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Research Article

Experimental investigation of a Scheffler reflector for the medium temperature applications

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ABSTRACT

This research problem reveals the experimental investigation at a pressure of 1.5 bar and temperature of 120°C for the medium thermal applications utilizing the four Scheffler reflectors with 16 m^2 surface area each. The Scheffler collector associated with absorber plate of mild steel of size, 0.45 m diameter, and 0.025 m thick was assessed in June 2018. The variation in solar beam radiation over the entire day was observed from 840 W/m^2 to 1278 W/m^2, while, the absorber plate temperature was recorded within the extent of 116–195°C, however, the maximum heating temperature was measured 129°C at the end-use. The Scheffler collectors performed appropriately in the morning and evening time with substantial heat loss factor and lower optical efficiency factor. The energy efficiency of 59.28% has been achieved which is higher as compared to the parabolic solar concentrator. The higher concentration ratio of the Scheffler collector indicates it as an efficient substitute to replace fossil fuels. The system is viable for more than 1600 kWh/m^2 yearly solar potential while the cost of heating is greater than 0.05 $/kWh for them. This paper concludes that the Scheffler reflector is the most promising solar technology for the medium-temperature applications.

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INTRODUCTION

India suffers tough challenges to accomplish the requirement of energy, its need can be encountered even some extent in sustainable modus at the different competitive prices. If India wants to eradicate poverty and set human development goals, it requires to endure an economic growth rate of 8–10% over the next 25 years.

Now the power generation capacity is 1,80,760 MW from all the plants, it must be increased approximately 8,00,000 MW by 2022. Currently, the industrial thermal demands are executed by using traditional fossil fuel sources such as oil, gas, and coal. The limitations prevail to exploit these energy sources. The needs must be encountered through technical efficient, safe, economically viable, clean, and atmospherically sustainable modus. Since the source of solar energy is dispersed in the universe everywhere and it leads us from low to high temperature and pressure applications. It would be the standard as it is a neat

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and clean and plentifully found source of the energy on the earth.

The technology of Scheffler concentrator is one of the greatest technologies for the industrial, as well as the domestic demands, exist for thermal applications such as water heating and steam generation. Mr. Wolfgang Scheffler developed the fixed focus concentrator which has been established as a milestone in the harnessing of solar thermal energy for different uses. A viable option of solar concentrating technology needs to grow for the joint applications of water heating and steam generation [1–2].

In this context, the performance of the Scheffler collector was assessed with the 20 l capacity of a drum situated at the focal point, which serves twofold purposes such as the absorber and the storage tank. A generalised data-based model was developed using the experimental results for the evaluation [3]. The movement of the sun is tracked by the concentrating primary reflector, which focuses sunlight on a fixed area. A very large pot is heated by these focused sun rays. This heat can also be utilised for various applications such as water heating, cooking, generation of steam, baking loaves of bread, heating, and incineration, etc. A water storage tank cum absorber plate placed at the fixed focus of the Scheffler collector is utilised for the providing of the hot water and steam for the domestic aims [4]. A study explains the mean temperature range required for the most important industrial processes such as; extraction, sterilising, pasteurising, solar cooling, distillation, drying, and air conditioning, hydrolysing and evaporation, cleaning and washing, and polymerisation. The temperature level of all the above processes has been found between 60°C and 280°C [5].

In order to get the cooling by the solar energy-operated absorption system, a parabolic trough collector with an absorber was installed. These kinds of collectors can successfully be used in baking, distillation, solar community kitchen, water distillation, etc. The comparative study has shown that the paraboloidal dish collector with two tracking axes facing towards the sun has a better design for concentrating technology and that has justified the best utilize of the Scheffler collectors for the industrial thermal usages [6].

The medium temperature applications range of 300°C can be delivered by the Scheffler concentrators which is technically fit for the medium thermal processes [7]. In an evaluation, a receiver was installed at the focal point which absorbs all the concentrated thermal radiations and converts them into the heat to be utilised in the consequent processes. The main function of a receiver is to engage the utmost quantity of the reflected solar energy and provide it to the working medium with the least amount of energy losses [8].

A Scheffler collector of 2 m^2 area integrated with an absorber as a receiver cum water storage of 2 l capacity was designed and developed. Different experiments were conducted on this experimental set-up to assess its efficiency as well as mean power at a fixed level of water internally the tank as a receiver. It obtained 1.3 kW mean power and 21.61% energy efficiency in the duration of the boiling test [9].

A researcher originated an idea of an industrial oven operated by the Scheffler collector with 16 m^2 surface area and experimented with it in Dhule's weather conditions, India. This pioneering research could generate nearly 9 kW thermal power which is the best suitable for the various industrial processes in a range of 100–200°C [10]. A multi-stage evaporation system associated with Scheffler solar collectors was designed, evolved, and analysed at different operating conditions. The results of this evaluation were very encouraging for commercial scale applications [11]. It was found that the Scheffler reflectors can also be utilised for refining the raw oils in a research laboratory and in the distillation systems. The key purpose of this investigation was to determine the optimal thermodynamic parameters and to originate simple and competent methods for easy adoption and decentralised applications [12]. A parabolic trough solar collector was designed, manufactured, and analysed for the generation of the steam. The fixed focus located black absorber was illuminated by the Scheffler collector. The water contained in this absorber was heated to convert into the steam [13].

An oil extraction system was evolved and operated by the Scheffler collector of 6 m^2 surface area. The chief purpose of this exploration had to compare the performance of the Scheffler reflector-operated oil extraction system to the conventional system. They offered a new idea of the hybrid system for the rainy and off-sunshine days, in which the Scheffler reflector was coupled to a biomass gasifier to obtain the higher temperature to an alone Scheffler system [14].

A combined reflector storage solar water heater was evolved and analysed thermodynamically. The purpose of this design was to fulfil the requirement of hot water of a four member family during a few sunny days and nights. The calculations detail can be used in an accurate prediction of the system performance as per the requirement. An experimental analysis of a parabolic trough reflector with 2.2 m diameter was performed, in which a reflecting surface covered the interior surface, which concentrates sunlight at the fixed focus, where a disc receiver was equipped [15, 24]. A data logger was installed to evaluate the temperature profile inside the receiver in the experimental environment [16]. A Scheffler collector of 8 m^2 area was designed and investigated with the principle of medium temperature applications. In this paper, the designing method is very easy, resilient, and does not require any distinctive computational setup, for desirable domestic as well as industrial applications [17, 25].

A researcher Jayasimha used Scheffler's collector explored by Scheffler that can avail about the half quantity of solar power to the cooking vessel at the focus. The steam generation using the solar energy cookers has now been an economically, attractive, and possible way in which the payback period is between 1.5 years and 2 years. These solar cookers have reasonably been feasible if they are utilised frequently. This technology is an economical provision for small-scale applications such as in the agriculture, food industry, and post-harvest technology [18, 26].

The above-mentioned solar energy systems are often used for various purposes. Therefore, the study of the Scheffler collector is highly desirable so that the exact technology could be developed with quantitative performance characteristics. The **purpose of this article** is to analyse experimentally the concentrating Scheffler reflector based on energy approach for the medium temperature applications of the domestic as well as industrial uses.

Since the scarcity of energy is increasing day by day. The solar thermal power is free and feasible to harness which is falling on the earth. It **motivates** us that the solar beam radiation obtained on a given surface area at a given time should be captured. The average solar insolation at the full sun is 1 kW/m^2 all over the globe. There are changes in the solar insolation during the day. Consequently, the obtained power output is varied the whole day. Henceforth, it is significant to harness the maximum power from a solar light at a given time. To make these operations, numerous Maximum Power Tracking devices are utilised.

OPERATING PRINCIPLE OF SCHEFFLER REFLECTOR

Scheffler reflector was designed and developed by Mr. Wolfgang Scheffler that has been set up as a standard in harnessing solar energy in solar technology. The Scheffler reflector is made spin about an axis parallel to the polar axis which passes through the North and South Pole. The direction of rotation of Scheffler collector and earth is opposite thus, it cancels out the earth's rotation, and as a result, the face of the reflector is always towards the sun. This is acknowledged as polar mounting or mounting on a polar axis. The length between the focus and centre of the collector is determined by the constructive parabola. The incident light on the absorber rotates about its own axis all day and doesn't spread at the edges of the receiver thereby light focuses at a fixed point and the receiver does not even spin. The speed of the reflector is counted as one revolution per day or better to say, half a revolution in a day because it is not used at night. A mechanical tracking device known as clockwork is used to maintain the constant speed of the reflector. The change in inclination and deformation of the reflector is a mechanically combined work: the two pivots, one is in the centre of the collector and the other one is at each side of the framework of the collector but does not stay on one straight line due to the location of first one pivot below side pivots.

This method provides the inclination of the collector and has towards a change in its deepness; hereby, the centre of the reflector is raised (crossbars' big radius) or lower (crossbars' small radius) regarding the framework of the collector. It is enough to regulate the topmost and bottommost end of the reflector to their specific position to get a suitable and precise reflector shape. The fixation of each end of the reflector is executed by the proper coordination of a telescopic bar. The reflector -shape must be adjusted manually every 2–3 days. When all the concentrated light is on the focus, where the receiver is mounted, the reflector is stated to achieve the correct and required shape.

Once the effulgence is cast on the receiver and the clockwork is working, the sun rays keep on concentrating on the receiver over the whole day. Since the distance between the sun and earth varies seasonally so the angle between the axis of the collector and its revolution as well as the shape of the reflector must be doing change from time to time. The Scheffler reflector is made of numerous flat glass mirror or acrylic mirror facets. The day-to-day rotational axis passes through the centre of gravity of the collector and thus, the gravitational equilibrium of the reflector is always upheld and there is no essential to enforce so much force by the mechanical tracking device (i.e. clock mechanism) to revolve the reflector. The inclined cut yields a definite elliptical appearance of the concentrating Scheffler reflector. The generated heat by this Scheffler technology is carried by the water into the receiver, from where it can be achieved for numerous domestic as well as commercial uses. Owing to the practical goals, the shape of the reflector is established in such a way that the concentration of the light is constantly made exterior of the reflector, either on the northern sideways or the southern sideways. In such a way, the reflector concentrates the light at its focal point inside the building while it remains outside perpetually [1, 17, 23, 27, 28].

METHODOLOGY

Experimental Perspective

In the experimental perspective, initially, the raw water stored in a tank passes into an osmosis plant (R.O.) where entire impurities and the hardness are removed with priority. After the osmosis process, the pure water is again stored in the pure water tank. Now, this pure water is circulated into the insulated and placed down pipeline around the collectors. The nitrogen gas is injected with pure water in the pipeline so that the conversion of water into the vapour could be stopped. The pure water circulates through the receivers installed in the fixed position at the focus of the reflector. The reflector focuses the sun rays at the fixed point where the receivers are installed, whatever the amount of water passes through the receiver that gets heated because of the higher temperature provided by the collector and then this warm water is passed towards the end practices.

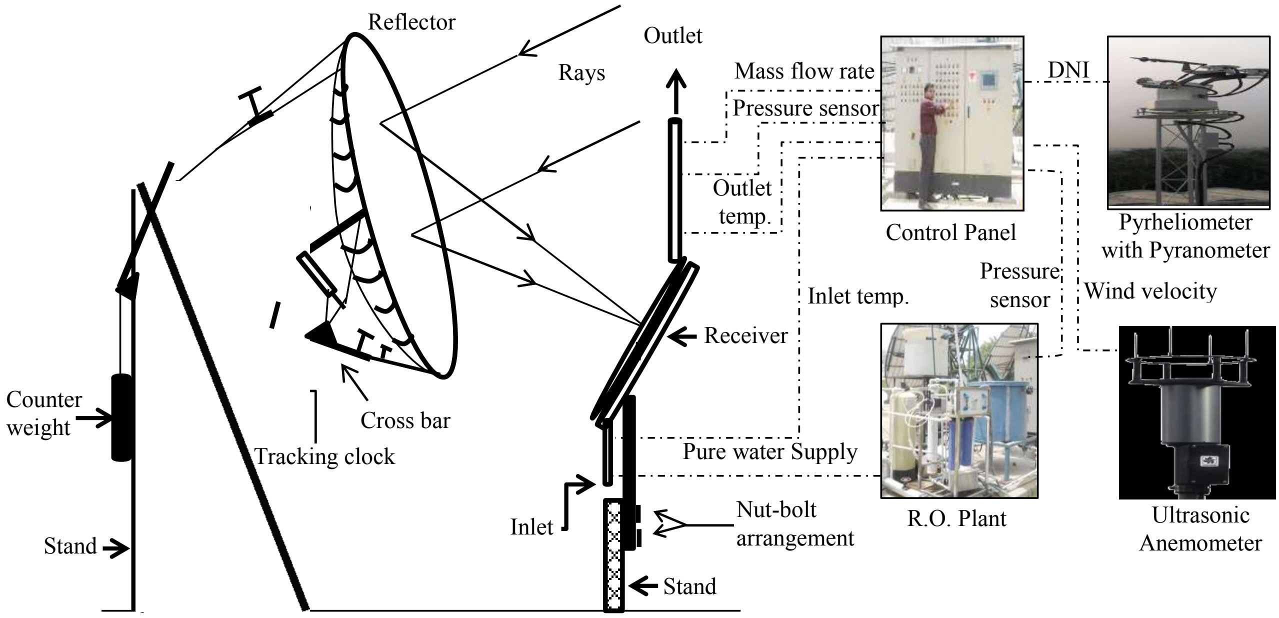

Figure 1. Schematic view of the experimental device with instrumental set-up.

Now all essential parameters are noted in this running condition of the system.

Experimental Appliance with Measuring Instruments

The experimental appliance and its measuring instruments are demonstrated in Fig. 1. The experimental setup comprises the Scheffler reflector, receiver, piping, and its united instruments like fittings, valves, etc., feed pump, and osmosis plant. The data collection device is linked to several measuring instruments such as a pyranometer and pyrheliometer for solar beam radiation, ultrasonic anemometer with an inbuilt digital thermometer for wind velocity and environmental temperature, flow meter (rotameter), pressure and temperature sensors of flowing water (K-type thermocouple of range from –200°C to 1250°C).

The different radii arcs are signed out on the best templates. The crossbars are made of circular mild steel rods, which are cut according to the arc length. These circular mild steel rods are then bent as per signed-out arcs on the templates and these rods get a shape of curves. These curve rods are welded on the reflector frame as per signed-out position after the accomplishment of its straightness examinations. Now, the precision and evenness of the curved rods are made by using the device jig. A primer is coated on the reflector's frame and then a good quality paint is applied to protect it from corrosion. Subsequently, primarily, the aluminium profiles are set to provide the needed shape to the reflector and then these are attached with the crossbars with the help of mild steel wires and now, the silicon glue is utilised to stick the aluminium reflecting sheets on the aluminium profiles to give the final appearance of the paraboloid. The aluminium reflecting sheets are extremely secular aluminium sheets, which have an exceptional capability to achieve the standard of the medium temperature applications.

As demonstrated in Fig. 1, the mass flow rate inside the water flowing pipe is measured by the sensor associated with the display of the control panel. One pressure sensor and two thermocouple sensors (type-K) were also fitted for making the measurements. The thermocouples were installed at the pipe's inlet and outlet as depicted in Fig. 1. An ultrasonic anemometer was also fitted to measure the wind speed. The pyrheliometer and pyranometer are used to measure the direct normal beam solar irradiation and global beam radiation respectively. The osmosis plant (RO water plant) was utilised to provide the purified water into the laid down pipeline when the pressure inside the pipeline is measured decreasing.

The measuring instruments for the pressure, temperatures, mass flow rate, wind velocity, and solar radiation

Table 1. Specification of Scheffler Collector

Make	Thermax Pvt. Ltd.
Maximum temperature at focal	1020°C
Maximum efficiency	84%
No. of collectors	4
Aperture area of each collector	16 m^2
Average DNI	700 W/m^2 Steel profiles and glass mirrors
Used materials	Steel profiles and glass mirror

Table 2. Apparatus accuracy

Item	Instrument	Device	Accuracy	Range
1.	Pyranometer	Kipp & zonen with model number CM4	±1 W/m²	0–4000 W/m²
2.	Pyrheliometer	Kipp & zonen with model number CHP1	±1 W/m²	0–4000 W/m²
3.	Infrared thermometer	Fluke 51 II Handheld Digital Probe Thermometer	±1°C	0–500°C
4.	Thermocouples	EMSON Pvt. Ltd. Ajmer	±1°C	–200°C to 1250°C
5.	Electronic manometer	COMARK C9507/IS-MANOMETER INTR SAFE	±0.2%	0–7 bar
6.	Data logger	DATA TAKER, Model No.-DT600 and Series-3	±1°C	0–1500°C
7.	Ultrasonic anemometer	R.M. YOUNG COMPANY, USA, Model No. YOUNG 85000	± 2%	0–70 m/s

were interconnected to the control panel. The record of data was made promptly of this experimental set-up and some inbuilt programs execute evaluation automatically. The data exhibited on the screen were in tabular form. The experimental investigation was performed in June 2018. More than 500 readings were noted during the experimental examination.

Thermodynamic Analysis

The thermodynamic analysis is imposed for the assessment of the thermal values such as; thermal capacity and thermal efficiency. The thermal capacity is called the rate of available heat which is contained by the solar light, while the thermal efficiency is known as the quantity of heat gained after the heating process of water against the input amount of the heat. For this investigation, the experimental data have been collected and the following formulae are applied:

According to Duffie and Beckman [19] the 'solar inclination' or seasonal angle deviation of sun for all the days of the year:

$$\delta = \frac{180}{\pi}\left[0.006918 - 0.399912\cos\frac{(n-1)2\pi}{365} + 0.070257\sin\frac{(n-1)2\pi}{365} - 0.006758\cos\frac{2(n-1)2\pi}{365} + 0.000907\sin\frac{2(n-1)2\pi}{365} - 0.002697\cos\frac{3(n-1)2\pi}{365} + 0.00148\sin\frac{3(n-1)2\pi}{365}\right] \tag{1}$$

If the aperture area is 'A_s' of the Scheffler reflector, its calculation can be performed for any day of the entire year by the under mentioned formulation:

$$A_s = \text{Reflector area} \times \cos\left\{43.23 - \frac{\delta}{2}\right\} \tag{2}$$

Energy efficiency of Scheffler dishes [3]:

$$\eta = \frac{\text{Total Power obtained by sun}}{\text{Power given by radiation}} = \frac{\text{P}}{\text{Beam radiation} \times \text{Aperture area}} = \frac{\text{P}}{\text{Average DNI} \times \text{Aperture area}} \tag{3}$$

Total power obtained by sun is given by:

P = mass flow rate×specific heat of water × (T_f – T_i) (4)

While, power given by radiation = Average DNI × A_s

The ratio of aperture area of reflector and receiver area is known as concentration ratio:

$$C = \frac{A_s}{A_r} \tag{5}$$

Pavlovic et al. [20] gives the financial evaluation i.e. Payback Period (PP) of the solar collector as follows:

$$PP = \frac{C_o}{A_s.YSP.\eta_m.C_{heat}} \tag{6}$$

Where, C_0 is capital cost of collector, η_m is mean thermal efficiency and C_{heat} is cost of heating.

$$\text{Heat loss factor, } FU_L = \frac{m_{pot}.C_{pot} + m_w.C_w}{A_{pot}.\tau_o} \tag{7}$$

Optical efficiency factor;

$$F\eta_o = \frac{\frac{FU_L.A_{pot}}{A_s}\left[\left(\frac{T_{wf}-T_a}{DNI}\right) - \left(\frac{T_{wi}-T_a}{DNI}\right)e^{\frac{-\tau}{\tau_o}}\right]}{\left(1 - e^{-\frac{\tau}{\tau_o}}\right)} \tag{8}$$

The heat loss factor FU_L and optical efficiency Factor $F\eta_0$ were calculated experimentally by the heating and cooling tests. In the heating test, a pot filled with 8 kg of water was placed at the fixed focus of the Scheffler reflector. The temperatures during the heating test were noted with an interval of 10 minutes till it reached 90°C to 95°C [Figure 2(a)]. When the water temperature reached 95°C, the cooling test was started. The reflector was totally blocked from solar radiation. Again, the measurements were made of falling temperatures at an interval of 10 minutes till the temperature of water got nearly to the atmospheric air temperature. [$\ln(T_w - T_a)$] was calculated for each reading of the cooling test and these values were plotted on Y-axis, while the time taken on X-axis [Figure 2(b)]. In this graph, the slope equals $\left(\frac{1}{\tau_0}\right)$, where τ_0 stands for time-constant of cooling curve. It is used to calculate FU_L, while τ is the time interval to evaluate the optical efficiency factor $F\eta_0$.

The rate of total heat loss $\dot{Q}_L$ at the receiver's surface is the summation of the heat losses due to the conduction, convection and radiation. Mathematically;

$$\dot{Q}_L = \dot{Q}_{\text{cond}} + \dot{Q}_{\text{conv}} + \dot{Q}_{\text{Rad}} \tag{9}$$

The glass cover is at the outer surface of the receiver, which gives the conductive heat loss, while, the study of the heat losses due to convection is very complex because it comprises of the free and the forced convections in which the major complicated part of heat losses are included. Kumar and Mullick [21] developed the following correlation for estimation of heat loss from the absorber to the glass cover as well as from the glass cover to surroundings:

$$\dot{Q}_L = \left[\left\{\frac{k_g}{l_g} + h_{cpg} + h_{rpg}\right\}\left(T_p - T_g\right) + \left(h_w - h_{rga}\right)\left(T_g - T_a\right)\right]A_r \tag{10}$$

Where, the heat transfer coefficient due to radiation (h_{rpg}) between absorber to glass cover is given by:

$$h_{rpg} = \frac{\sigma\left(T_p^2 + T_g^2\right)\left(T_p + T_g\right)}{\left[\dfrac{1}{\varepsilon_p} + \dfrac{1}{\varepsilon_g} - 1\right]} \tag{11}$$

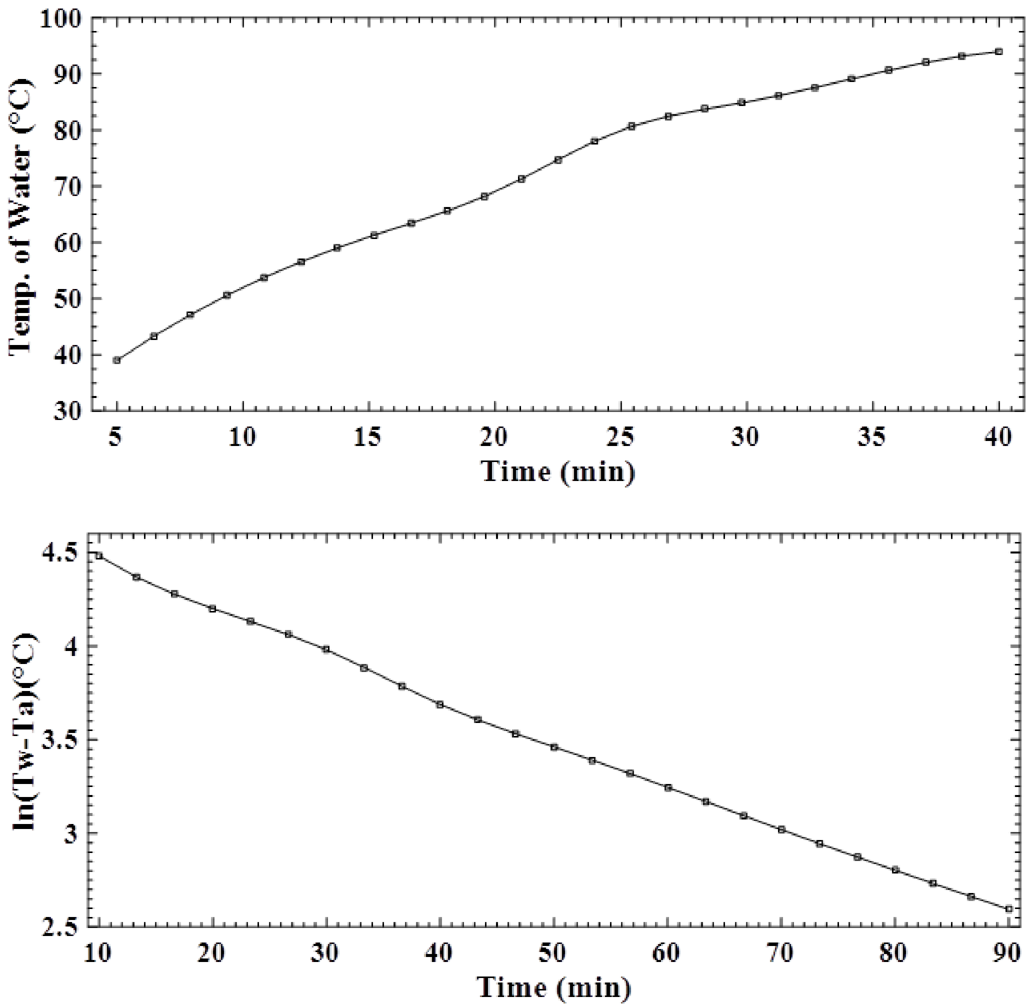

Figure 2. (a) Heating curve for 8 kg of water. (b) Cooling curve for 8 kg of water.

The heat transfer coefficient due to radiation (h_{rga}) between the glass cover to the surroundings is given as:

$$h_{rga} = \sigma\varepsilon_g\left(T_g^2 + T_a^4\right)\left(T_g + T_a\right) \tag{12}$$

The heat transfer coefficient due to convection h_{cpg} between absorber plate to glass cover is found as:

$$h_{cpg} = \frac{N_u k_{air}}{L} \tag{13}$$

Paitoonsurikarn et al. [22] established a correlation with an independent function of angle for evaluation of the heat loss due to convection from the receiver that is

$$N_u = 0.106 G_r^{\frac{1}{3}}\left(\frac{T_p}{T_a}\right)^{0.18}\left(4.256\frac{A_s}{A_p}\right)^{s} h(\varphi) \tag{14}$$

Where, $G_r = \dfrac{g\beta'(T_p - T_a)L^3}{\nu^2}$ = Grashof Number and $s = 0.56 - 1.01\left(\dfrac{A_s}{A_p}\right)^{0.5}$ and an angle dependent function; $h(\varphi) = 1.1677 - 1.0762\sin(\varphi^{0.8324})$

To calculate the heat losses due to convection from the receiver are most difficult because it includes many factors such as the heat transfer from the free or forced convections, the orientation of the receiver and reflector, properties of its material, etc. All these factors contribute to the huge amount of losses of the heat from the receiver. In this experimental investigation, the receivers are set up in inclined positions and all the properties of the air are considered for the analysis.

RESULTS AND DISCUSSION

Figure 2 states the variation of power obtained by the sun and power given by radiation against the direct beam radiation. Since the power given by radiation depend upon the variation of direct beam radiation, according to the above relation cited, the power given by radiation must increase because the DNI increases. The power obtained or gain by the sun also goes on increasing as the DNI increases. The increase in the power obtained by the sun is the reason for the proper absorption of the solar beam radiation by the receiver.

Figure 3 indicates the variation of the heat loss factor and optical efficiency factor against the direct beam radiation. The heat loss factor enhances with the rise in the DNI. The reason for this is that the cosine losses for the Scheffler collector increase with an increase in DNI there by the aperture area reduces and the heat loss factor increases. In other words, the incident of sunlight rays on a collector to receiver always goes decreasing over the day, owing to the design considerations of the Scheffler collector. This nature of the collector affects the power obtained (output) by the sun, due to which the heat loss factor decreases with the time of a day.

Table 3. Main assumptions considered for the analysis

Environment temperature (°C)	35
Environment pressure (MPa)	0.10135
Pressure of generated steam (bar)	1.5
Number of receivers	04
Concentration ratio	47.21
Focal distance [m]	2.21
Mass of pot [kg]	3.2
Aperture area of collector [m^2]	37.056
Area of pot [m^2]	0.29
Specific heat of pot [kJ/kgK]	0.9
Specific heat of water [kJ/kgK]	4.18
Thermal conductivity of air [W/mK]	0.0267
Thermal conductivity of glass cover [W/mK]	34.7
Air space between absorber plate and glass cover [m]	0.025
Thickness of glass cover [m]	0.007
Stefan–Boltzman constant [W/m^{2}K^4]	5.67×10^{-8}
Emittance of coating of absorber plate	0.095
Emittance of glass cover	0.91
Absorber absorbance	0.91
Kinematic viscosity of air [m^2/s]	1.651×10^{-5}
Volumetric coefficient of expansion [% per K]	10
Receiver tilt angle [deg.]	20–60
Time constant for cooling curve [s]	2702.4
Average cost of heating [$/kWh]	0.08

The optical efficiency factor is also evaluated as depicted in Figure 4. It has been found to be slightly increasing but close to same. Thus, the dominance of the solar incidence is very little on the optical efficiency factor. It is hugely influenced by the absorptance of the absorber, reflectance of the reflector, sun-tracking mechanism, material of the collector, and its own geometry. It also provides the calculus of shading loss, cosine loss, reflection loss, absorption losses, transmission losses, and energy outflow.

Figure 5 demonstrates the variation of heat absorbed by the receiver and heat lost by the receiver with the velocity of wind which reports that the heat absorbed by the receiver goes on decreasing as wind velocity increases, because the higher value of the wind velocity has the capability to disperse the impassibility of heat into the surrounding, as a result, the heat absorbed by the receiver decreases with the increase of the wind velocity.

The heat lost by the receiver at various wind velocities is also shown in Figure 5. The performance test makes available some significant parameters which can be established as a standard for the evaluation of the Scheffler

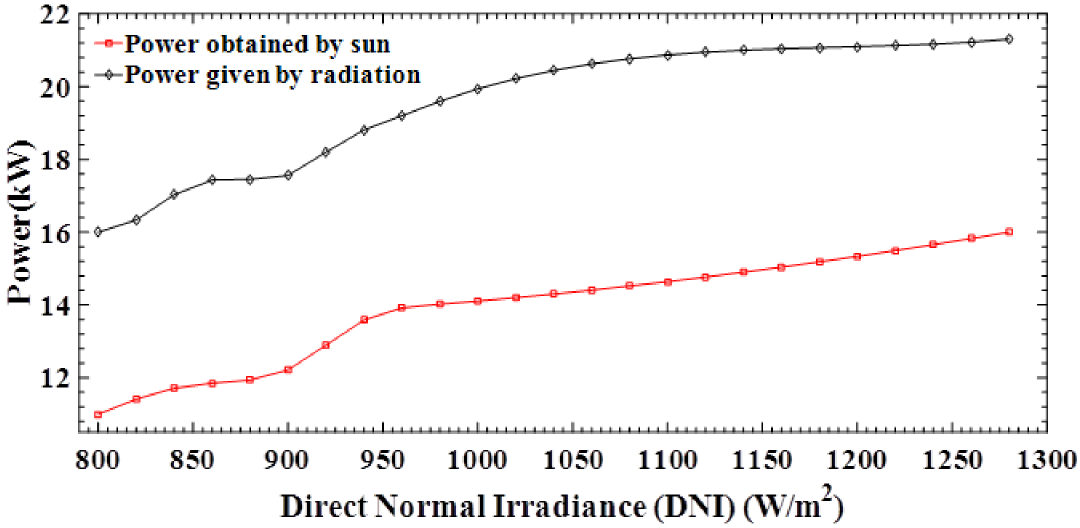

Figure 3. Variation of power obtained and given by beam radiations with DNI.

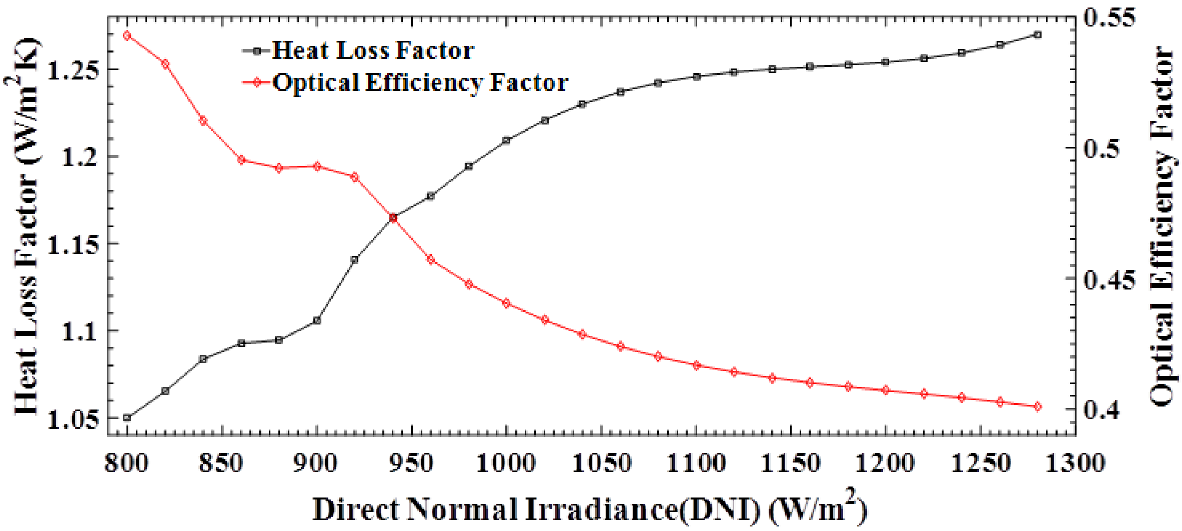

Figure 4. Variation of the heat loss factor and optical efficiency factor with DNI.

concentrator. The heat lost by the receiver prevails over the efficiency of the system therefore these losses must carefully be assessed. The heat losses due to convection through the receiver are the most dominating losses for the receiver and some researchers have developed mathematical models to evaluate it in the windy atmosphere.

Figure 6 depicts that the solar temperature gain changes with time. The changes in the temperature are due to the variation in the intensity of the solar energy on that day. There must also be other reasons such as reflectance and absorbance of the Scheffler collector, the intensity of the incident rays, time and timing of the operation, quantity of water used, area of dish, ambient temperature, wind velocity, dish position, acceleration due to gravity, etc.

Figure 7 exhibits the variation of energy efficiency against the receiver's temperature. The energy efficiency goes on decrease with an increase in the receiver's temperature. It occurs due to the decrease in the difference of mean and atmospheric temperature and design considerations of the Scheffler collector owing to that the heat loss factor increases. The energy efficiency of the collector decreases because the energy output also decreases. The energy efficiency can be enhanced if all the losses of heat are cautiously examined to minimize.

Figure 8 represents the changes in the ambient temperature, wind velocity, and energy efficiency with the time of half an hour consecutive interval of the day. According to the results, the higher wind velocity of 1.41 m/s was achieved at the ambient temperature of 39°C, while the efficiency was obtained at 52.21%. The lowest wind speed of 0.61 m/s was observed at 34.21°C ambient temperature and an efficiency of 59.28% was noted. Thus, the highest

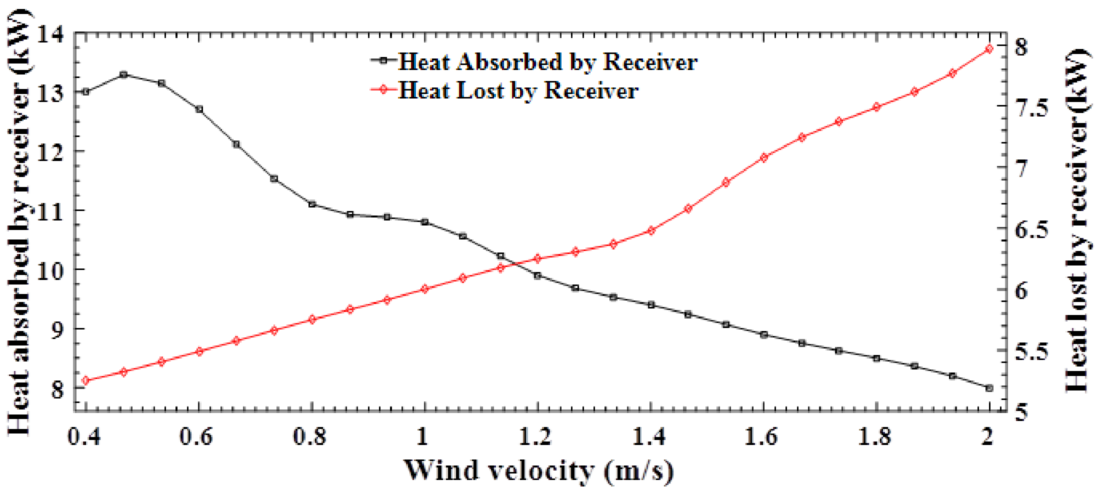

Figure 5. Variation of heat absorbed by receiver and heat lost by receiver with wind velocity.

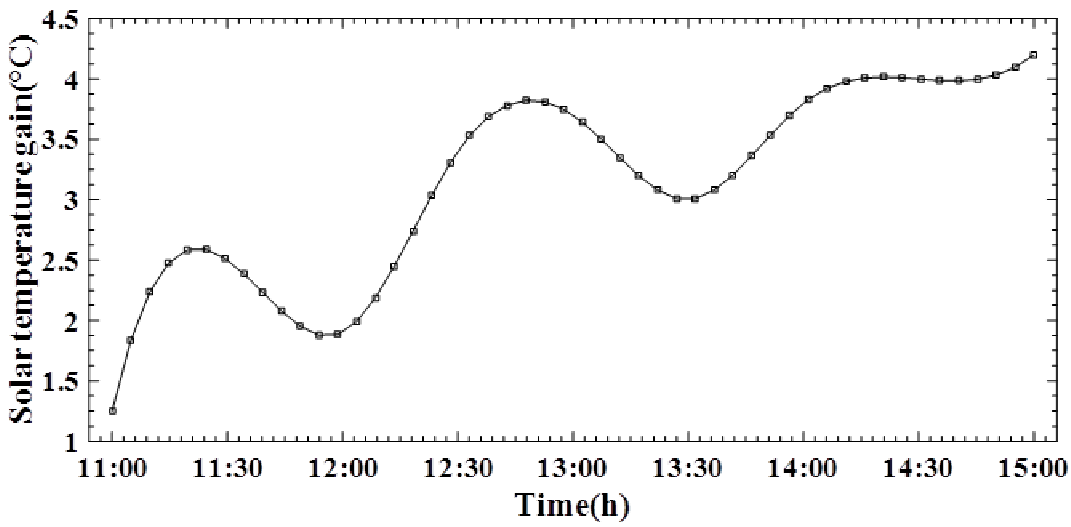

Figure 6. Variation of solar temperature gain with time.

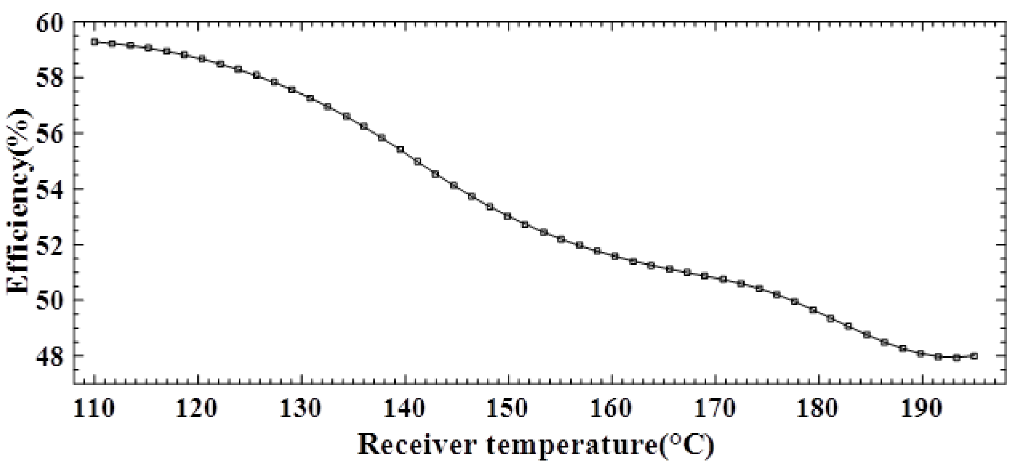

Figure 7. Variation of energy efficiency with receiver temperature.

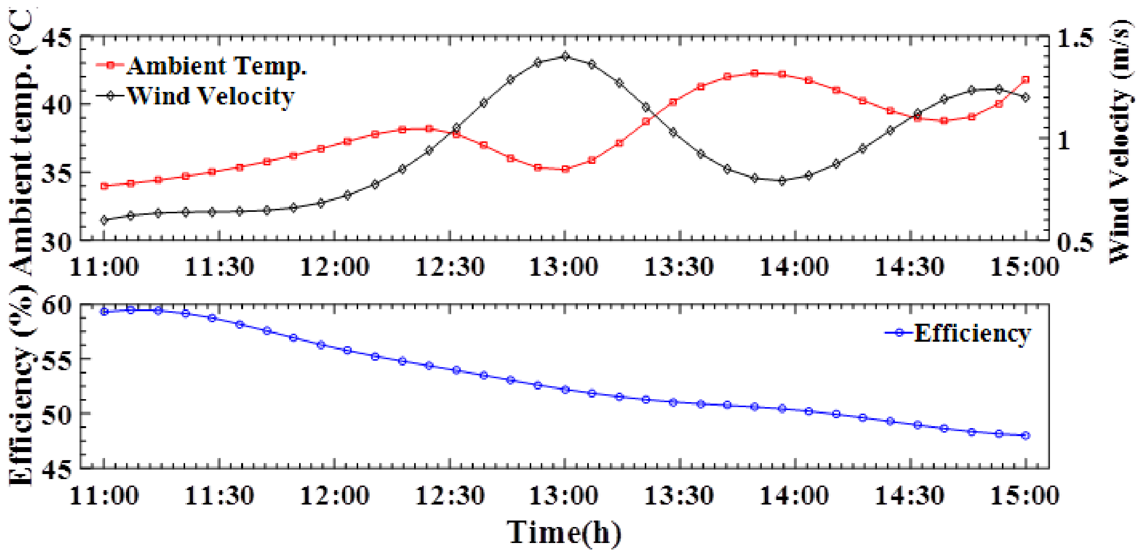

Figure 8. Variation of wind velocity, ambient temperature and energy efficiency with time.

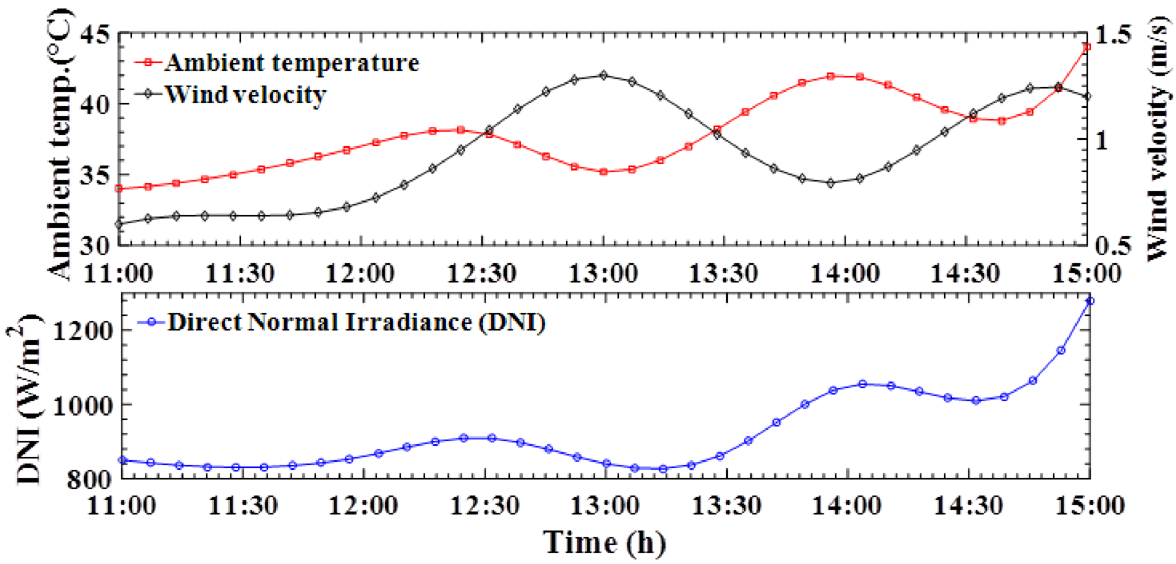

Figure 9. Variation of wind velocity, ambient temperature and direct radiation with time.

value of energy efficiency was achieved at the least value of the ambient temperature. It also states an inverse relation between the ambient temperature and energy efficiency. Although the wind velocity and ambient temperature vary during the entire day, it has been observed most of the time that the wind velocity increases with the decrease in the temperature of the ambient.

Figure 9 shows the changes in the ambient temperature, wind velocity, and direct radiation with the variation of time. The results demonstrate the increase and decrease of the ambient temperature together with the increase and decrease of direct solar radiation, while the enhancement of the wind velocity occurs with the decrement of the ambient temperature. It has been found to be greater wind velocity in the morning and evening hours at the low intensity of the direct solar radiation and ambient temperature. Therefore, it is very clear and justified that a relationship among the ambient temperature, direct solar radiation, and wind velocity is in existence.

Figure 10 indicates the economic assessment of the Scheffler collector. The payback period (PP) is an economic parameter that evidently shows the viability of a system. There is the analysis of various scenarios based on a two-parametric examination. Specifically, Figure 10 shows the PP for various pairs of heating costs and yearly solar potential. The equation (6) is used to estimate the PP in which, the capital cost of the reflector C_0 is taken as 8000$ and a mean thermal efficiency is equal to 30% at

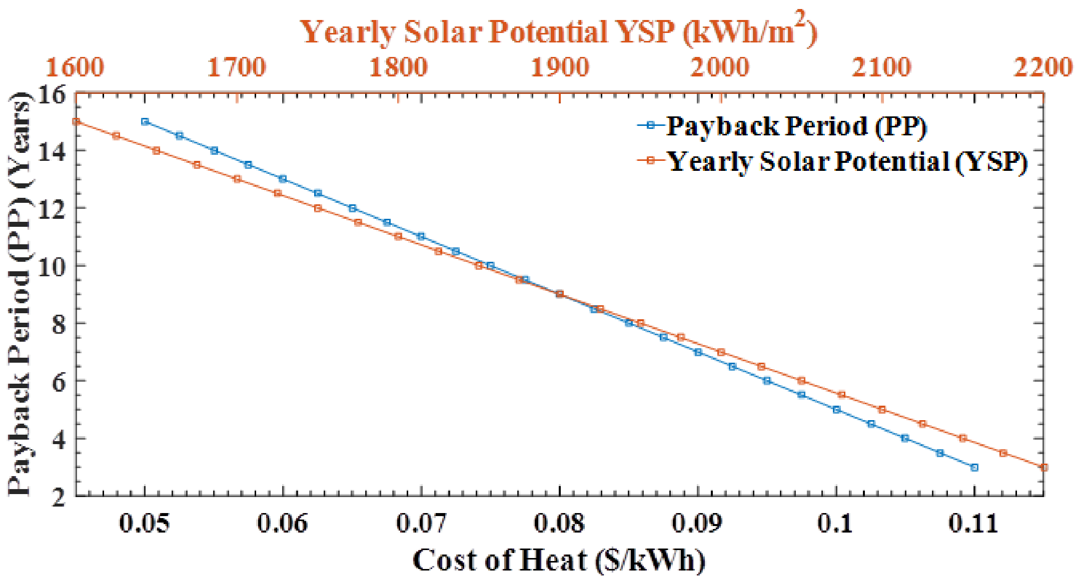

Figure 10. Scheffler collector payback period for various pairs of heating cost and yearly solar potential.

65°C temperature of the inlet. Figure 10 displays that the PP limits from smaller than 4 years to around 15 years. Usually, the PP of up to 10 years is acceptable for renewable energy operated systems, which denotes that this system can be viable in the areas with the YSP greater than 1600 kWh/m^2 and where the cost of heating is greater than 0.05 $/kWh.

Although, the sunlight can be reflected a stationary point during the day with a heliostat rotating on a single axis, polar mount and it can be brought into operation in a little bit of a minute. In developing countries for industrial uses, a telescopic clamp mechanism performs the seasonal tracking by twisting the collector at of the solar declination (nearly 1° after 3 days). The ease of construction and maintenance provides an exceptional chance for decentralised applications in tropical countries. This can establish a new standard in the processing operations of small-scale industries, especially in the rural and semi-urban areas. It makes us enables to perform the different thermal applications ranging from medium temperature domestic uses to industrial processes.

CONCLUSIONS

The experimental investigation has been made for the performance evaluation of the Scheffler collector and the results have been compared with a "parabolic solar concentrator". The following conclusions can be extracted from this investigation:

- The results of power obtained by the sun and power given by radiation are analogous, which reflects the proper functioning between the Scheffler collector and energy receiver. The power obtained by the sun for the Scheffler collector is adequately higher than the parabolic solar concentrator.
- The Scheffler collector cannot efficiently be used in mid-day because of the high value of heat loss factor, while the parabolic solar concentrator works moderately during this period.
- The meteorological variables are highly correlated with the performance of the parabolic solar concentrators. The effective performance of the Scheffler collector is noticeable, while the wind blows with the normal velocity.
- There is always variation in the solar temperature gain due to unavoidable and uncontrollable reasons.
- The efficiency and wind velocity have a positive correlation, while the ambient temperature is negatively correlated with the performance.
- The wind velocity is negatively correlated with direct solar beam radiation and ambient temperature, therefore there is the existence of a relationship among these parameters, which affects the performance of the Scheffler collector. However, this correlation has a significant effect on the performance of the parabolic solar collector.
- The maximum heating temperature has been recorded 129°C at the end uses, while, the absorber plate temperature is found to be within the range of 116°C to 195°C, however, it occurs at lower ambient temperature and moderate wind velocity.
- The substantial value of the heat loss factor, as well as the lower value of the optical efficiency factor, indicate the further scope of effective utilisation of the solar energy after providing the proper design of the reflector.

- The payback period of the Scheffler collector is 4 years to 15 years, which is acceptable. The system in its existing condition can be viable in areas with a yearly solar potential of greater than 1600 kW h/m^2 and where the cost of heating is greater than 0.05 $/kWh.
- The Scheffler collector has a maximum efficiency of 59.28%, which is far better than that of the parabolic solar collector. It means that Scheffler collectors can effectively be used in water heating and medium-temperature industrial applications.

It can be concluded through the above discussion that, the Scheffler reflector provides the most promising technology from the viewpoint of medium temperature applications for industrial and domestic utilities. It has also been found that the Scheffler collector has better potential as compared to the parabolic solar concentrator.

APPENDIX. CONSIDERED DATA

Table 1 describes the specifications of the Scheffler collector used in the investigation. More detailed information about the apparatus accuracy has been provided in Table 2, while, the consideration of the assumptions related to the analysis are listed in Table 3.

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NOMENCLATURE

$\dot{Q}$	Rate of heat transfer [kW]
P	Power [kW]
h_{cpg}	Heat transfer coefficient of convection between absorber plate and glass cover [W/m^{2}K]
h_{rga}	Heat transfer coefficient of radiation between glass cover and surrounding [W/m^{2}K]
h_{rpg}	Heat transfer coefficient of radiation between absorber plate and glass cover [W/m^{2}K]
h_w	Heat transfer coefficient of wind [W/m^{2}K]
RO	Reverse Osmosis
DNI	Direct Normal Irradiance
K_g	Thermal conductivity of glass cover [W/mK]
K_{air}	Thermal conductivity of air [W/mK]
C_w	Specific heat of water [kJ/kgK]
C_0	Capital Cost of collector [$]
C	Concentration ratio
C_{heat}	Cost of heating [$/kWh]
PP	Payback Periods [Years]
YSP	Yearly Solar Potential [kWh/m^2]
L	Air space between absorber plate and glass cover [m]
I_g	Glass cover thickness [m]
N_u	Nusselt Number
T_a	Ambient temperature [K]
T_p	Temperature of absorber plate [K]
T_g	Temperature of glass cover [K]
A_s	Aperture area [m^2]
A_r	Receiver area [m^2]
A_{pot}	Area of pot [m^2]
g	Gravity [m/s^2]
m	Mass [kg]
n	Day of the year

Greek Symbols

σ	Stefan–Boltzman constant [W/m^{2}K^4]
ε_p	Emittance of coating of absorber plate
ε_g	Emittance of glass cover
δ	Solar Inclination or Seasonal angle [deg.]
η	Efficiency [%]
v	Kinematic viscosity of air [m^2/s]
β'	Volumetric coefficient of expansion [% per K]
φ	Receiver tilt angle [deg.]
τ_0	Time constant for cooling curve [s]
τ	Time interval [s]

Subscript

L	= Loss
a	= Air/atmosphere
w	= Water
i	= Initial
f	= Final
m	= Mean
Cond.	= Conduction
Conv.	= Convection
Rad.	= Radiation

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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