Current Journal of Applied Science and Technology

40(43): 36-43, 2021; Article no.CJAST.83033
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Exergy Analysis of Passive Solar Distillation Unit in India at Udaipur

Raj Kumar [a*], Sudhir Kumar Jain [a] and Kapil Kumar Samar [a]

[a] *Department of Renewable Energy Engineering, College of Technology and Engineering, MPUAT, Udaipur, Rajasthan, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2021/v40i4331617

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/83033

Original Research Article

Received 20 October 2021
Accepted 23 December 2021
Published 25 December 2021

ABSTRACT

The present research involved exergy analysis of a passive solar distillation unit. A developed unit of solar distillation of 40 litres of holding capacity was optimized for desired output of 5 litres of distilled water. Performance of the developed unit was observed during 8AM to 5PM. The solar still produced 4.5 litres of freshwater per day per m^2. According to the thermal evaluation of the solar still, the maximum daily exergy efficiency was found to be 5.44%.

Keywords: Passive solar still; exergy efficiency; solar desalination; distilled water.

1. INTRODUCTION

The sun is the great wellspring of energy. India benefits from a lot of sunlight because it is a tropical country. The average number of clear radiant days in a year is closer to 300, with an average of 8 hours of sunlight per day. In different parts of the country, daily sun-oriented radiation varies between 4 and 7 kWh per square metre. According to these calculations, India has a renewable power potential of around 900 GW [1].

Water is a chemical substance that is used in a variety of applications including residential, industrial, and agricultural. The most crucial factor in determining and driving economics is clean water. Drinking water is still a major issue

**Corresponding author: E-mail: rajkumardorwal@gmail.com;*

in deserts and rural areas of both developed and developing countries around the world. It is estimated that 97 percent of the water in the ocean is saline [2]. Desalination methods for removing salts from seawater (66 percent), bitter water (19 percent), river water (8 percent), wastewater (6 percent), and other sources (1 percent) are used around the world [3]. In hospitals, distilled water is commonly used to clean medical instruments during surgeries and laboratory tests [4].

Researchers have proposed possible solutions, materials, and operating parameters for varied weather situations in order to increase the performance of solar stills. A thermodynamic analysis is required for obtaining precision in any solar energy system. Engineers utilize thermodynamic analysis to determine how energy influences thermal and mechanical system performance. The most essential goal of the solar distillation process is to use as much solar energy as possible while minimizing heat losses in the system to achieve the most distilled water possible.

A thermodynamic analysis of single basin solar distillation system is discussed by Ranjan et al. [2] and by Kwatra [5]. Energetic and exergetic analysis of single basin and double basin solar distillation system has been calculated by Singh et al. [6]. The result of this paper show the energy and exergy efficiency of single slope solar still remain higher in comparison to that of the double slope solar still. Sow et al. [7] carried out a thermodynamic analysis of a triple effect solar distillation system. The triple effect system gives exergetic efficiencies between 19-26 %, double effect system gives 17-20%, and single less than 4% for a single effect system. Torchia-Nunez et al. [8] presented second law analysis of a solar distillation unit. It is found that the most influential parameter is solar irradiance. For same exergy input to brine, collector and passive solar still have exegetic efficiencies of 6%, 12.9% and 5% respectively. It was found that collector is the major exergy destructive component. Efforts should be made for better collector designs.

Throughout the distillation process, the quantity and quality of energy, as well as mass transfer, should be evaluated. The first law of thermodynamics (energy analysis) gives a qualitative assessment of the losses in the system. The second law of thermodynamics gives a clearer picture of energy losses of a system by presenting a quantitative and qualitative assessment of the various losses. As a result, a detailed examination of the convection and radiation processes should be based on exergy balance process. A general approach for calculating exergy efficiency of a simple single effect passive solar still is discussed in this study.

2. MATERIALS AND METHODS

The performance evaluation of a developed Passive solar distillation unit was carried out in April 2021 at the Department of Renewable Energy Engineering, College of Technology and Engineering, Udaipur. The experiments were conducted between sun shine hours 8:00 AM to 05:00 PM. Details of developed solar distillation system is mentioned in Table 1.

Gunny bags were used on the surface of basin area to increase the surface area of basin which helps to evaporate water. The solar distillation unit was poured with a quantity of 4.55 liters of water daily (Fig.1.) to evaluate energy efficiency of unit with the help of equation 1 to equation 4 [9].

$$\sum E_{dest.} = \sum E_{x,in} - \sum E_{x,out} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The exergy input to the solar still is the solar irradiance exergy and is given by

$$E_{x,in} = E_{x,sun} = A_b I_{sc}\left[1 - \frac{4}{3}\left(\frac{T_a+273}{T_s}\right) + \right.$$
$$13Ta+273Ts4\ldots\ldots\ldots\ldots\ldots\ldots$$
(2)

where A_b is the effective area of the solar still basin (m^2), It is the accumulated solar irradiance incident on the solar still (W/m^2), T_s is the sun temperature, 6000 K, and $\dot{E}_{x\ sun}$, is the exergy input to solar still from the solar insolationb [10]

Exergy output of the product (distillate water) for defined solar still can be written as [7]:

$$E_{out} = E_{x,evapo} = \frac{m_{ew}\lambda_{fg}}{3600}\left[1 - \right.$$
$$Tamb+273Tw+273\ldots\ldots\ldots\ldots\ldots\ldots$$
(3)

where $\dot{E}_{x\ evaporation}$ is the output evaporative exergy and λ_{fg} is the latent heat of vaporization.

The exergy efficiency can be computed as the ratio between the desired output exergy and the input exergy and can be expressed as:

$$\eta_{ex} = \frac{E_{x,out}}{E_{x,in}} = \frac{E_{x,evap}}{E_{x,in}}\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Table 1. Specification of developed solar distillation unit

S.N.	Particular	Specification
1	Absorber area of the basin, m^2	1.00
2	Basin area, m^2	1.00
3	Area of the glass cover, m^2	1.16071
4	Insulation thickness, m	0.025
5	The angle of inclination of the glass	30°
6	Width of the basin, m	1
7	The thickness of glass cover, m	0.005
8	Dimensions of gunny bag, m	1.12 ×0.68
9	Total absorber area, m^2	1.32

Fig. 1. Developed Passive solar distillation unit

2.1 The Exergy Efficiency of Solar Distillation Unit: Kwatra, H. S. [5]

The exergy balance equation can be described in general form as follows [4].

3. RESULTS AND DISCUSSION

The experimental investigation was carried out at Department of Renewable Energy Engineering, College of Technology and Engineering, Udaipur. The study area lies at 24° 38' N- latitude, 73° 43' E- longitude at an altitude of 582.5m above mean sea level. Several experiments were conducted to evaluate exergy efficiency of passive solar still. The exergy efficiency was found in the range of 0.08% to 5.44% during the experiment period as shown in Table 2 and Fig. 2 to Fig. 5. During the experiment wind velocity of 5-8 km per hour was observed. Maximum exergy efficiency of the passive still was found 5.44% on 6th April 2021.

The experimental results of all the tests showed that an increment in the water temperature that is happened until it reached the maximum in the afternoon because the absorber solar radiation exceeds the losses to the ambient temperature. The water temperature decreases after 2 PM due to losses of solar still becomes higher than the absorber radiation. The difference between temperatures and trend of maximum and minimum temperature was the novel agreement with another solar distillation unit developed by Barden et al. (2007) and Abdenaces et al. (2007).

The inner and outer glass temperatures have observed and found that the temperatures have almost same values, which means the absorbed energy by glass is negligible. The glass temperature is less than the water temperature which causes the condensation of the vapor on the inner surface of the glass. The gunny bag was used on the surface of basin area to increase the surface area so that, water can easily evaporate from the basin.

3.1 Distilled Output of the Passive Solar Unit

The distilled output of the passive solar still was measured hourly and a relation between solar insolation and output was established. The first test (Test-1) was held on 1st April 2021 and maximum output of 980 ml was found at 1 P.M. The total output of 4540 ml was measured on the same test.

The second test (test-2) was conducted on 5th April 2021 and the maximum fresh water output was found to be 920 ml at 2 P.M with a total value of 4798 ml.

Table 2. Variation in energy and exergy efficiency of passive solar still unit

Date	Exergy efficiency		Distilled water at 2 p.m. (ml)	Cumulative distilled water (ml)
	Maximum	Minimum		
1st April 2021	4.63	0.08	980	4540
5th April 2021	4.17	0.18	920	4798
6th April 2021	5.44	0.21	960	4380
7th April 2021	4.74	0.35	960	4400

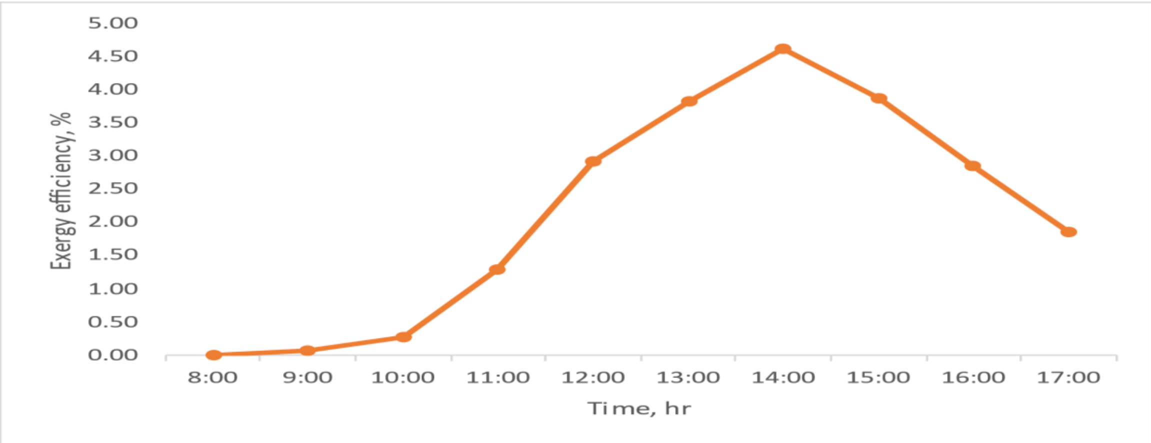

Fig. 2. Hourly variation of the exergy efficiency on 1st April 2021

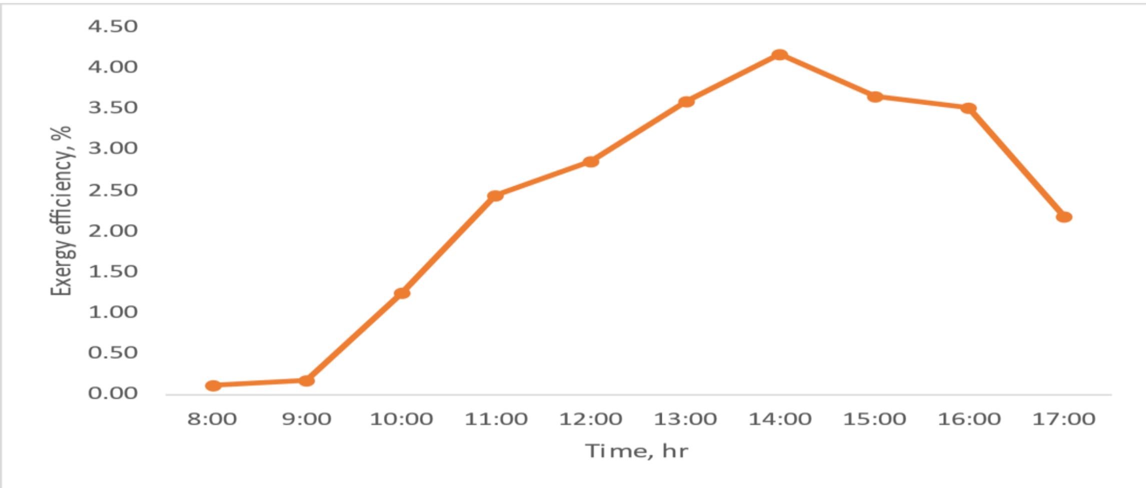

Fig. 3. Hourly variation of the exergy efficiency on 5th April 2021

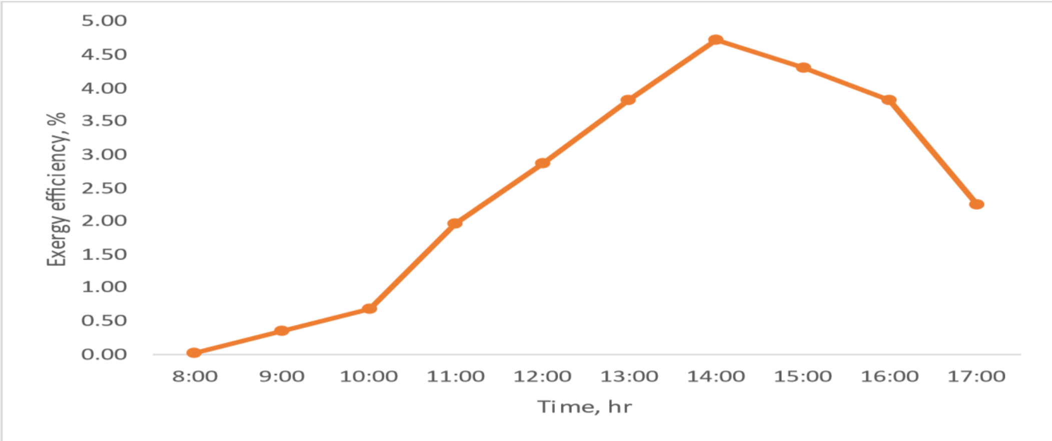

Fig. 4. Hourly variation of the exergy efficiency on 6th April 2021

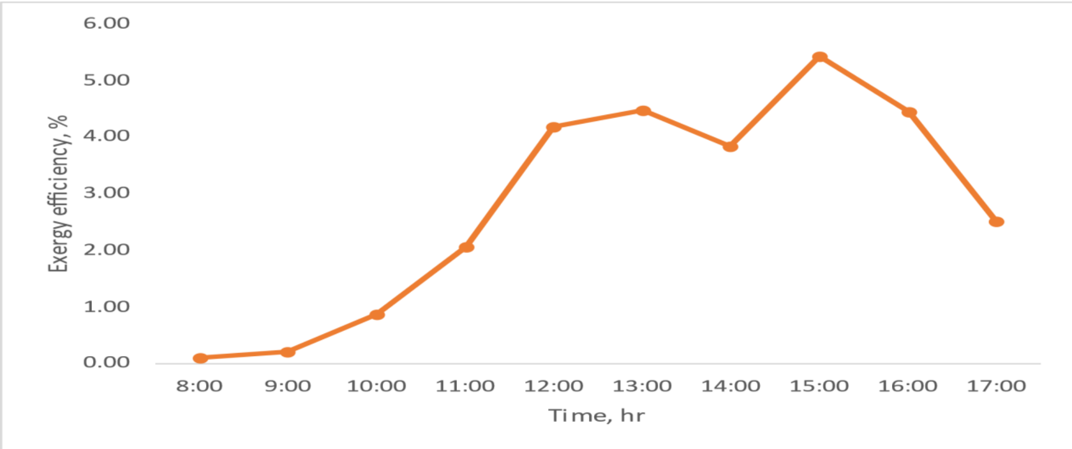

Fig. 5. Hourly variation of the exergy efficiency on 7th April 2021

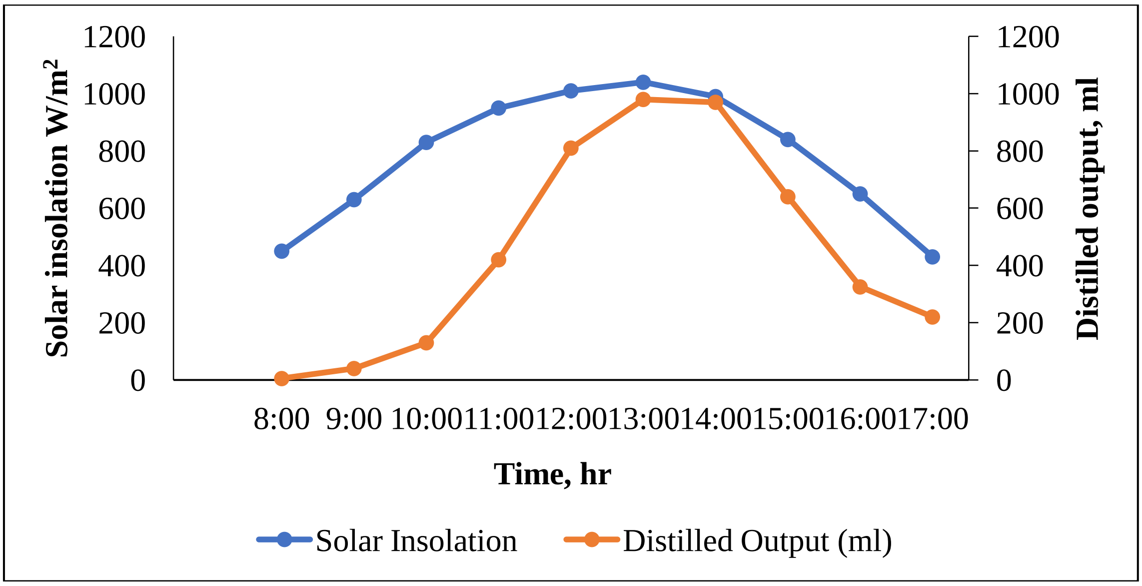

Fig. 6. Hourly variation of the distilled output and solar insolation on 1st April 2021

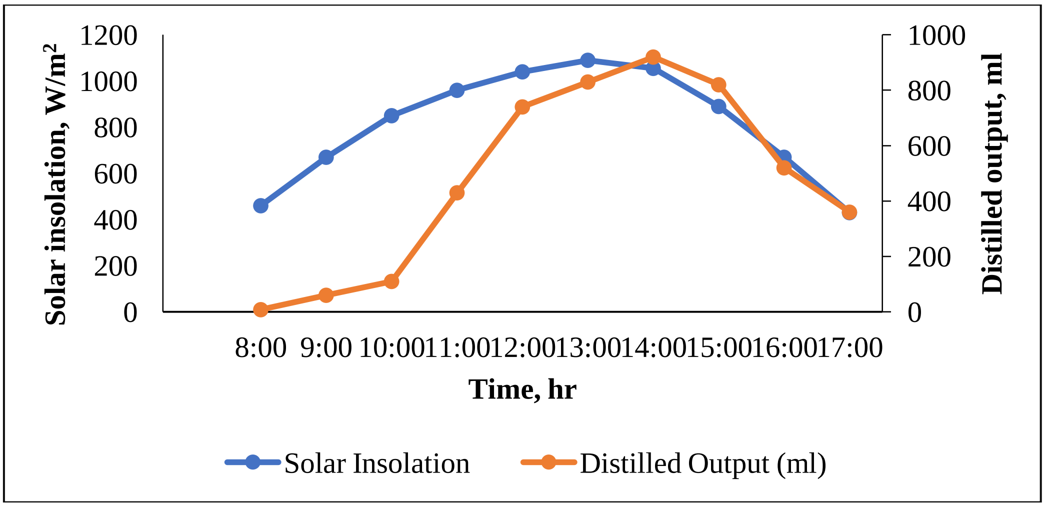

Fig. 7. Hourly variation of the distilled output and solar insolation on 5th April 2021

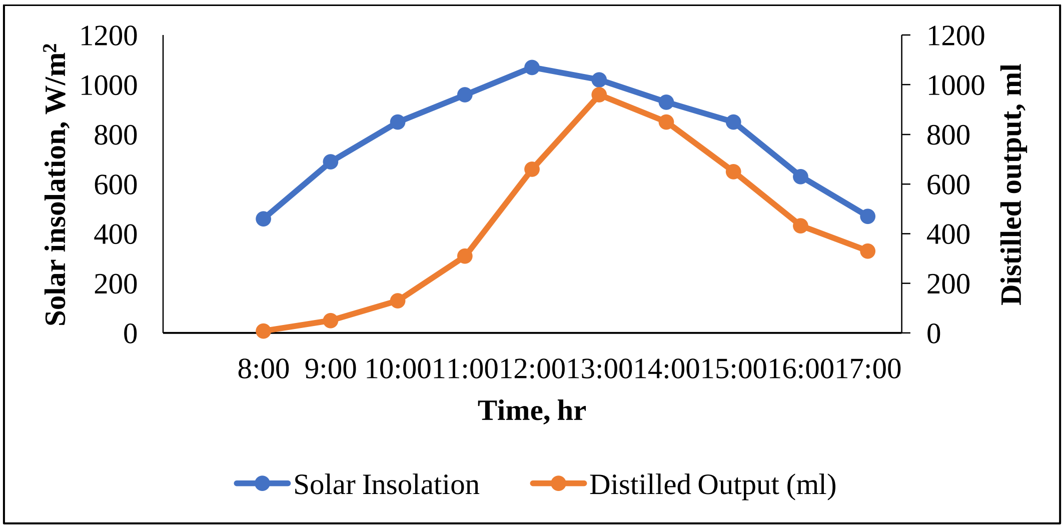

Fig. 8. Hourly variation of the distilled output and solar insolation on 6th April 2021

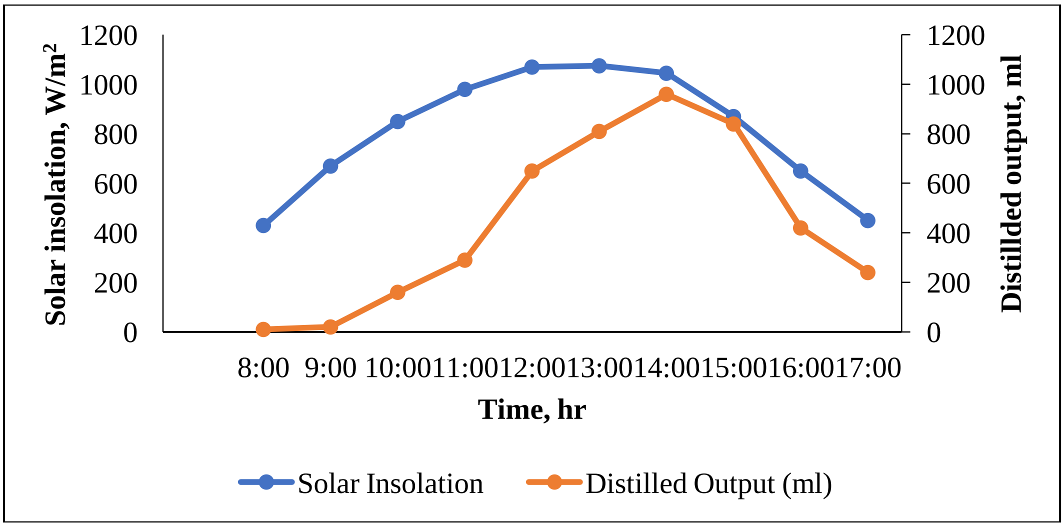

Fig. 9. Hourly variation of the distilled output and solar insolation on 7th April 2021

The third test was conducted on 6th April 2021. The maximum fresh water yield was measured to be 960 ml at 1 P.M with the help of volumetric flask. The total output of 4380 ml was found on the same day.

The fourth test was conducted on 7th April 2021 and a maximum fresh water yield of 960 ml was found at 2 P.M. Total amount of 4400 ml was found on the same day.

The output of the passive solar distillation unit was lower during morning early hours due to lower solar radiation. The fresh water output was observed maximum at time period between 1.00 to 2.00 P.M. The yield of the passive solar still has a direct relationship with solar insolation and the results were supported by Ahmed, H. M. [11].

4. CONCLUSION

A parametric study has been conducted to find out the effects of solar radiation on production of distilled water at fixed parameters such as saline water depth, thickness of insulation and angle of inclination of the glass cover. The exergy efficiency of the passive solar still found lower due to less available energy in the form of evaporative heat transfer. Temperature in saline water varies in the lower range of 18–97^0 C [6]. The total output of the still was found 4.54, 4.79, 4.38 and 4.4 l/m^2/day respectively for test-1, test-2, test-3 and test-4. However, the solar distillation process is one of the simplest and most widely used technologies for converting seawater or water into distilled water. Good economy, low operating and maintenance costs, enough sunlight and all-day operation. The maximum instantaneous overall exergy efficiency was observed 5.44% [12-19].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCE

1. Kaushal A, Varun. Solar Stills: A review. Renewable and Sustainable Energy Reviews. 2010;14:446-453.
2. Ranjan KR, Kaushik SC. Energy, exergy and thermo economic analysis of solar distillation system: a review. Renewable and sustainable energy review. 2013;27: 709-723.
3. Delyannis E. Historic background of desalination and renewable energies. Solar Energy. 2003;75:357-366.
4. Tiwari GN, Tiwari AK. Solar distillation practice for water desalination systems. Anamaya Publishers, New Delhi, India; 2007.
5. Kwatra HS. Performance of solar still: Predicted effect of enhanced evaporation area on yield and evaporation temperature. Solar Energy. 1996;56:261-266.
6. Singh RN, Dev R, Hasan MM, Tiwari GN. Comparative energy and exergy of various passive solar distillation systems. World renewable energy congress. 2011;3929-3936.
7. Sow O, Siroux M, Desmet B. Energetic and exergetic analysis of a triple effect distiller driven by solar energy. Desalination. 2005;174:277-286.
8. Torchia-Nunez JC, Porta-Gandara MA, Cervantes-de Gortari JG. Exergy analysis of a passive solar still. Renewable Energy. 2008;33:608-616.
9. Dwivedi VK, Tiwari GN. An energy, exergy and life cycle cost analysis of single and double slope solar stills. Applied Science Research. 2008;3:225-241.
10. Bejan A. Advanced engineering thermodynamics. John Wiley and Sons, Inc; Hoboken, New Jersey; 2006.
11. Ahmed HM, Al Taie A, Almea M. Solar water distillation with a cooling tube. International Renewable Energy Congress, Sousse, Tunisia. 2010;6-11.
12. Garcia-Rodriguez L, Gomez-Camacho C. Exergy analysis of the SOL-14 plant. Desalination. 2001;137:251-258.
13. Gupta MK, Kaushik SC. Exergy analysis and investigation for various feed water heaters of direct steam generation solar-thermal power plant, Renewable Energy. 2010;35:1228-1235.
14. Kabelac S. Exergy of solar radiation. International Journal of Energy Technology and Policy. 2005;3:115-122.
15. Kapurkar PM, Kurchania AK. Performance evaluation of Fresnel lens concentrated solar water heater cum distillation unit. Internat. J. Agric. Engg. 2013;6(1):71-74.
16. Kaushik SC, Mishra RD, Singh N. Exergetic analysis of a solar thermal power system. Renewable Energy. 2000;19:135-43.
17. Kumar Shiv, Tiwari GN. Analytical expression for instantaneous exergy efficiency of a shallow basin passive solar

still. International Journal of Thermal Sciences. 2011;50:2543-2549.
18. Petela R. Engineering thermodynamics of thermal radiation for solar power utilization. The McGraw -Hill Companies, Inc; 2010.
19. Samee MA, Mirza UK, Majeed T, Ahmad N. Design and performance of a simple single basin solar still. Renewable and Sustainable Energy Reviews. 2007;11: 543-549.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/83033