EXPERIMENTAL ANALYSIS OF SCHEFFLER REFLECTOR WATER HEATER

by

Rupesh J. PATIL [a*], ***Gajanan K. AWARI*** [b], ***Mahendra P. SINGH*** [a]

[a] Priyadarshini College of Engineering, Nagpur, Maharashtra, India
[b] Tulsiramji Gaikwad-Patil College of Engineering & Technology, Mohgaon, Nagpur, Maharashtra, India

Original scientific paper
UDC: 683.97:697.329
DOI: 10.2298/TSCI100225058P

The performance of Scheffler reflector has been studied. In this system storage reservoir was installed at Focus point. It has a single large diameter drum which serves the dual purpose of absorber tube and storage tank. The drum is sized to have a storage capacity of 20 liter for experiment. The tests were carried out with this set-up and were repeated for several days. Performance analysis of the collector has revealed that the average power and efficiency in terms of water boiling test to be 1.30 kW and 21.61%, respectively, against an average value of beam radiations of 742 W/m^2*. The maximum water temperature in the storage tank of 98 °C has been achieved on a clear day operation and ambient temperature between 28 °C to 31 °C.*

Key words: *Scheffler reflector, thermal performance, energy in sensible heat*

Introduction

German scientist Wolfgang Scheffler has devised a parabolic reflector set-up to harness solar energy using low cost set-up which can be used in rural areas in India. A concentrating primary reflector tracks the movement of the Sun, focusing sunlight on a fixed place. The focused light heat a very large pot, which can be used for heating, steam generation, cooking, baking breads, and water heating [1-5].The Scheffler reflector can be used for the supply of hot water for domestic purposes. These systems can have one water storage tank which performs dual function of absorbing solar radiation and preserving heat of water.

Many methods are suggested to keep water temperature at a satisfactory level. Among them, the use of a selective absorber that reduces radiation thermal losses and double glazing, transparent insulation, and inverted or evacuated absorber to suppress convection thermal losses are suggested methods that preserve water storage heat. In the literature, few works are referred to Scheffler reflector with cylindrical water storage tanks mounted at focal point. The use of Scheffler reflectors can result in effective water heating by using the non-uniform distribution of solar radiation on the cylindrical absorber surface. In most of this systems the part of the cylindrical absorber is thermally insulated in order to reduce storage

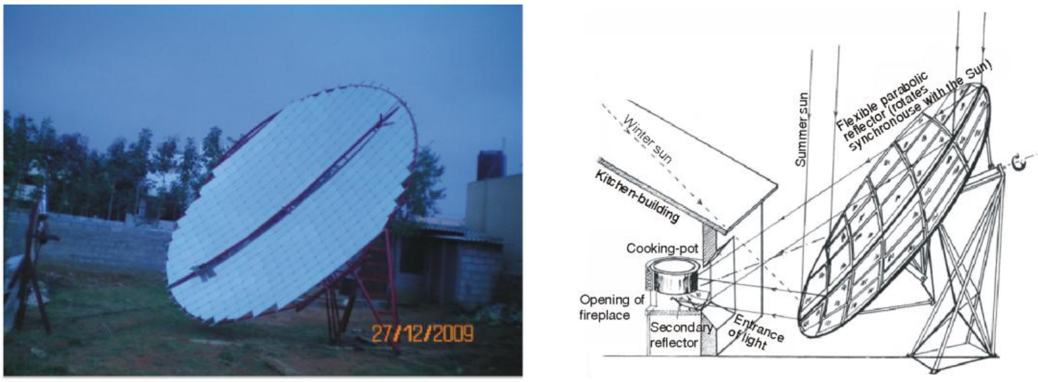
* Corresponding author; e-mail: rupesh1002001@yahoo.com

tank thermal losses [6]. Considering that this reflector systems aim to cover domestic needs of about 100-200 liter per day, the aperture area of this can be up to about 2.0-2.5 m^2 which corresponds to use cylindrical storage tank with diameter of 0.2 m to about 0.4 m [7].

In the present work experimental study of Scheffler reflector water heater (SRWH) consisting single storage tank as an absorber mounting in side curved reflector trough has been carried out. The solar reflector of 20 liter per day capacity is designed [8]. In this design the thermal insulation on storage tank is not provided to lower down the cost of water heater and for its wide applications in domestic sector. The paper is focused on the performance analysis of SRWH for average power and efficiency in terms of water boiling test at Bangalore in India [9-17].

Design concepts of the SRWH

Solar water heating system of this type defer to flat plate solar collector in design and operation as it consists of an unit with dual operation, to absorb solar radiation and to preserve the solar heat, instead of the absorbing solar radiation and the heating only the circulating fluid. The designed model for experimentation is shown in fig. 1. The solar reflector of 20 liter per day capacity is designed with dish diameter of 8 m^2.



(a) Scheffler reflector for community-kitchens (b)

Figure 1. (a) A model of SRWH system; (b) schematic of SRWH

The storage tank painted black is so positioned that its periphery lies on the focus of the parabolic reflector. Non return valve was fitted at the inlet line and air vent, pressure relief valve at the outlet line. For analysis and testing purpose, Al-Cr thermocouples were located at different positions in the heater. This type of compact solar water heater is simple in design, low in cost, easy in operation and maintenance, easy to install and of high efficiency compared to flat plate collectors and tubular type integrated collector storage systems.

The storage tank has an entrance for the water at the top of one side of it and an exit at the bottom of the other side of it. The SRWH inlet is connected directly to the overhead or supply tank and its out let is regulated by the valve. It is naturally circulated type water heater. The storage tank is hydraulically tested for fluid pressure of 0.588 MPa.

Testing procedure and experimentation

The Scheffler reflector used is having an area of 8 m^2. The sunlight that falls on this reflector is reflected sideways to the focus located at some distance of the reflector. The axis of daily rotation is located exactly in north-south-direction, parallel to earth axis and runs through the centre of gravity of the reflector. That way the reflector always maintains its gravitational equilibrium and the mechanical tracking device (clockwork) doesn't need to be driven by much force to rotate it synchronous with the Sun. The focus is located on the axis of rotation to prevent it from moving when the reflector rotates. During the day the concentrated light rotated around its own centre but not move sideways in any direction. That way the focus stays fixed. At the focus it has a container to hold 20 liter water. The parameters measured were water temperature, solar radiation, wind speed, and ambient temperature. K--types thermocouple is used to measure water temperature which has a range of –200 °C to 1250 °C.Wind speed is measured by battery operated digital anemometer, it has a range of 0.3 to 30 m/s. Same anemometer had a facility to show ambient temperature . A pyranometer is used to measure the radiation. The experimentation was carried in the month of June, September, and December 2009, and January, February, March, April, and May 2010.These months covers winter, summer and rainy season in India .The readings were taken at different time zones between 9 a. m. to 5 p. m. for various days. All readings were taken at the interval of 5 minutes. More than 600 observations were recorded. The sample observations are shown in tab. 1.

Table 1. Readings of water temperature, wind speed, ambient temperature and radiation

Date	Serial number	Time [hour]	Generated water temperature [°C]	Wind speed [kmh^{-1}]	Ambient temperature [°C]	Radiation falling [Wm^{-2}]
21 Feb. 2010	1	9	25	16	28	700
	2	9.05	28	16	28	750
	3	9.1	34	16	28	750
	4	9.15	40	15	28.5	750
	5	9.2	45	16	28.5	750
	6	9.25	52	15	29	750
	7	9.3	58	15	29	750
	8	9.35	66	17	29	750
	9	9.4	73	17	30	750
	10	9.45	80	17	30	750
	11	9.5	86	17	30	750
	12	9.55	87	15	30	750
	13	10	90	15	31	775
	14	10.05	91	15	31	775
	15	10.1	93	14	31	775
	16	10.15	94	15	31	775
	17	10.2	96	15	31	775
	18	10.25	97	16	31	775
	19	10.3	98	16	31	775
	20	10.35	98	16	31	775

Performance evaluation

The efficiency was calculated with the following equations:

$$\eta = \frac{10^3 \cdot E_\mathrm{p}}{\int_{t=0}^{t_\mathrm{p}} [(Gbave) \times A_\mathrm{s} \times \mathrm{d}t]} \times 100 \tag{1}$$

where E_p is the total heat energy, t – the time; *Gbave* – the beam radiation at time t, and A_s – the aperture area of the Scheffler reflector which is also a variable function whose value can be determined for any day of the year by the formula:

$$\text{Aperture area} = \text{Reflector area} \times \cos\left(\frac{43.23° - \text{seasonal angle deviation of the Sun}}{2}\right) \tag{2}$$

Different equations were used to calculate solar declination for all the days of the year. The equation quoted by Duffie *et al.* [9] with least error (<0.035°) is used for calculation of solar declination:

$$\begin{aligned}\delta &= (180/\pi)\,[(0.006918 - 0.399912)\cos(n-1)2\pi/365 + \\ &+ 0.070257\sin(n-1)2\pi/365 - 0.006758\cos 2(n-1)2\pi/365 + \\ &+ 0.000907\sin(n-1)2\pi/365 - 0.002679\cos 3(n-1)2\pi/365 + \\ &+ 0.00148\sin 3(n-1)2\pi/365]\end{aligned} \tag{3}$$

where n is the day of the year.

Funk [18] described the procedure for evaluating different types of solar cookers and his research was focused on the influence of test conditions on results minimization if uncontrolled variables are held to certain ranges. He has used water for the evaluation of the cookers in terms of power. For the performance test with water only, following equation was used:

$$E_\mathrm{p} = m_\mathrm{w} c_\mathrm{w} \frac{\Delta T}{3600} \tag{4}$$

where m_w is the mass of water used, C_w – the specific heat at constant pressure (for water 4.187 kJ/kgK), and ΔT [K] – the change in temperature for a specific time.

The average power available, P_{ave}, during the experiment is given as:

$$P_\mathrm{ave} = \frac{E_\mathrm{p}}{t_\mathrm{p}} \tag{5}$$

where t_P is the total process time.

In between the beam radiation range of 700 to 800 W/m^2, Scheffler reflector showed that about half of the solar power collected by the reflector becomes finally available in the cooking vessel. The details of one performance evaluation of the solar system with 20 liter of water on February 21, 2010 is shown in tab. 1. Figure 2 illustrates the variation of water temperature and solar radiation.

During the performance evaluation test with 20 liters of water, 2.000 ml water was evaporated. The average power and efficiency in terms of water boiling test was calculated to be 1.30 kW and 21.61%, respectively, against an average value of beam radiations of 742 W/m^2. This efficiency figure relates to the perfection of the reflector surface area, its reflectance, absorbance of the outer surface of the distillation tank exposed to radiations and insulation of the remaining surface. The results are also compared with the result obtained by the other investigator. Our results are in good agreement with the investigator mentioned in paper.

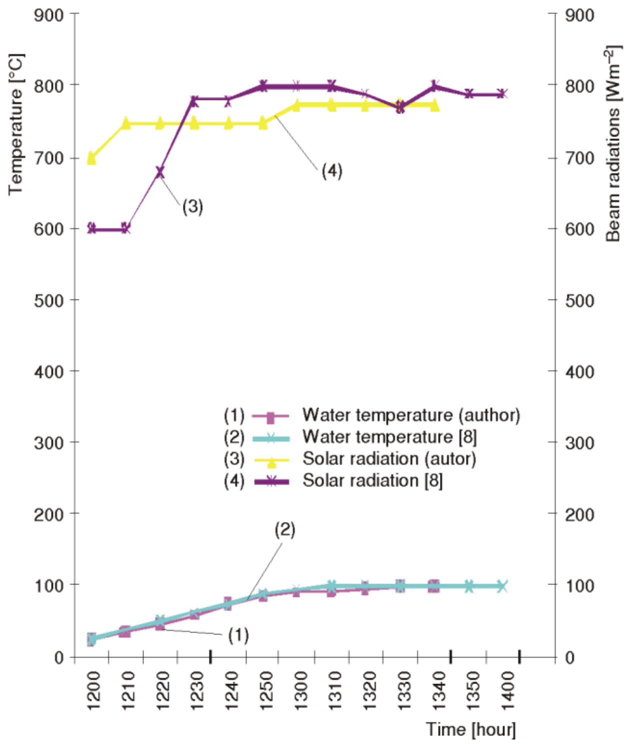


Figure 2. Variation of solar radiations and water temperature

Conclusions

The present study was conducted with one of most temperature sensitive process industry using solar energy. This study also concludes that these types of innovative solar concentrators can open new landmarks in decentralized solar based systems. In addition, other benefits like reduction of fossil fuels consumption and global warming cannot be ignored. The study also suggests that such types of systems must be equipped with necessary mountings and instrumentations to monitor and control the desired thermal parameters during temperature sensitive industrial processing.

Nomenclature

A_s – aperture area of the Scheffler reflector
C_w – specific heat at constant pressure, $[kJkg^{-1}K^{-1}]$
E_p – total heat energy
Gbave – beam radiation at time *t*, $[Wm^{-2}]$
m_w – mass of water used
P_{ave} – the average power available
ΔT – change in temperature for a specific time, [K]
t – time, [hour]
t_P – total process time, [hour]

References

[1] Scheffler, W., Introduction to the Revolutionary Design of Scheffler Reflectors, 6th International Conference on Solar Coockers, Granada, Spain, 2006, e-mail: Info@Solare-Bruecke.org
[2] Oelher, U., Scheffler, W., The Use of Indigenous Materials for Solar Conversion, *Solar Energy Materials and Solar Cells, 33* (1994), 3, pp. 379- 387
[3] ***, www.prince.com

[4] Jayasimha, B. K., Application of Scheffler Reflectors for Process Industry, 6th International Conference on Solar Cocker, Granada, Spain, 2006
[5] Scheffler, W., Development of a Solar Crematorium, 6th International Conference on Solar Cooker, Granada, Spain, 2006
[6] Varghese, J., Batch Type Solar Water Heater, Thesis Submitted to S. G. Amravati University, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, India, 2000, pp. 28-32
[7] ***, http://www.solare-bruecke.org/English/scheffler_e-Dateien/scheffler_e.htm.
[8] Munir, A., Hensel, O., Solar Distillation for Essential Oils Extraction – A Decentralized Approach for Rural Development, International Solar Food Processing Conference, Indore, India, 2009
[9] Duffie, J. A., Beckman, W. A., Solar Energy Thermal Processes, John Wiley and Sons, New York, USA, 1991
[10] Cetiner, C., *et al*., Generating Hot Water by Solar Energy and Application of Neural Network, *Applied Thermal Engineering 25* (2005), 8-9, pp. 1337-1348
[11] Thomas, A., Guven, H. M., Parabolic trough Concentrators – Design, Construction and Evaluation, *Energy Conversion and Management, 34* (1993), 5, pp. 401-416
[12] Odeh, S. D., Morrison, G. L., Behnia, M., Modeling of Parabolic trough Direct Steam Generation Solar Collector, *Solar Energy, 62* (1998), 6, pp. 395-406
[13] Halici, F., *et al*., The Investigation of the Performance of a Fix-Focused Parabolic Concentrator, *Proceedings*, 12th National Heat Science and Technology Congress (ULBTK_99), Sakarya, Turkey, 1999
[14] Kalogirou, S. A., Parabolic trough Collectors System for Low Temperature Steam Generation: Design and Performance Characteristic, *Applied Energy, 55* (1996), 1, pp. 1-19
[15] Garg, H. P., Prakash, J., Solar Energy for Industrial Process Heat, in Solar Energy Fundamentals and Applications, Tata McGraw-Hill, New Delhi, 2006
[16] Zhai, H., *et al*, Experimental Investigation and Analysis on a Concentrating Solar Collector using Linear Fresnel Lens, *Energy Conversion and Management, 51* (2010), 1, pp. 48-55
[17] Munir, A., Hensel, O., On-Farm Processing if Medicinal and Aromatic Plants by Solar Distillation System, *Biosystems Engineering Journal, 106* (2010, 3, pp. 268-277
[18] Funk, P. A., Evaluating the International Standard Procedure for Testing Solar Cookers and Reporting Performance, *Solar Energy, 68* (2000), 1, pp. 1-7

Paper submitted: February 25, 2010
Paper revised: April 13, 2010
Paper accepted: August 9, 2010