



PERFORMANCE EVALUATION OF DUAL-ABSORBER WITH DOUBLE CONCENTRATOR SOLAR WATER HEATER

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ABSTRACT

The growing global demand for clean and sustainable energy has intensified research into improving the efficiency of solar thermal systems. Solar water heaters, while established, often suffer from performance limitations due to reliance on direct insolation alone. This paper presents a performance evaluation with respect to efficiency of a solar water heater enhanced with double absorber plates and concentrators. The research involves two solar collectors, two plane mirror concentrators, a water circulation system, and two storage parts. Two thermometers were used to measure temperatures, and the intensity of the solar radiation was measured using a solar power meter (TES 1333). Plots of Temperature against Time and Average Power against time were made for all the readings taken. The efficiencies were obtained for two collectors with reflectors; two collectors without reflectors and the respective values are 43.4% and 36.7%. The advantage of using the concentrating mirror is evidently clear for its ability to improve the efficiency by 6.7%, demonstrating a significant and practical method for enhancing solar thermal collection.

Keywords: Solar Heating, Solar Absorber, Light Concentrator, Efficiency, Water Circulation System

INTRODUCTION

Heating is one of the major necessities for people's life all over the world. It plays important roles in different aspects of life at homes and industries. However, there is a great problem in the process of obtaining the required heat energy due to many factors which include: insufficient fuel and high cost of the available sources.

These problems are mostly encountered in developing countries and in particular, in remote areas like villages and rural areas. Most of the heating energy in these countries is obtained from firewood, agricultural residue, etc. Cutting of trees for heating purposes causes deforestation which leads to desertification. The problem of heat energy cost and its daily increase made people not only in rural areas and villages but also in cities to search for alternative heating energy sources (Kimambo, 2007). There is need for alternative, appropriate and affordable methods of heating for use in developing countries. (Kimambo, 2007). In Nigeria there is abundance of sunshine especially in the northern part. In spite of this high potential, solar energy technologies are not widely used (Aburrahim *et al*, 2011).

There are favourable climatic conditions in African countries like Nigeria for all solar energy applications (Kimambo, 2007). Thus; all solar energy applications are recommended to harness such enormous energy. Solar water heater seems to be a good substitute for heating with firewood. The use of solar water heater would help in conservation of conventional fuels, such as firewood and agricultural residue in rural areas, and kerosene in urban areas. Conservation of trees helps in preserving the ecosystems and animal residue could be used as fertilizer, which could aid in increase of production of agricultural products. Moreover, the use of solar water heater would result in the reduction of the release of Carbon (IV) Oxide into the environment (Huseyin *et al*, 2010).

Therefore, this work is expected to help in many ways in terms of heat energy generation and utilization. The work would greatly assist in eliminating the suffering of the rural dwellers in particular in obtaining heat energy for daily The efficiency is determined using the equation (1) (Bello *et al*, 2010):

activities of life. The sun is the ultimate origin of most of the energy presently available on earth. This includes the energy for direct heating, as well as wind energy, hydroelectric power, and energy derived from fossil fuels (Musa, 2006). Hot bodies emit electromagnetic radiation with spectral distribution determined by the body's temperature (Nelkon and Parker, 1995).

A greenhouse is a small house made of glass that is used to trap sun's rays and thus grow plants. A greenhouse traps the sun's rays and keeps the heat from escaping. It is warm inside in the same way that atmospheric gases trap heat next to the earth's surface. Certain gases in the atmosphere such as carbon (iv) oxide, methane and water vapour trap energy from the sun. The natural greenhouse gases acts like a big blanket around the earth, keeping it warm (Musa, 2010).

Researches confirmed that as the sun moves in the sky it is mostly concentrated in the southern hemisphere. Therefore, based on the results obtained from many works, it is suggested that the angle of inclination should be equal to the latitude of the location (Bolaji, 2006). Any dark surface that faces the sun is a heat collector, it is dark because it has absorbed some light energy and converted it to heat instead of reflecting the radiation away (Aku, 2013).

This work is driven by the dual aim of enhancing the technical performance of solar thermal systems and addressing critical socio-energy challenges. The primary objectives are twofold: (1) to design and evaluate an efficient solar water heater with integrated concentrators, optimizing it for maximum heat energy utilization, and (2) to propose a practical and sustainable model that directly alleviates the dependency and hardships faced by rural dwellers in securing clean thermal energy for their daily necessities

Determination of Efficiencies of Solar Water Heater

The efficiencies of the solar water heater are evaluated for the cases of two solar collectors without plane mirror reflectors; two solar collectors with plane mirror reflectors.

$$\eta_c = \frac{(m_p c_p + m_w c_w)(T_w - T_a)}{A_c Q_c t} \quad (1)$$

where; η_c is the collector efficiency, m_p , the mass of the pipes, c_p , the specific heat capacity, m_w , the mass of water, c_w , the specific heat capacity of water, T_w , the average temperature of hot water, T_a , the average ambient temperature, Q_c , the

average radiation intensity, A_c , the collector area, and t the time in seconds.

The complete diagram of the solar water heater is shown as in Plate 1.



Plate 1: Complete Diagram of the Solar Heater with all Components Coupled

RESULTS AND DISCUSSION

Two solar heater systems were constructed as displayed in plate 1, one consisting of a plane mirror and the other without mirror. The temperature and sunlight radiation were carefully tracked using the mercury in glass thermometer and digital TES1333 solar power meter. Various temperature and Solar power readings were taken for both setups between the period of 15th – 20th November 2022 and the results tabulated.

Results Taken Without the Mirror Concentrator

Table 1 and 2, show the measured temperature and radiation intensities of the solar collector when exposed to the sun without the plane mirror reflectors. The readings were taken at intervals of 1 hour from 8:00am to 5:00pm. For accuracy, three readings of the power radiation intensities were taken and their average evaluated. Also, two readings of temperature, including, ambient and hot water temperatures were taken. The readings were taken from 15th November 2022 to 18th November 2022.

Table 1: Summary of data taken without the concentrating mirrors on 15th November 2022

Time	Power of Radiation (w/m ²)				Temperature (°C)	
	1	2	3	Average	Ambient	Hot
8:00	774.00	799.10	794.8	789.3	25.0	25.0
9:00	887.40	893.10	895.0	891.83	26.5	61.0
10:00	854.60	857.00	855.4	855.67	28.0	72.5
11:00	865.70	873.80	877.7	872.40	30.0	78.0
12:00	880.00	885.60	884.2	883.27	36.0	89.5
1:00	843.30	856.60	855.0	851.63	33.0	76.0
2:00	840.60	848.50	850.0	846.36	32.5	72.0
3:00	775.60	774.60	769.5	773.23	32.0	67.0
4:00	581.50	592.80	603.9	592.73	31.0	59.0
5:00	358.30	357.10	360.2	358.53	30.0	49.0
Average				771.495	30.4	64.9

Plates 2-5 show the plot of the temperature and average solar radiation against time for the setup without reflecting mirrors. It can be observed that the temperature increases from 8:00 am to 12:00 pm and in some cases up to 1:00 pm. Peak temperatures were recorded after 1:00 pm and the temperature generally begins to fall until 5:00 pm. This is the general

nature of solar radiation changes of the location particularly during the month of November, every year. The maximum temperature achieved in the four graphs ranged from approximately 74°C to 89.5°C. This could be as a result of the presence of clouds in some of the days for the given time.

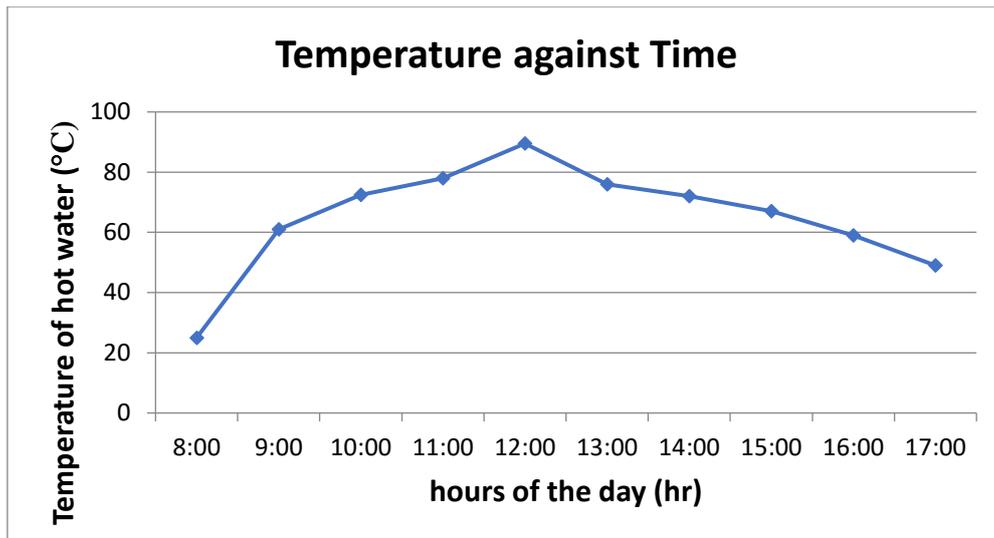


Plate 2: Plot of Temperature against Time for 15th November, 2022

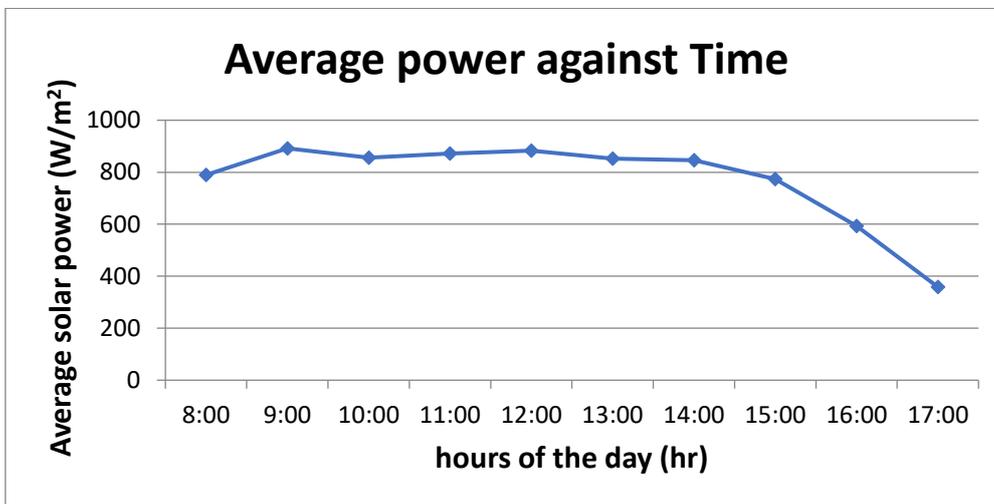


Plate 3: Plot of average radiation against time for 15th November, 2022

Table 2: Summary of Data taken without the Concentrating Mirrors on 16th November 2022

Time	Power of Radiation (w/m ²)				Temperature (°C)	
	1	2	3	Average	Ambient	Hot
8:00	774.00	799.1	794.80	789.30	26.0	26.0
9:00	889.70	886.5	886.20	887.47	26.5	58.0
10:00	924.30	931.9	933.90	930.03	27.0	63.0
11:00	941.10	943.8	951.70	945.53	31.5	74.0
12:00	957.90	956.4	959.00	957.77	36.0	88.0
1:00	952.90	949.1	947.70	949.90	35.5	86.0
2:00	918.70	914.3	910.50	914.50	35.0	70.0
3:00	856.30	860.5	862.50	859.77	33.0	60.0
4:00	635.40	633.3	640.40	636.37	31.0	49.5
5:00	453.70	462.9	452.60	456.40	28.0	48.0
Average				832.704	30.95	62.25

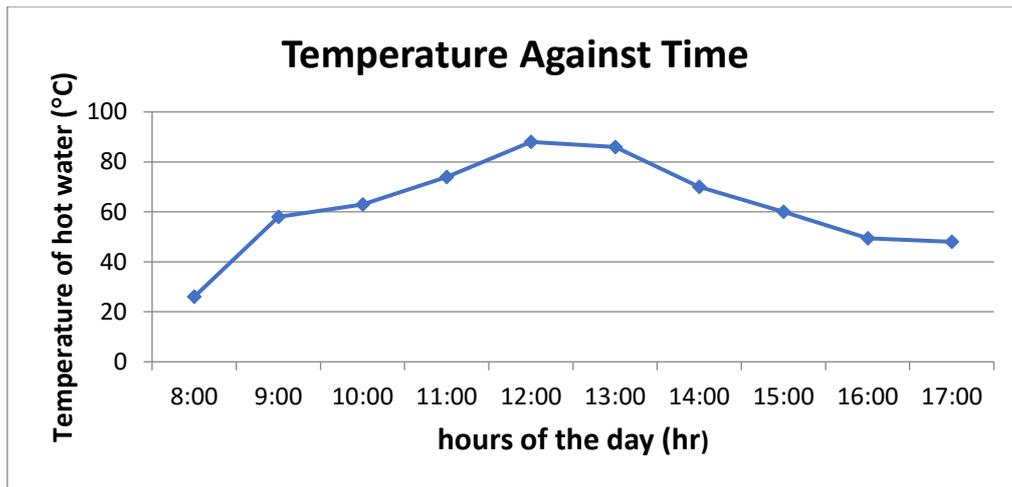


Plate 4: Plot of Temperature against Time for 16th November, 2022

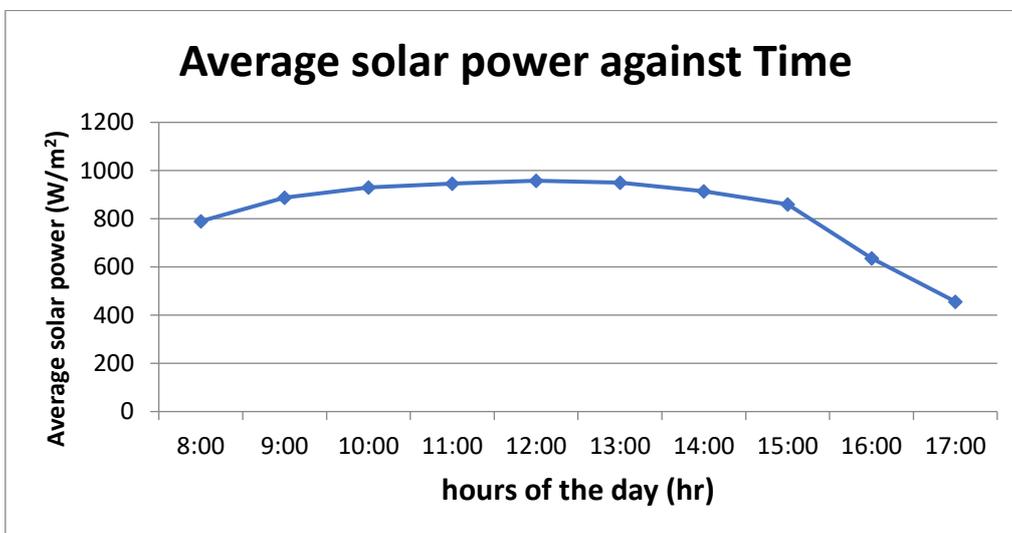


Plate 5: Plot of Average Solar Radiation against Time for 16th November, 2022

Results Taken with the Concentrating Mirror

Consistently, Table 3 and 4 presents the results for the measurements taken when the solar collector was exposed to sun with plane mirror reflectors. Similar to the solar collector without plane mirror reflectors, the readings were taken at

intervals of 1hour between 8:00am in the morning to 5:00pm in the afternoon. Also, three readings of the power radiation and two readings of temperature were taken and the mean values calculated.. These readings were taken from 19th to 22nd November 2022.

Table 3: Summary of Data taken with Concentrating Mirrors on 19th November, 2022

Time	Power of Radiation (w/m ²)				Temperature (°C)	
	1	2	3	Average	Ambient	Hot
8:00	678.30	685.10	690.80	684.73	26.0	26.0
9:00	890.00	924.40	927.00	824.57	28.0	68.0
10:00	913.00	823.10	825.10	926.10	32.5	72.0
11:00	922.20	932.50	933.20	929.30	34.0	78.5
12:00	926.90	924.40	927.00	930.10	31.0	83.5
1:00	930.00	927.80	929.20	925.00	30.5	75.0
2:00	932.10	931.50	930.00	921.20	30.0	72.5
3:00	882.50	879.30	887.60	883.13	29.5	65.5
4:00	825.50	823.10	825.10	824.57	29.0	60.0
5:00	629.30	632.00	635.60	632.30	28.0	58.0
Average				848.1	29.85	65.9

Plates 6 to 9 depicts the plot of the temperature and average solar radiation against time for the solar collector with the concentrating mirror. The maximum temperature is achieved

at approximately 79 °C to 89.5 °C. This shows that the lowest maximum temperature in this case with reflectors is higher than the one without reflectors, but the highest maximums are

the same. This could also be as a result of presence of overcast sky during these measurements. The efficiency achieved in the experiment with two collectors each with reflecting mirror is 43.4%. The efficiency achieved in the experiment with two collectors each without reflecting mirror is 36.7%. This

results show that the highest efficiency is obtained with more number of collectors with a reflecting mirror. Also, it was observed that when the reflectors were removed the efficiency dropped significantly.

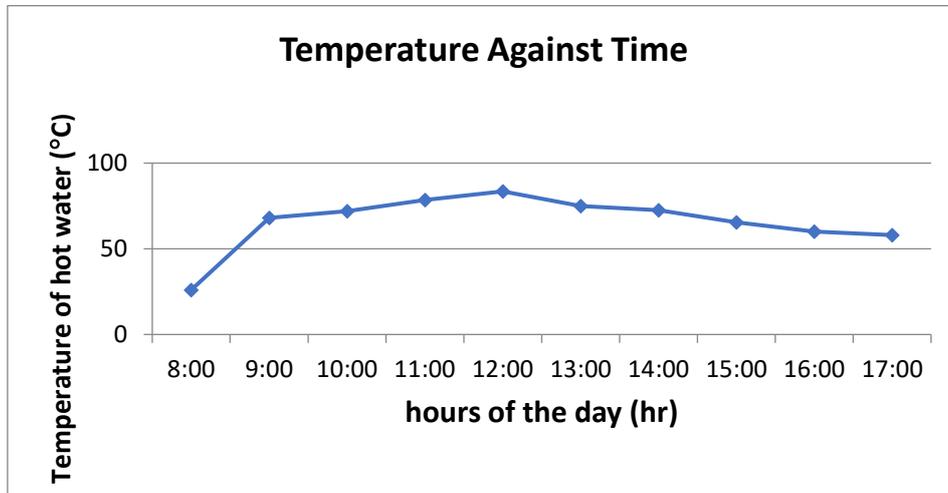


Plate 6: Plot of Temperature against Time for 19th November, 2022

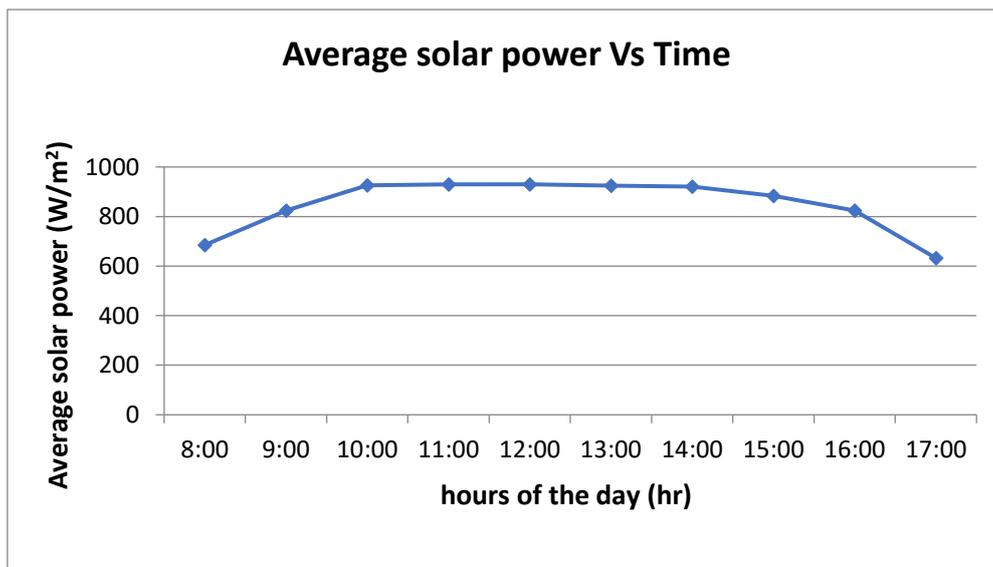


Plate 7: Plot of Average Solar Radiation against Time for 19th November, 2022

Table 4: Reading taken on 20th November, 2022 (Data is taken with Concentrating Mirrors)

Time	Power of Radiation (w/m ²)				Temperature (°C)	
	1	2	3	Average	Ambient	Hot
8:00	678.3	685.1	690.8	684.73	25	25
9:00	801.9	800	810	803.97	26	65.5
10:00	837.5	845.3	840	840.93	27.5	71
11:00	874.2	885.6	889.8	883.2	31.5	74.5
12:00	895.6	892.3	896.4	894.77	34.5	87
1:00	863.8	870	869.5	867.77	33	84
2:00	871.9	873.3	878.2	874.47	32.5	65
3:00	779.8	785	786.3	783.7	31	58.5
4:00	661.2	674	675.9	670.37	30.5	55
5:00	302.2	308	312.5	307.57	29	44
Average				761.148	30.05	62.95

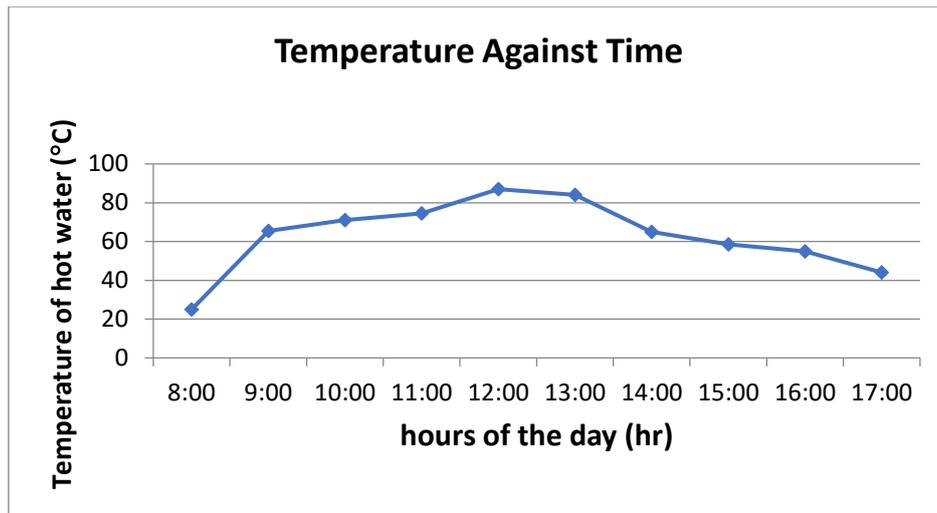


Plate 8: Plot of Temperature against Time for 20th November, 2022

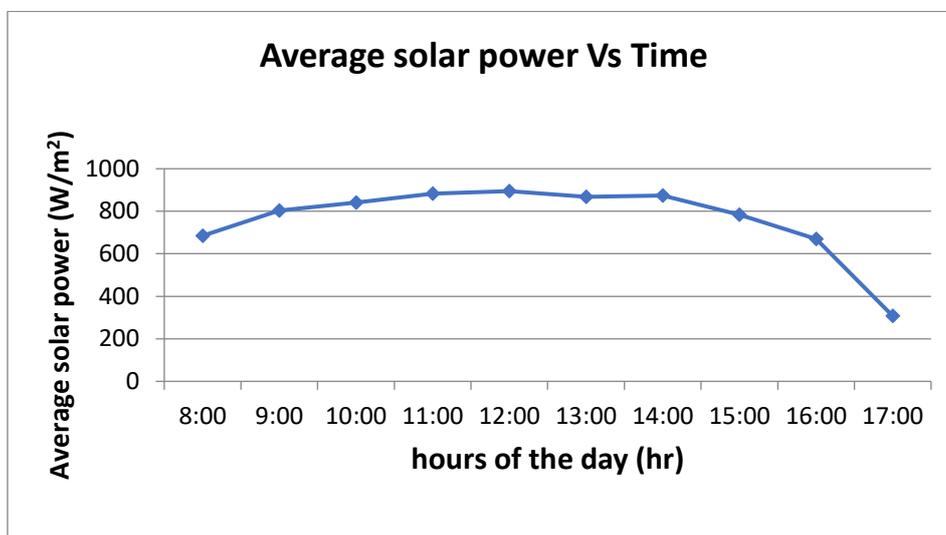


Plate 9: Plot of Average Solar Radiation against Time for 20th November, 2022

Efficiency for Measurements without Concentrating Mirrors

Table 5, presents the average values of radiation intensity, ambient temperature and hot water temperature for the solar collector without mirrors over the four days period of the

experiment. From the table, it is visible that an average temperature of 63.5750°C is achieved for experiment conducted without mirrors.

Table 5: Average Values of the Measurements without Mirrors

Days	Average Radiation Intensity (Q_c)(w/m ²)	Average Ambient Temperature (T_a)(°C)	Average Hot Water Temperature (T_w) (°C)
Day-1	771.4950	30.4000	64.9000
Day-2	832.7040	30.9500	62.2500
Average	802.0995	30.6750	63.5750

Considering a pipe of 16 ½ inch of mass 0.8 kg and 4, 1 inch each of mass 1 kg, the efficiency of the solar collector is calculated using equation 1:

$$n_c = \frac{(16.8 \times 460 + 20 \times 4200)(63.575 - 30.575)}{0.5700 \times 802.0995 \times 18000} \quad 2$$

$$= 36.7\%$$

where; $m_p = (0.8 \times 16) + (1 \times 4) = 16.8kg$, $c_p = 460Jkg^{-1}K^{-1}$, $c_w = 4200Jkg^{-1}K^{-1}$, $m_w = 20kg$ $A_c = (95cm \times 60cm) = 0.5700m^2$, and $t = 5hrs = 18,000sec$.

Therefore, the efficiency achieved in the experiment with the two collectors each without reflecting mirror is 36.7%.

Thermal Efficiency for Measurements with Concentrating Mirrors

Also for the measurement with concentrating mirrors, the efficiency for these measurements and the average values of radiation intensity; ambient temperature and hot water temperature were also evaluated for the four days of the

experiments as presented in Table 6. The average temperature for this setup is obtained to be 71.150°C. compared to the average temperature without reflecting mirror, the value is higher by approximately 12%.

Table 6: Average Values of the Measurements with Mirrors

Days	Average Radiation Intensity (Q_c)(w/m ²)	Average Ambient Temperature (T_a)(°C)	Average Hot Water Temperature (T_w)(°C)
Day-1	848.1000	29.8500	65.9000
Day-2	838.9067	30.5000	76.4000
Average	843.5030	30.1750	71.1500

where; $m_p = (0.8 \times 16) + (1 \times 4) = 16.8kg$; $c_p = 460Jkg^{-1}K^{-1}$; $c_w = 4200Jkg^{-1}K^{-1}$

$m_w = 20kg$; $A_c = (95cm \times 60cm) = 0.57m^2$ and $t = 5hrs = 18,000sec$. Also, from equation (1), we have:

$$n_c = \frac{(16.8 \times 460 + 20 \times 4200)(71.1500 - 30.175)}{0.57 \times 843.503 \times 18000} \quad (3)$$

= 43.4%

Therefore, the efficiency achieved with the two collectors each with reflecting mirror is 43.4%. Also, it can be observed that compared to the efficiency of the solar reflector without mirrors, the efficiency is higher by 6.70%.

CONCLUSION

The performance evaluation was conducted on a solar water heater enhanced with double absorber plates and concentrators. The solar collectors in the absence of reflecting mirrors exhibited an efficiency of 36.7%. The efficiency increased to 43.4 % with the incorporation of reflecting mirrors. This 11.9 % improvement in the efficiency underscores the significance of reflecting mirrors in enhancing the thermal performance of the solar collectors, thereby mitigating the persistent challenge of low efficiency commonly observed in renewable solar energy sources.

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