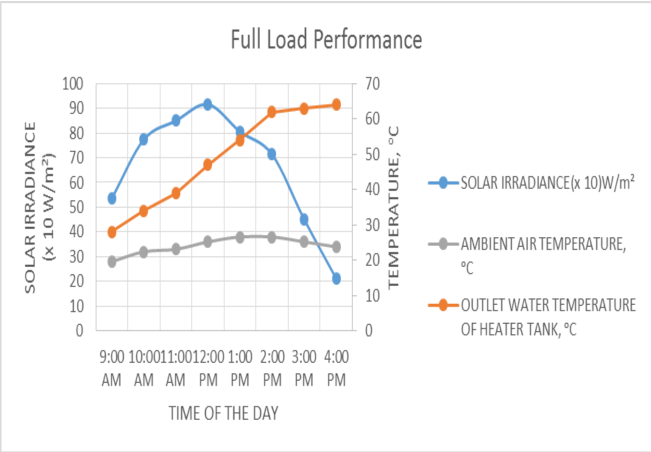

Fig. 2. Full load thermal performance of water desalination unit

5.2. Maximum Efficiency Performance

The testing was done to find out the optimum volume of water that can be stored to get the maximum efficiency. The testing procedure is similar to that of full load test. A variation in the volume of water stored results in a change in efficiency. And the maximum efficiency for distillation unit was found to be 55.97%. The volume of water stored in the heating tank was 33 liters and the output from the distillation tank in the subsequent morning was found to be 2.7 liters. The average amount of distilled water per unit area of distillation tank was 15.42 *l/m^2 day*.

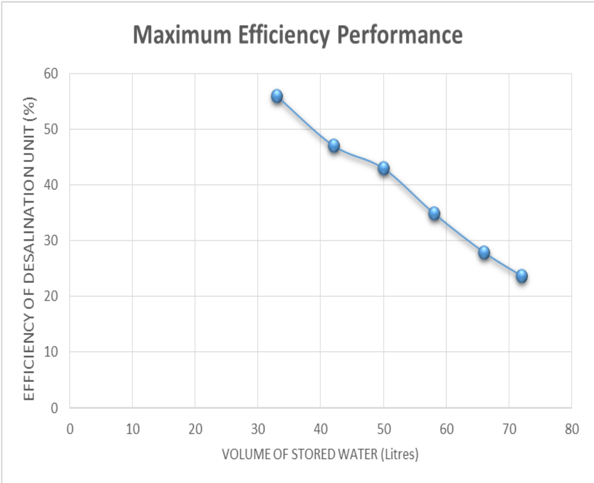

Fig. 3. Efficiency of distillation tank with varying volume at fixed temperature of water in the heater tank

6. Conclusion

The use of solar energy in desalination process is one of the best applications of renewable energy. Solar energy driven desalination units can reduce carbon emissions and can provide desalinated water in a sustainable way with minimal impacts on environment. Fresnel lens offers a simpler and cheaper method for concentrating solar energy that can be used for pre-heating water. The experimental observations of the behavior of Fresnel lens concentrator alone as pre-heating device can improve the performance of desalination system. The experiment reveals a maximum temperature of 64˚C in the heater tank at an average irradiance of 750 W/m^2. The yield was increased by reducing the water level in the desalination tank and the increased yield was 2.8 liters with 15 liters of water in the desalination tank with 55% efficiency.

References

[1] Kulkarni, Sunil Jayant, "Solar Distillation: A Review", *International Journal of Research*, vol. 11, pp. 1171-1176, 2014. (Article)

[2] Goosen, Mattheus FA, Shyam S. Sablani, Walid H. Shayya, Charles Paton, Hilal Al-Hinai. "Thermodynamic and economic considerations in solar desalination", *Desalination 129*, No. 1, pp. 63-89, 2000.(Article)

[3] K. Sampathkumar, T. V.Arjunan, P.Pitchandi, P. Senthilkumar,"Active solar distillation—A detailed review ", *Elsevier*, pp.1503–1526,2010. (Article)

[4] Sumit M. Kamble, A. D. Pitale, "A Review on Solar Powered Desalination Systems",*International Journal of Engineering Research & Technology (IJERT)*, pp: 2278-0181, Vol. 4 Issue 03, 2015. (Article)

[5] Ahamed M, Aswin A, Badrivishal B, Deventheran.D, Lokesh Kumar C, "Water Purification by Heating Using Solar Power as Fuel", *International Journal of Scientific Research*, vol:3, Issue:11, pp. 2277-8179, 2014.(Article)

[6] Akash Bilal A., Mousa S. Mohsen,WaleedNayfeh. "Experimental study of the basin type solar still under local climate conditions", *Energy conversion and management,* 41(9)pp.883-890. (Article)

[7] Boukar, M, A. Harmim, "Effect of climatic conditions on the performance of a simple basin solar still: a comparative study" *Desalination* 137.1,pp: 15-22,2001.(Article)

[8] Hitesh N Panchal, Dr. P. K. Shah," Effect of varying glass cover thickness on performance of solar still in winter climate condition ", *International Journal of Renewable Energy Research (IJRER*)Vol.1, pp: 212-223,2011. (Article)

[9] Nafey, A. S., et al. "Solar still productivity enhancement", *Energy conversion and management,* 42.11,pp: 1401-1408,2001. (Article)

[10] Dr. Omar.El-Hadad," A New Solar Technology Technique for waste water and sea water treatment"conference Water Asia 2014

[11] Sathyamurthy, Ravishankar, S. A. El-Agouz, and Vijayakumar Dharmaraj, "Experimental analysis of a portable solar still with evaporation and condensation chambers", *Desalination*, vol. 367, pp.180-185, 2015(Article).

[12] Hansen, R. Samuel, C. Surya Narayanan, and K. Kalidasa Murugavel. "Performance analysis on inclined solar still with different new wick materials and wire mesh", *Desalination*, vol.358, pp. 1-8, 2015. (Article)

[13] Sathyamurthy, Ravishankar, DG Harris Samuel, and P. K. Nagarajan. "Theoretical analysis of inclined solar still with baffle plates for improving the fresh water yield", *Process Safety and Environmental Protection*, 2015.(Article)

[14] Matrawy, K. K., A. S. Alosaimy, and A-F. Mahrous. "Modeling and experimental study of a corrugated wick type solar still: Comparative study with a simple basin type." *Energy Conversion and Management* , vol.105, pp.1261-1268, 2015.(Article)

[15] El-Samadony, Y. A. F., A. S. Abdullah, and Z. M. Omara. "Experimental study of stepped solar still integrated with reflectors and external condenser", *Experimental Heat Transfer*, vol. 28 pp. 392-404, 2015.(Article)

[16] Bryce. S. Richards, Andrea. I. Schafer, "Renewable Energy Powered Water treatment Systems" *Elsevier*, Issn No 353-374, 2009.(Article)

[17] S.H.Sengar, A.K.Kurchania. “Solar Geyser cum Distiller for Domestic Use”, *World Applied Sciences Journal*,4 (6): pp. 808-811, 2008. (Article)

[18] Qiblawey, HazimMohameed, Fawzi Banat, "Solar thermal desalination technologies", *Desalination 220*, vol.220, pp. 633-644, 2008. (Article)

[19] Zilan, Ruken. "Optimization of Geometry and Material of Solar Water Heaters." *Ph.D. Diss., Middle East Technical University*, 2001.

[20] Tiwari, G. N. "Feasibility study of solar distillation plants in south pacific countries",*Desalination,*vol.82,pp. 233-241, 1991.(Article)

[21] Delyannis, E-E. "Status of solar assisted desalination: a review." *Desalination 67*, pp. 3-19, 1987.(Article)

[22] Cooper, P. I. "Appleyard." *Sun at Work 12*, No. 4, 1967.