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Comparative Analysis of Spiral Coil Receiver and Cylindrical Pot like Receiver on the Performance of Parabolic Solar Concentrating System for Thermal Steam Generation.

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ABSTRACT

The technology aspect of solar energy is crucial to solving the current global environmental and energy issues. Scientists, engineers, governmental and non-governmental organizations are becoming more aware of the exciting new potential that is solar concentrating systems for thermal heat energy generating use for residential, commercial, and industrial enterprises. The purpose of the research work was to compare the performance of the Parabolic Solar Concentrating (PDSC) system for thermal steam generation between a spiral coil receiver and a cylindrical pot-like receiver. Materials used to construct the PDSC, SCR, and CPR were stainless steel reflector sheet, copper tube pipe, and aluminum sheet, in that order. To facilitate the rotation of the system in the direction of solar radiation, a basic manual tracking mechanism was used. A limited experimental trial was carried out in different weather circumstances, and the thermal steam produced by the system using SCR and CPR as receiver absorbers was utilized for comparison analysis along with the performance assessment. High temperature steam was found to be produced by the parabolic solar concentrating system using SPR and CPR as receivers, with values of 225.3 ^{O}C and 210 ^{O}C, respectively. This temperature variation by the two receivers could be as the results of differences in term of material used in construction the receivers' absorber.

Keywords: Solar energy, spiral coil receiver, cylindrical pot reciever, Parabolic Dish Solar Concentrator.

INTRODUCTION

The measure of a country's economic progress is its energy consumption per capital, which has grown to be a crucial indicator for global sustainable development. Due to population growth and industrialization, there has been a sharp increase in the world's energy demands recently. It's clear that demand for traditional energy sources of fossil fuels is rising, and finding alternative energy sources to supplement existing sources is necessary (Sadik *et al*., 2013).

With the world's reserves of coal, oil, and natural gas running low and energy consumption rising, the global energy dilemma is an urgent problem. Instead of using traditional fossil fuels, the world should rely more on renewable, green energy sources. Research is still being conducted to determine more effective ways to use renewable energy sources such sunlight, wind, biomass, tides, and geothermal heat (Zhilei, 2013).

A solar dish collector using a modified cavity receiver was studied by Reddy *et al.,* (2016). To find out how wind conditions, receiver setup, and receiver orientation affected the receiver heat loss, they conducted a numerical investigation. To calculate the total convection heat losses from the receiver, they suggested a link between the Nusselt number and wind effects.

Sarwar *et al.,* (2015) investigated the impact of aperture size on the steady-state temperatures of a cylindrical solar receiver throughout the day using both numerical and experimental methods. The impact of different parameters on the thermal efficiency and total heat loss of the cylindrical cavity receiver for a parabolic solar concentrator was examined in an experimental and analytical study given by Azzouzi *et al.,* (2017).

The semi-spherical cavity receiver used for the parabolic dish collector piqued the curiosity of Tan *et al.,* (2014). To determine how much heat was lost, they carried out an experiment. Experimental correlations for Nusselt number as a function of Grash of number were developed by examining various fluid inlet temperatures, receiver inclination angles, and aperture sizes. A temperature distribution of the receiver tube has been experimentally and numerically demonstrated by Roldan *et al,* (2013).

Wang *et al.,* (2012) conducted another investigation in which they calculated the temperature distribution of the receiver tube numerically for various materials. Yu *et al.,* (2015) carried out an experimental investigation to look at a steel plate receiver's temperature distributions and concentrated solar heat flow.

The reduction of losses due to natural convection is noticed when the receiver's tilt angle increases from 0° to 90°, where 90° represents the receiver aperture looking downward and vertically. When compared to receiver geometries with spherical and cubic shapes, the hemispherical cavity showed the greatest amount of energy losses. According to Prakash *et al.,* (2012), a lower aperture ratio (*d/D*) results in an increase in the stagnation zone volume and a decrease in convection energy loss.

By regulating airflow with air curtains, the cavity receiver's convective losses can be minimized. According to a CFD research, effective airflow control may cut energy losses by roughly 45% (Zhang *et al.,* 2015). At a dish rim angle of roughly 45°, the receiver aperture experiences the highest concentration of solar radiation. The optimal aperture ratio recommended by (Beltran *et al.,* 2012) is achieved by compromising between the received radiative heat and energy losses to construct a cavity-type receiver using several modes.

THEORETICAL CONSIDERATION

Heat Losses of the Reciever

The sum of the conductive, convective, and radiative heat losses from the receiver surface is the total heat loss rate (Q_L) from the receiver (Gorjan *et al.,* 2013). As illustrated in Figure 1, the majority of the thermal losses in a Stirling dish system happen at the receiver prior to the energy being transformed into electricity in the Stirling engine. The reflectivity of the mirror causes 37% and 24% of the collector losses (Mancini *et al.,* 2003).

$$Q_{loss} = Q_{loss.cond} + Q_{loss.conv} + Q_{loss.rad} \tag{1}$$

Where

Q_{loss} = Total amount of heat lost by the receiver, $Q_{loss.cond}$ = Conduction-based heat loss

$Q_{loss.conv}$ = Loss of heat through convection, $Q_{loss.rad}$ = Heat loss by radiation method

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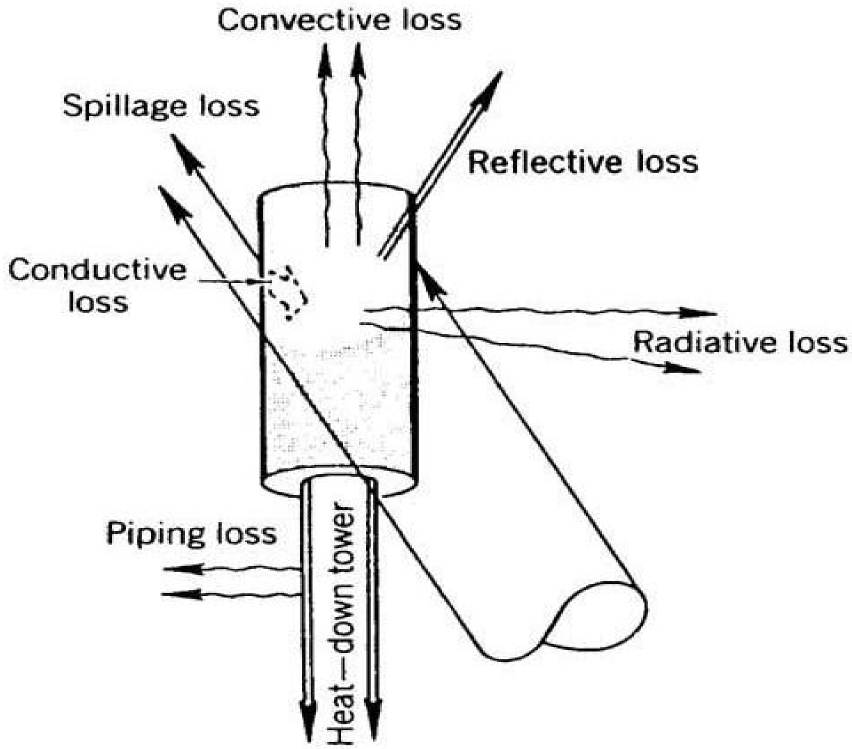

Figure 1: Various losses in the receiver (Vanita *et al.,*2015)

i. **Conduction Losses**:
Radiation is the main receiver loss mechanism, with the receiver housing accounting for a little portion of the overall receiver loss and natural convection losses accounting for roughly 40% of the receiver losses (Mancini *et al.,* 2003).

ii. **Radiation Losses:**
A sizeable portion of the total losses in the receiver and the Stirling dish system as a whole are caused by the radiation losses in the receiver. According to experimental data from Sandia National Laboratories, radiation losses could account for up to 60% of receiver losses in the morning and evening (Hogan, 1994). Once a steady state temperature is established, radiation losses, in contrast to convection losses, remain essentially constant throughout the day (Mancini *et al.,* 2003).

iii. **Reflectivity Loss:**
It is the ratio of energy that is impinging on the reflecting dish surface and energy that is reflected. A mirror with low iron content and a silver back coat that is clean should have a reflectivity of 94-54% (Kribus *et al.,* 2006).

MATERIALS AND METHODS

Materials

The construction of spiral coil receive (SCR), cylindrical pot like reciever (CPR) and parabolic solar concentrating (PSC) collector were made using locally available materials. The following factors were given careful consideration while choosing the building materials: low cost, ease of handling during fabrication, light weight for easy handling during use, resilience to working conditions and the environment, and non-toxic effects. Table 1 provides a comprehensive inventory of all the materials, along with their specifications and amounts that were used to build the parabolic dish collector.

Table 1: Specifications and Quantity of Materials Used for Construction of the Concentrator

MATERIAL	SPECIFICATION	QUANTITY
Thin foil reflective material	10.0 m	6
Copper pipe tube	0.40 m	4
Aluminium sheet	8.00m	2
Adjuster	0.30 m by 0.23 m	1
Receiver sitter	0.51 m	1
Receiver adjuster	0.43 m	1

Instruments Used

The parabolic concentrating system's maximum temperature was measured using a mercury-in-glass thermometer during the water boiling test tests for steam generation. The temperature was recorded, and the thermal efficiency of the systems was also assessed. The following instruments are included in Table 2 as instruments utilized during instrumentation.

Table 2: Instruments utilized during instrumentation

PARAMETER MEASURED	INSTRUMENT USED
Solar irradiation	Pyranometer
Wind speed	Anemometer
Content temperature	Mercury in glass thermometer
Ambient temperature	Digital thermocouple data logger
Weight of water and other food substance	Electronic Weighing balance

Design Procedure of Parabolic Solar Concentrating collector

The shape of the dish concentrator served as the basis for designing the solar radiation concentration in a concentrating system. The locus of a moving point that maintains equal distances from two fixed points and a fixed line is known as a parabola shape reflector. The geometric coordinate system of a parabola is depicted in Figure 2, and plate (I) displays the geometry measurement of a parabolic dish. Where the aperture plane's coordinates are x and y. Plates (II) (a) and (b) display the parabolic dish collector throughout and after the construction process, respectively.

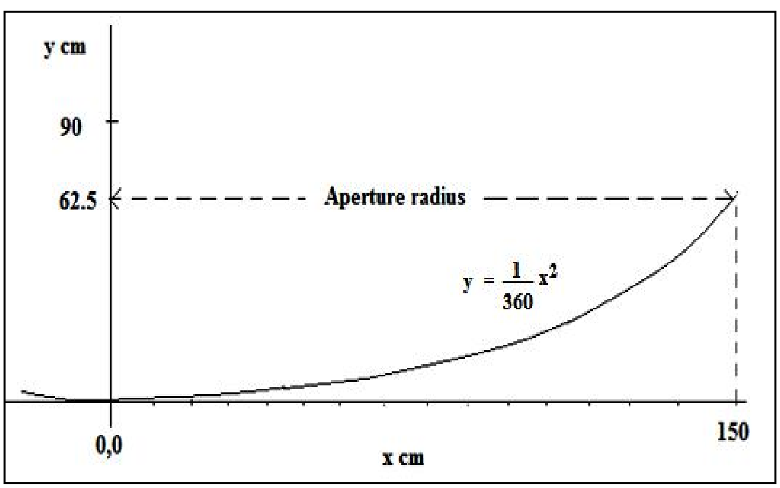

Figure 2: Geometrical Coordinate system of the Parabola shape

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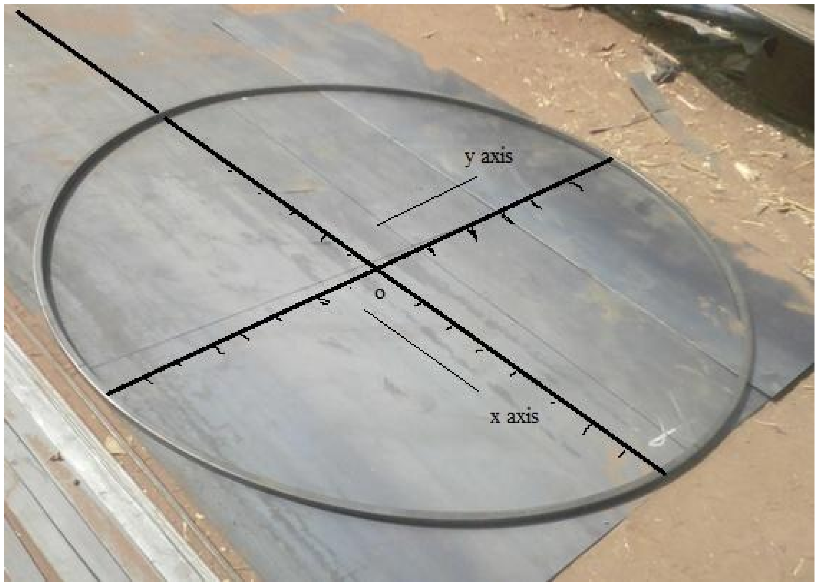

Plate (I): Geometry measurement of a parabolic dish

Plate II (a): the parabolic dish collector throughout (b): after the construction process

The mathematical equation of parabola was used similar method was employed by (Fareed, 2012).

$$y = ax^2 + bx + c \tag{2}$$

Where a, b and c are constants of the equation.

Similarly, the equation for the parabolic dish in Cartesian and cylindrical coordinate system was also compared with equation (2) (Pavlovic *etal.,* 2014)

$$x^2 + y^2 = 4fz \tag{3a}$$

Therefore equation (3a) is simply written

$$x^2 + y^2 = r^2 \tag{3b}$$

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Where $r^2 = 4fz$, $z = \frac{r^2}{4f}$ and the same for

$$y = \frac{x^2}{4f} \tag{4}$$

The simple form of the equation (2) can be written in form of equation (5) stated

$$y = ax^2 \tag{5}$$

Where the vertex is at (0, 0) and symmetry is on the y-axis

For the simple prototype parabolic dish concentrating collector the equation was simply made to be equation (6)

$$y = \frac{1}{360}x^2 \tag{6}$$

Comparing equation (4) and (6) to obtained

$$\frac{x^2}{4f} = \frac{x^2}{360} \tag{7}$$

Where a is the coefficient of the equation and simply written as

$$a = \frac{1}{360} \tag{8}$$

The focus of the parabola was obtained using equation (9).

$$\boldsymbol{f = \frac{1}{4a}} \tag{9}$$

Description of Spiral coil receiver-absorber Type (SCR)

A spiral coil receiver-absorber (SCR) was built using a copper pipe tube with a suitable diameter and cross-sectional area, and it was positioned at the focal point where the reflected radiation from the solar concentrator was gathered. The goal of developing parabolic solar concentrators is to minimize the receiver's size at all times. One can lower heat losses and the system's overall cost by using tiny receivers. Furthermore, a smaller receiver size increases the absorbed flux on the receiver's surface. This is the method for increasing the efficiency of solar radiation to heat conversion. As indicated in plate (III), the receiver-absorber system that is being suggested for this work is spiral coiled and has a 160 m diameter. Placement of the receiver near the focus of the parabolic reflector was necessary because the parabolic dish collector is a focusing type collector. Table 3 provides an overview of the spiral coil receiver's parameter measurements.

Table 3: The spiral coil receiver's parameter measurements

Pipe's internal diameter	9.30 mm
Pipe’s external diameter	12.20 mm
Thickness of the pipe wall	0.25 mm
The coil's minimum radius	25.0 mm
The coil’s maximum radius	202 mm
Pitch of a spiral coil	13.6 mm
Number of coils turns	24.0 turns

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Plate (III): Spiral coil receiver- absorber insulated with glass fibre

Description of Cylindrical Pot-like Receiver (CPR)

Aluminum was chosen over copper and steel for the cylindrical pot-like receiver (CPR) due to its lower cost, light weight, ease of production, and energy-efficient material use. Black paint was used for the absorber coating and to paint the receiver. Because of its increased absorptivity at angles other than normal incidence, adhesion and durability to weathering, sunshine, and high stagnation temperatures, as well as its cost-effectiveness and protection of the absorber material, as seen in plate (IV), it is chosen over other coating.

Plate (IV): Cylindrical Pot-like receiver.

The cylindrical pot-like receiver, also known as the receiver absorber, had the following dimensions: height l, thickness t_x, exterior diameter D_{abs}, and interior diameter d_{abs}. Equation (10), which is for the cylindrical form of receiver, was used to determine its volume. (Ibrahim, 2012)

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$$V_c = \frac{\pi d_{abs}^2}{4} \times l \tag{10}$$

In order to simplify the equation and create the best possible absorber design (a cylindrical receiver), the height l was set to equal the diameter dabs. Table 4 describes the measurements of the cylindrical pot-like receiver's characteristics.

Table 4: The measurements of the cylindrical pot-like receiver's characteristics

Internal diameter	(d_{abs})	0.234 m
External diameter	(D_{abs})	0.238 m
Thickness	(t_x)	2.000 mm
Length or height	(*l*)	0.240 m
Absorber area	(A_{abs})	0.219 m^2

Efficiency of the Receiver

In the absence of heat loss to the environment, cooking and water heating applications occur faster or at greater temperatures; so, Adams and Allday (2000) simply describe the heat lost as;

$$Q_{loss} = \frac{V\Delta T}{R} \tag{11a}$$

Where ΔT is the temperature difference between the starting and finishing points Given that V is the receiver's volume and R is its thermal resistance,

$$Q_{loss} = \mu A \Delta T \tag{11b}$$

Note that, the value of the R increases with the receiver's wall thickness. Thus

$$\mu = \frac{conductivity}{thickness} \tag{12}$$

Therefore, as mentioned by Huseyin (2004), equation (13) can be used to compute the solar energy reflected upon the receiver per unit area.

$$Energy = IVT \tag{13}$$

Where I is the Solar Insolation and V is the volume of the receiver and T is the time taken.

Therefore, the efficiency of the receiver can be deduced from specific heat capacity i.e. $IVT = MC\theta$ (heat exchange) equations as:

$$\eta = \frac{E_o}{E_i} = \frac{Q}{VIT} = \frac{M_{ex}C_{ex} + M_w \times C_w(T_{wf} - T_{wi}}{VIT} \tag{14}$$

RESULTS AND DISCUSSION

Steam Generation Test using Spiral Coil Receiver (SCR)

The steam generation test was conducted with spiral coil reciever as a reciever- absorber on the third day of experimental test of steam generation of the concentrating system. The day is characterized by clear weather condition. Figure 3.1, represent the results test from the graph, it is evident from the experiment that atmospheric conditions affect the system's temperature rise, with the maximum temperature being reached well before midday. In this clear weather, the maximum solar insolation measured and recorded was 884 W/m^2.

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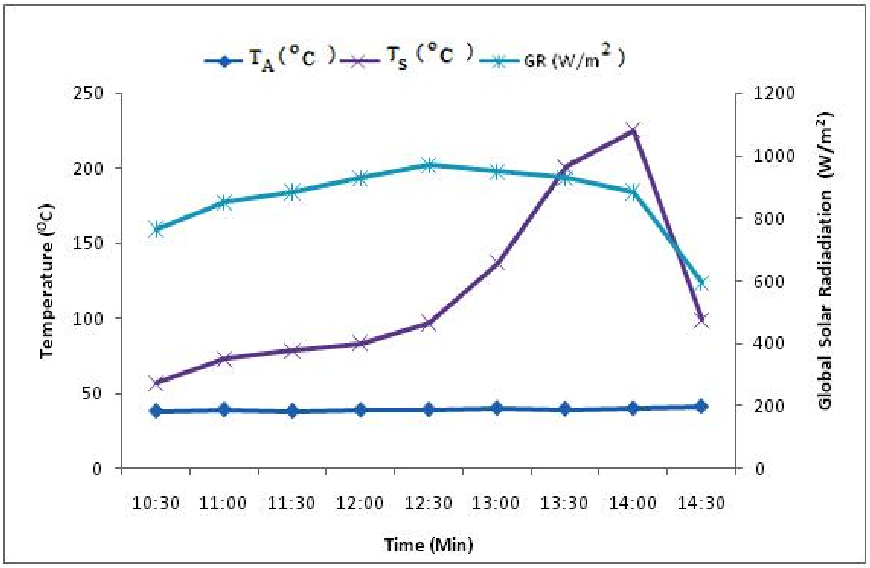

Figure 3: Results of the steam generation test for SCR involving temperature change over time and associated global solar radiation

The results of the experimental test of steam generation using SCR are displayed in Figure 3. At 14:00 pm during the experiment, the highest temperature recorded was 225.3 ^{O}C, and the corresponding global solar radiation and wind speed were 884 W/m2 and 225.3 ^{O}C, respectively. Around 12:30 to 14:00 pm on that particular day, the weather or atmospheric condition cleared. The peak temperature is therefore quickly reached, even before midday, as a result of atmospheric conditions influencing temperature. In this clear weather, the highest recorded solar insolation was 884 W/m^2. The system's exceptional performance was influenced by a clear sky (an atmospheric uncontrollable element) that reduced travel time in comparison to the last test. This matches the findings and contributing element disclosed by Funk (2000). The temperature value of 300 ^{O}C is less than Kashika and Reddy's (2000) estimated. Because of convective and radiative heat losses brought on by the day's greater ambient temperature, a lower temperature value may have been achieved.

Steam Generation Test Using Cylindrical Pot-like Reciever (CPR)

On the fourth day of the experiment, a steam generation test was conducted using a cylindrical pot-shaped receiver as a reciever-absorber of the parabolic concentrating system. The system indicates that at 13:30 pm on the day of the experiment, the maximum temperature recorded was 210 ^{O}C, and the corresponding global solar radiation was 917 W/m^2, respectively. The results of the test of steam temperature and system generation are displayed in Figure 4. The findings also demonstrated the relationship between the change in receiver temperature over time and the corresponding variations in solar radiation worldwide, as well as the impact of atmospheric conditions on receiver temperature when heat transfer fluid (HTF) is employed.

The system's temperature fluctuated, potentially as a result of the overcast sky, which tends to block out solar energy and slow down the receiver's temperature or system performance. Between 11:00 am and

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12:00 pm, there was a continuous change in the air temperature.

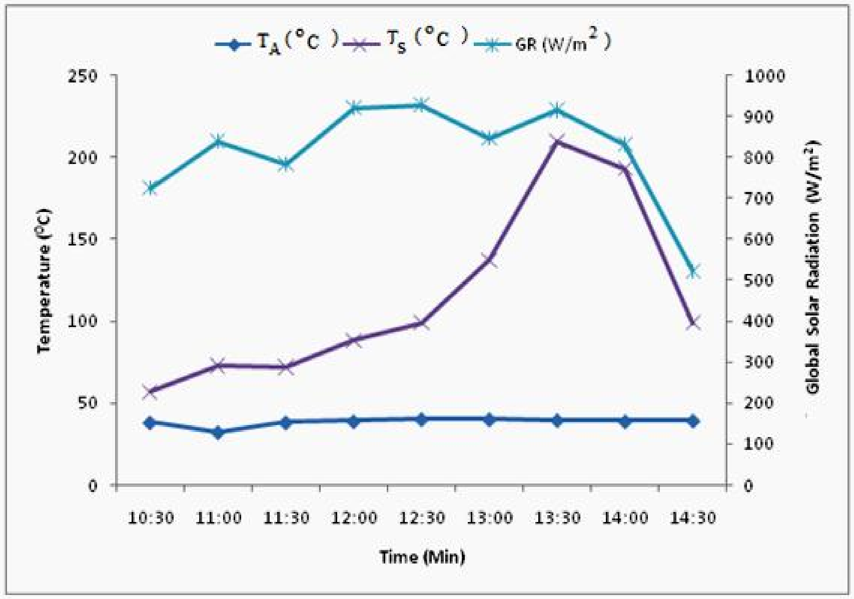

Figure 4: Results of the CPR steam generation test's temperature changes over time and corresponding global solar radiation

The figure illustrates the relationship between temperature change, wind speed, and matching global sun radiation throughout time. According to the results, the system reached its maximum temperature of 210 ^{O}C, rising steadily to that level when the outside temperature soared to 39.6 ^{O}C and the wind speed increased accordingly. This is comparable to the findings reported by Funk (2000) and Serah (2014). By 13:30 pm, the system's temperature had progressively dropped to a specific value. This could be caused by a steady decrease in both ambient temperature and solar radiation intensity as a result of cloud cover.

Thus, the system's maximum temperature of 210 ^{O}C was achieved, which is a considerable improvement over Santosh and Shobhit's temperature of 180 ^{O}C (2019). In comparison to the 350 ^{O}C temperature found in Khaled and Nadir's (2013) work, the temperature determined by this investigation is low. The reduced temperature on the day of the experiment may have been caused by convective and radiative heat losses brought on by the day's greater outside temperature and wind speed.

Comparison of Steam Generation Test between Spiral Coil Receiver and Cylindrical Pot-like Reciever

The steam generation tests of the two receivers SCR and CPR with parabolic concentrating system were measured and compared. The parabolic concentrating system with two receives were exposed to the sun under steady weather conditions for experimentation. The wind speed, global solar radiation and ambient temperature were recorded for both two receivers during the test day. The comparative temperature variation of the two receivers with time and corresponding global solar radiation were presented graphically in Figure 5. The figure indicates that at 14:00 pm, the maximum temperature of SCR was measured at 225.3 ^{O}C, with equivalent global solar radiation and wind speed of 834 W/m^2 and 0.4 m/s. In a similar vein, around 13:30 pm, the greatest temperature, equivalent global solar radiation, and wind speed for the CPR receiver absorber were 210 ^{O}C, 917 W/m^2, and 0.30 m/s, respectively.

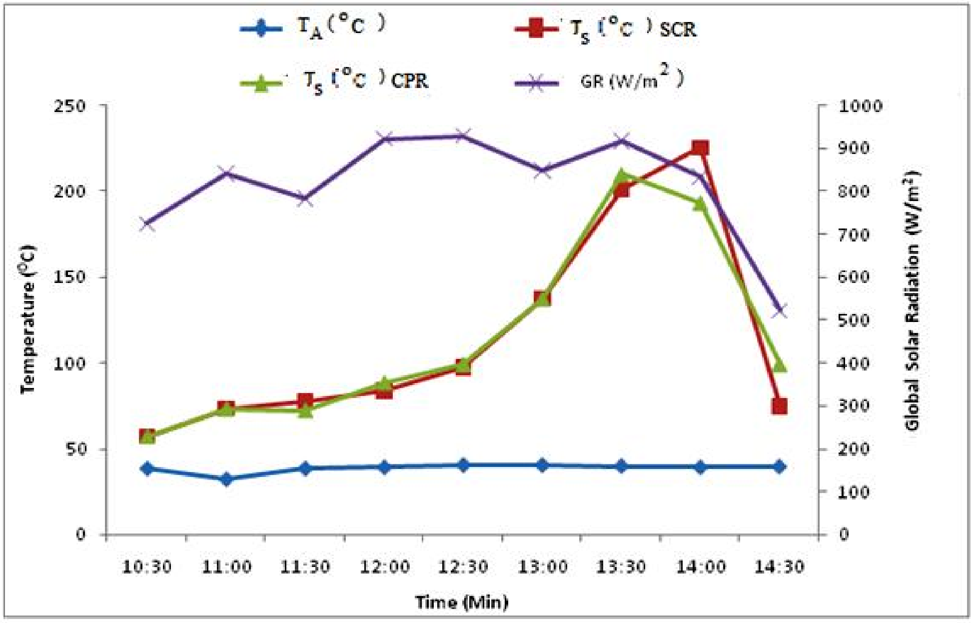

Figure 5: The relationship between the temperature variation of CPR and SCR over time and the related global solar radiation for steam generation temperature

The experimental result of the parabolic concentrating system utilizing both two receivers and their performance in terms of temperature change with time are shown in Figure 3.3, which also displays the results of the comparative test for steam generation between SCR and CPR receivers. As seen in Figure 3.3, at 14:00 pm, the SCR system's maximum temperature, matching global solar radiation, and wind speed were measured to be 225.3 ^{O}C, 884 W/m^2, and 0.40 m/s, respectively.

Similarly, the figure with the CPR receiver displays the temperature variation results over time and the corresponding global solar radiation of the concentrating system. At 13:30 pm, the highest temperature recorded for the system with the CPR receiver was 210 ^{O}C, the corresponding global solar radiation was 917 W/m^2, and the wind speed was 0.30 m/s. In terms of temperature variations, the system using SPR was able to reach the maximum and bigger value of temperature of 225.3 ^{O}C compared to the highest temperature value of 210 ^{O}C produced by CPR as a receiver. This is evident when comparing the two outcomes of the system utilizing various receivers, SCR and CPR.

This temperature variation by the two receivers could be as the results of differences in term of material used in construction the receivers' absorber. SCR was made up of copper tube while CPR was made up of aluminum sheet material. Therefore, copper has a higher electrical and thermal conductivity compared to aluminum (Kathori *et al.,* 2012).

CONCLUSION

The parabolic concentrating solar collector with SPR and CPR as receiver-absorber was found to produce a thermal steam generation of highest temperature values of 225.3 ^{O}C and 210 ^{O}C respectively. The result obtained

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shows the performance of reciever made up of copper tube pipe (SCR) was able to produce a high temperature reading compared to reciever made up of aluminum material (CPR), this could be as a result of difference in thermal conductivity between copper and aluminum. The system's low performance evaluation during the experimental test on certain days at a specific time can be attributed to convective and radiative heat losses brought on by higher ambient temperatures and wind speeds. Additionally, because the system is manual tracking, there is a lack of an appropriate tracking device to focus the Sun's lateral movement.

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