Experimental Investigation of Thermal Performance of Scheffler Reflector in India

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Abstract—*In this article, the thermal performance of Scheffler reflector is experimentally investigated by using modified and new designs of receivers. In the experimental setup, the receiver was placed on fixed focusing point of Scheffler reflector (2.7m2). Solar radiations falling on this reflector and it concentrate radiations at a point on the receiver. The receiver receives these radiations from the front side and water in the receiver gets heated. This reflector rotates during sunshine hours. It has been found that water temperature increases by23.7℃, 44℃ and 49℃withinone hour for beam radiation in the range of 750-850 W/m2 for plane receiver, receiver with black coating and receiver with black coating with glazing both respectively. The efficiency ofplane receiver, receiver with black coating and receiver with black coating and glazing both is found as 17.7%, 32.2% and 35% respectively*.

Keywords—Thermal performance, Scheffler reflector, Designs of receivers

I. Introduction

As conventional energy sources are depleting at a very fast rate, so we need renewable energy sources. Solar energy has become one of the most reliable alternative energy resources as it is free, eco-friendly and sustainable. Solar energy has the capacity to play a remarkable role in replacing conventional fuels. From last few decades, solar energy is used for different applications using different types of collectors. The important applications are hot water production, sterilizing, extraction, pasteurizing, drying, solar cooling, air conditioning, distillation, evaporation, washing, cleaning and polymerization.

German Scientist Wolfgang Scheffler has constructed a parabolic reflector for utilizing solar energy. The first well-functioning Scheffler-Reflector (size: 1.1m x 1.5m) was built in 1986 at a mission-station in North-Kenya and is still in use. It is a low cost set up which can be used in rural areas in India. The biggest solar kitchen of the world in Abu Road, Rajasthan (India) is catering for up to 18,000 visitors to a Yoga center.

Oelher U. and Scheffler W. [1994] presented two examples of applications of solar technology. One is solar cooker made of a polymer based insulated material and the other one is solar hybrid kitchen employing fixed focus concentrator. This system is easy to construct, fulfill human needs and ecofriendly.

Chandak A. et al. [2009] designed and experimented with multistage evaporation system for production of distilled water. Two Scheffler concentrators of 16 m^2 were used for generating steam, in first stage at 8 bar pressure and pressure is gradually brought to 1 bar in four stage distillation unit. It was found that this system has great potential in food processing industry for applications of juice thickening, sauces, jams, salt concentrating systems and distilled water applications.

Munir A. [2009] studied and experimented the decentralized agro-based industries by using innovative solar collectors which can open new landmarks in rural development especially in tropical countries. Essential oils extraction from herbs through distillationprocess, is one of the medium temperature agro-based industries. These oils are used in food, medicines, fragrances, perfumery and cosmetics. Receiver temperatures were recorded between 300-400°Cfor beam radiations range of 700-800 W/m^2.

Munir A. and Hensel O. [2010] studied and investigated distillation method of extracting refine essence of plant materials and herbs by evaporating volatile components. Research optimize thermal parameters and develop simple and best methodologies for easy adaptation of this technique for decentralized applications using solar energy. It was found that system power and efficiency of solar based system to be 1.58 kW and 43.25% respectively.

Munir et al. [2010] studied and developed Scheffler fixed focus concentrator of 8m^2 surface area for medium temperature applications. The study concludes that the simple tracking mechanism is used for daily and seasonal tracking of the sun. The design procedure is simple, flexible and does not need any special computational setup, thus offering a huge potential for application in domestic as well as industrial configurations.

Munir A. and Hensel O. [2010] presented development, evaluation and experimented an on-farm solar distillation system for functional, environmental and economic reasons. The system comprises of primary reflector (8m^2), secondary reflector, distillation still, condenser and Florentine flasks. The temperature at the focus was recorded as between 300-400°C for beam radiation in the range of 700-800 W/m^2. The average power and efficiency of the system were found to be 1.548 kW and 33.21% respectively.

PatilR.J.et al. [2011] tested the performance of Scheffler reflector of 8 m^2 with the help of a drum of 20-liter capacity. The performance of Scheffler reflector was analyzed by average power and efficiency in terms of water boiling test. The maximum temperature attained by water is 98°C on clear sunny day and ambient temperature varies from 28° C to 31° C within 1.5 hours.

Rout S.K. [2011] studied and described how effectively hoteliers and corporate can utilize solar energy. It involves the usage of Scheffler, solar parabolic reflectors, solar ovens, solar cookers, solar dryers, solar water heaters, biomass gasifiers, biogas plants etc. The digested slurry of biogas plant is used as humus rich fertilizer for spice garden. This method may also be implemented in vast rural mass and community center for cost effective and hygienic food production.

DafleV.R. et al. [2012] designed, developed and analyzed experimentally the performance of 16 m^2Scheffler reflector. Scheffler along with mild steel absorber plate was evaluated in February. It was observed that radiation varies from 620 W/m^2 to 937 W/m^2 and maximum temperature attained by steam is 107°C. This paper has concluded that Scheffler technology is having better efficiency than other technologies.

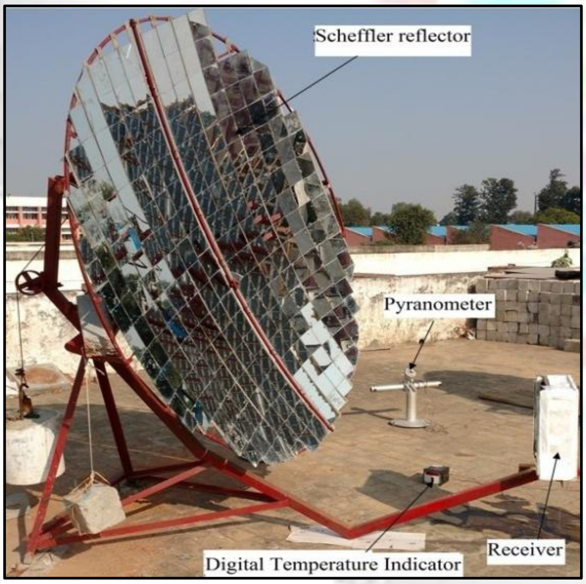
Ruelas J. et al. [2016] developed a new mathematical model of a Scheffler-type solar concentrator (STSC) with 3 kWe Stirling engine. In the experimental setup, the sterling engine is placed at the focal point which converts heat energy into electricity. The results showed for the determination of the focal length, which demonstrates that the largest concentration using the STSC with a rim angle of 45^0 is similar to the concentration achieved with a parabolic dish, but the receptor improves the efficiency by 7% compared with parabolic dishes.

Many researchers have worked on Scheffler reflector for different applications. But none of them worked on the improvement of efficiency of Scheffler reflector by modifying and using new designs of receivers. The objective of this paper is to investigate the thermal performance of the Scheffler reflector in Indian climatic condition. The experimental setup is installed at Kurukshetra, India [29°58´ (latitude) North and 76°53´ (longitude) East].

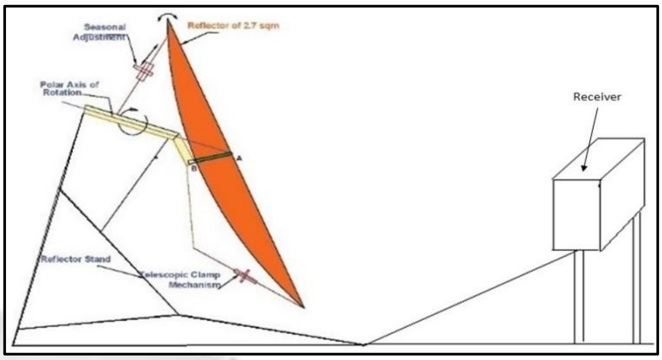
II. Experimental setup

This experiment is performed to investigate the thermal performance of Scheffler reflector. This system is shown in figure 1. The experimental setup consists of following components:

1) Scheffler Reflector
2) Receiver



(a)



(b)

Fig. 1: (a) Photograph of the experimental setup and (b) Schematic diagram of experimental setup

A. *Scheffler reflector*

The Scheffler reflector is a point focusing concentrator. The sunlight falls on the reflector, is reflected sideways to the focus. The focus is located at some distance from this reflector. The axis of rotation of Scheffler is lined up parallel to earth axis and runs through the center of gravity of the reflector. Reflector always sustains its gravitational equilibrium and it rotates in the east-west direction with the help of the mechanical tracking device. With the help of mechanical tracking mechanism, the dish is rotated to chase the sun from morning to evening. The focus is positioned on the axis of rotation to prevent it from moving when the reflector rotates. During the day, the concentrated light rotated around its own center, but not moves in any direction. So, the focus is fixed.

Major axis	2.2 m
Minor axis	1.6 m
Focal length of reflector	0.8 m
Area of reflector	2.7 m^2
Concentration ratio of reflector	135

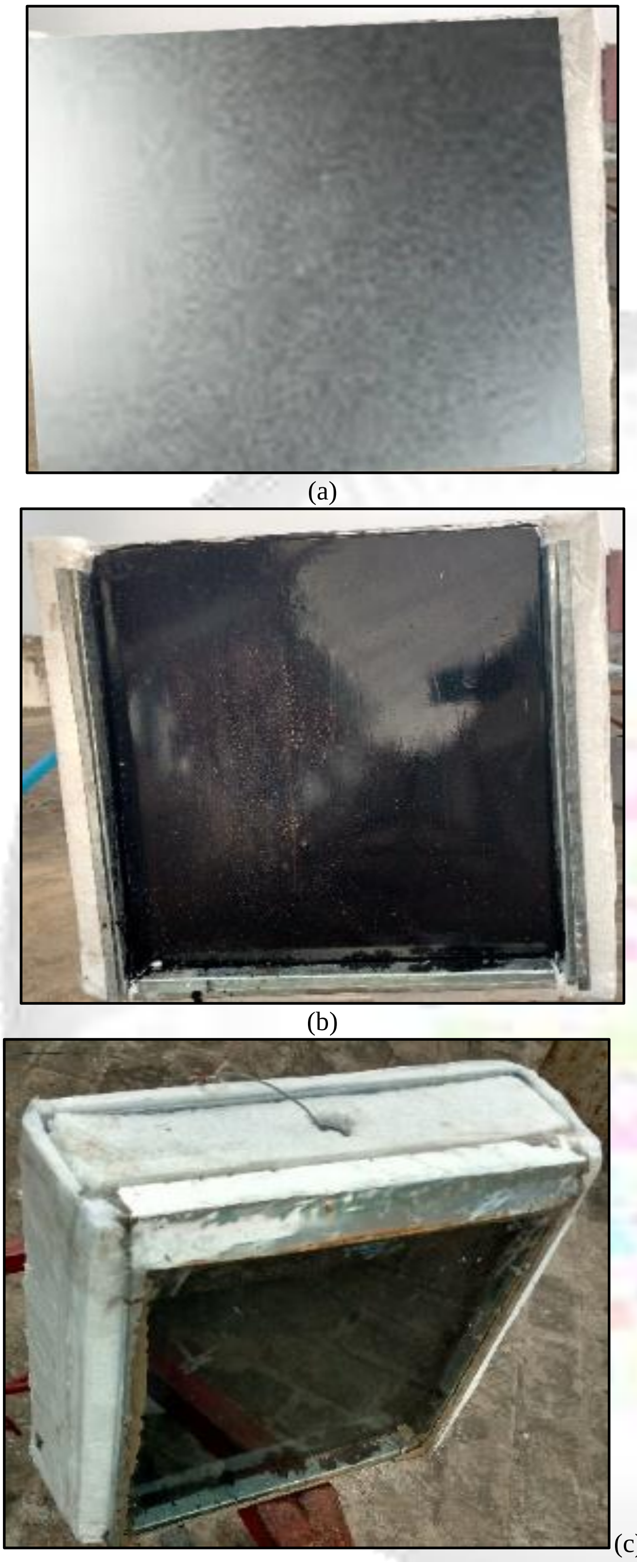
Table 1: Specifications of Scheffler Reflector

B. *Receiver*

The receiver is of a cuboidal shape of dimensions 400mm*400mm*90mm. The receiver is made up of tin material and of capacity 14 liters. A valve is provided on the top of the receiver for water filling and it is fully closed. Thermocol is used for insulation.

In the experiment, we are using cuboidal receiver in three ways:

1) Plane Receiver.
2) Receiver with black coating on front face.
3) Receiver with black coating and glazing both on front face.



(a)

(b)

(c)

Fig. 3: (a) Photograph of plane receiver, (b)Photograph of receiver with black coating and (c)Photograph of receiver with black coating and glazing both

III. MEASURING DEVICES & INSTRUMENTS

The parameters measured were water temperature, solar radiation, wind speed and ambient temperature. Water temperature was measured with thermocouple which was connected with a digital temperature indicator that shows the temperature with a resolution of 0.1℃. Wind speed was measured by Anemometer. Ambient temperature was measured using Hygrometer. A Pyranometer was used to measure the radiations.

IV. SYSTEM OPERATION

In the experiment, water was filled in the receiver and the system was exposed to solar radiation. Solar radiation was incident on Scheffler reflector and these radiations are reflected. These reflected rays are incident on the receiver which is placed at the focus of the Scheffler reflector. With the help of mechanical tracking device, primary reflector rotates about an axis parallel to the axis of rotation of the earth. A thermocouple is installed in the water of the receiver to measure water temperature. After every 10 minutes, the temperature is measured in all three cases for one hour. Other parameters like solar radiation, wind speed, and ambient temperature are also measured in every 10 minutes.

V. ANALYSIS OF EXPERIMENTAL DATA

The efficiency is calculated with the following equation:

$$\eta_{overall} = \frac{\text{heat gain} \times 10^3}{\int (\text{radiation} \times \text{aperture area})dt}$$

Where, dt is the time for which setup is exposed to solar radiation.

Aperture area–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 following formula:

$$\text{Aperture area} = \acute{\eta} \times \text{Design area} \times \cos\frac{(43.23 - \text{seasonal angle deviation of sun})}{2}$$

Where, $\acute{\eta}$ is the area efficiency (ratio actual area on which mirrors could be placed to the design area) which in our case is 93%, Seasonal angle deviation of the sun which in our case 23^0, design area is $2.7m^2$.

For the performance test with water, following equation is used:

$$\text{Heat gain} = \frac{m_w \times c_w \times \Delta T}{3600}$$

Where m_w is mass water which in our case is 14 kg. c_w is the specific heat at constant pressure (for water 4.187 kJ/Kg-K).

ΔT is the difference between initial and final temperatures of water recorded in each case.

VI. EXPERIMENTAL RESULTS & DISCUSSION

In the experiment, water heating was conducted at day time using a Scheffler reflector and receiver. The performance of the Scheffler reflector is studied for all three cases of the receiver. The experiments were conducted on 16th December 2017. Setup was exposed to solar radiation at 09:30hr and readings were taken from 09:30hr to 12:45hr.

A. Plane receiver from 09:30 hr to 10:30 hr; December 16th,2017:

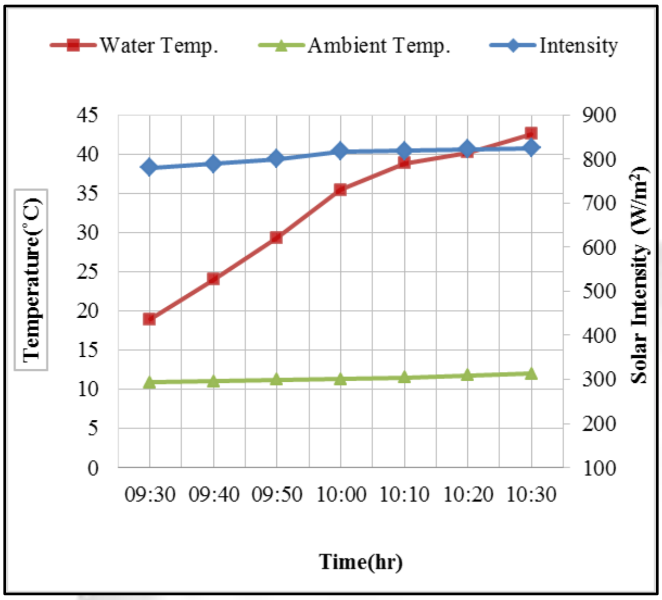


Fig. 4: Variation of temperature and solar radiation intensity from 09:30 hr to 10:30 hr;December 16th, 2017

Figure4 shows the variation of water temperature and solar intensity with time from 09:30 hr to 10:30 hr on December 16th, 2017. At 09:30 hr, water temperature was 18.9°C and solar intensity was 780W/m^2.At 10:30 hr, water temperature was 42.6°C and solar intensity was 825 W/m^2.During the 09:30 hr to 10:30 hr, the maximum intensity was 825W/m^2 at 10:30 hr and the ambient temperature was in the range of 10.9°C to 12°C. The maximum temperature of water was 42.6°C. Water temperature was increased continuously till 10:30 hr.

B. Receiver with black coating from 10:35 hr to 11:35 hr; December 16th, 2017:

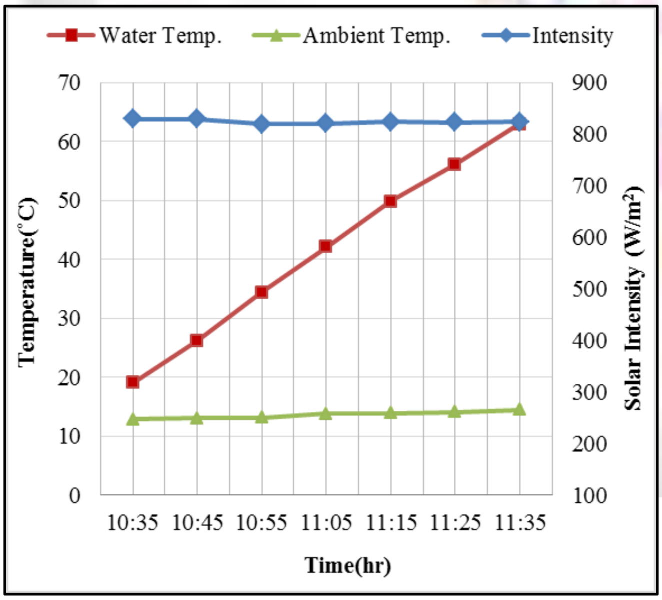


Fig. 5: Variation of temperature and solar radiation intensity from 10:35 hr to 11:35 hr;December 16th, 2017

Figure5 shows the variation of water temperature and solar intensity with time from 10:35 hr to 11:35 hr on December, 16th 2017. At 10:35 hr, water temperature was 19°C and solar intensity was 829 W/m^2. At 11:35 hr, water temperature was 63°C and solar intensity was 824 W/m^2. During the 10:35 hr to 11:35 hr, the maximum intensity was 830 W/m^2 at 10:45 hr and the ambient temperature was in the range of 12.8°C to 14.5°C. The maximum temperature of water was 63°C. Water temperature was increased continuously till 11:35 hr.

C. Receiver with black coating and glazing both from 11:45 hr to 12:45 hr; December 16th, 2017:

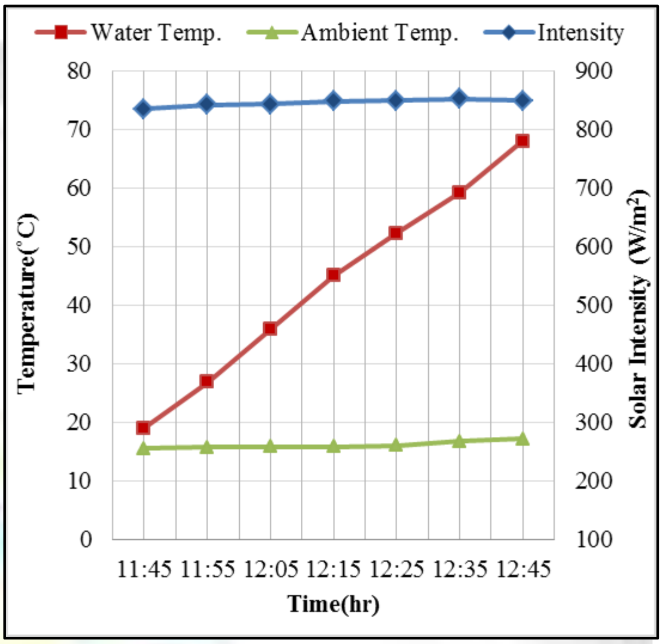


Fig. 6: Variation of temperature and solar radiation intensity from 11:45 hr to 12:45 hr;December 16th, 2017

Figure6 shows the variation of water temperature and solar intensity with time from 11:45 hr to 12:45 hr on December, 16th 2017. At 11:45 hr, water temperature was 19°C and solar intensity was 835 W/m^2.At 12:45 hr, water temperature was 68°C and solar intensity was 849 W/m^2. During the 09:30 hr to 10:30 hr, the maximum intensity was 852 W/m^2 at 12:35 hr and the ambient temperature was in the range of 15.6°C to 17.2°C. The maximum of water was 42.6°C. Water temperature was increased continuously till 12:45 hr.

D. Comparison of efficiency for different cases:

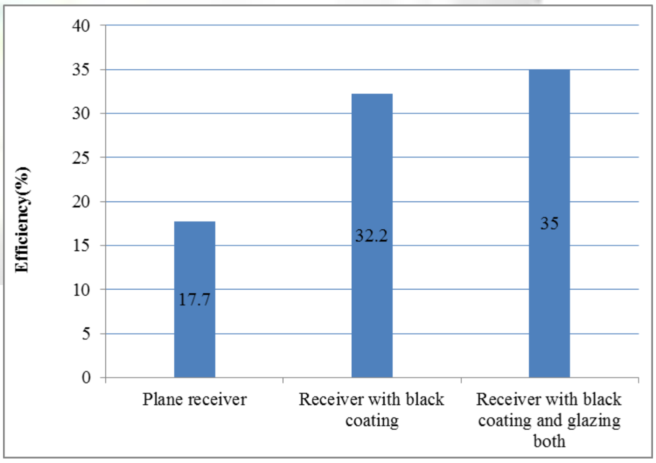


Fig. 7: Comparison of efficiency of Plane receiver, Receiver with black coating and Receiver with black coating and glazing both

In different cases of the experiment performed, the efficiencies are compared and plotted in figure 7. The efficiency of plane receiver, receiver with black coating and receiver with black coating and glazing both are 17.7%, 32.2% and 35% respectively.

VII. Conclusions

During the water heating process, the temperature differences are observed as 23.7℃, 44℃ and 49℃when plane receiver, receiver with black coating and receiver with black coating and glazing both are used respectively.

The maximum heat stored by water for plane receiver, receiver with black coating and receiver with black coating and glazing both is found as 1389 kJ, 2579 kJ and 2872 kJ respectively.

The efficiency forplane receiver, receiver with black coating and receiver with black coating and glazing both is found as 17.7%, 32.2% and 35% respectively.

Receiver with black coating and glazing both is found more efficient as compared to plane receiver and receiver with black coating.

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