Development and Performance Test of Solar Cooker using Scheffler Dish

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Abstract
As industrialized nations search for more sustainable energy solutions there still exist many communities that rely on basic forms of energy to survive. Majority of people in developing countries depend on wood, charcoal, agricultural waste and animal dung as energy sources for cooking. India has a very good potential for solar energy .India receives abundant solar radiation, which can be used to meet the demand of low to medium capacity solar kitchens.

Keywords: *Solar energy, Scheffler dish, low cost, small scale, PET sheet.*

I. INTRODUCTION

Sustainable energy solutions are necessary in developing nations as current food preparation practices are becoming harmful to the environment, economic development and also the health of the people. The use of Solar energy is increasing but efficient use of the radiation energy is challenging task. This project focuses on design and development of scheffler type of solar collector to use solar energy available for places like government schools, hostels, community centers, canteens having mid-day lunch programs where they can use solar energy to cook the meal. This project includes investigation of the performance of the scheffler dish.

II. DESIGN PHASE

We designed scheffler type reflector as per research references and the data used as constraints were as following:

Notations:

- Average solar irradiation, ir kW/m^2/day
- Average temperature of atm, ta = 27.24 □C
- Reflectivity of reflector, ρ
- Convective heat transfer co-efficient of air, h = 25 W/m^{2}K
- Stefan-Boltzmann constant, σ = 5.67 ×10-8 W/m2K4
- Temperature of absorber, tr = 200 □C (Design for maximum 200 □C)
- Emissivity of absorber, ε
- Diameter of absorber, d m
- Length of absorber, l m
- Aperture area of dish, Aa m^2
- Area of receiver (absorber),C=Ar m^2
- Concentration ratio, Aa/Ar

Table 1 : Weather information of Anand, Gujarat

Month	Direct normal solar irradiation (kWh/m^2/day)		Temperature (^{0}c)	
		Average		Average
Jan	6.49		20.5	
Feb	7.22		22.9	
Mar	7.2		27.2	
Apr	6.89		31.1	
May	7.22		33.4	
Jun	5.31	5.8	32.2	27.24
Jul	2.66		29	
Aug	2.52		28.2	
Sept	4.9		28.5	
Oct	6.9		28	
Nov	6.42		24.5	
Dec	5.97		21.4	

Design calculations:

→ Design of scheffler:

- Considering average sun-hour is 10 hours
- Taking calculation for two hours,

→ Average solar irradiation, i_r = 5.8 kWh/m^2/day

= 20,880 kW/m^2/day

= (20880 × 2)/10 = 4176 kW/m^2

→ Dish dimensions: a=2.4 m, b=1.3 m (As per lateral section of paraboloid)

→ Aperture area of dish, $A_a = \frac{\pi}{4}\, ab = \frac{\pi}{4}\, 2.4 * 1.3 = 2.45\ m^2$

→ Heat loss to the atm.

Heat loss = Loss due to convection + Loss due to radiation

$$q = h\, A_r\, (t_r - t_a) + \sigma\, \varepsilon\, A_r\, (t_r^4 - t_a^4)$$

$$q = 25 \times A_r\, (473 - 300.24) + 5.67 \times 10^{-8} \times 1 \times A_r\, (473^4 - 300.24^4)$$

$$q = 6696.358\, A_r\ W$$

→ Heat received by receiver,

- $Q_u = \rho\, A_a\, i_r - q$

$= 0.98 \times 2.45 \times 4176 - 6696.358\, A_r$

$= 10026.576 - 6696.358\, A_r$

→ Thermal efficiency, $\eta = \frac{Q_u}{A_a\, I_r}$

- Considering thermal efficiency is 75%

$$\eta = \frac{10026.576 - 6696.358\, A_r}{2.45 \times 4176} = 0.75 \qquad \therefore A_r = 0.3516\ m^2$$

→ Dimensions of receiver, (Later on we found out it's correct)

- Diameter, d m length, l = d m
- Area of receiver, $A_r = \pi\, d\, l + \frac{\pi}{4} d^2 = 0.3516\, m^2 \ \therefore\ l = d = 0.3\ m$

→ Concentration Ratio, $C = \frac{A_a}{A_r} = 6.968$

Analysis/Stimulation and Site Surveying Phase:

As per site surveying we found out that design of a scheffler parabola involves cutting section of a paraboloid to have its focal point at greater distance as shown in figure below:

In context of this design, we had equations

1) 0.5 x
2) 1.8x-1.45

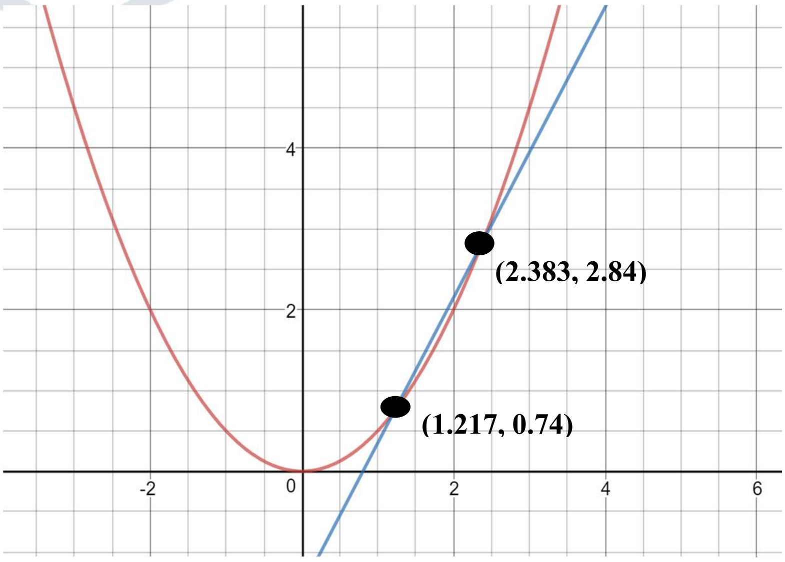


Fig. 1 Design of Scheffler Parabola (All Dimensions are in Meters)

→ Definition of Scheffler Dish and Aperture area:

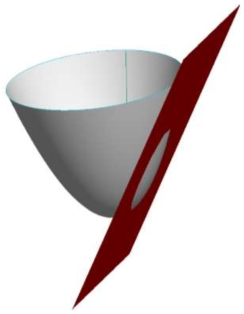
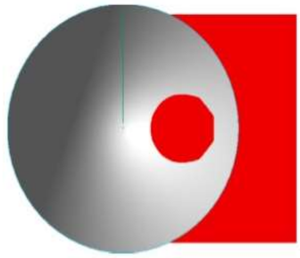
 Figure 2 Scheffler Parabola As A Lateral section	 Figure 3 Aperture Area of Scheffler Parabola
In this figure the scheffler parabola is defined as lateral section of paraboloid. Red plane is showing lateral section.	In this figure red plane intersecting with Paraboloid gives aperture area of scheffler parabola.

Figure 4 Experimental Setup

Implementation

1. Fabrication of Frame and metal working was done at industry.
2. 2-axis manual tracking mechanism is developed with help of hinges.
3. G.I. sheet is attached to frame with self drilling and tapping scews.
4. PET sheet was bonded to G.I. sheet with adhesive.
5. Receiver is of aluminium ,it was painted black and insulated with Polystyrene

III. EXPERIMENT WORK

1. Procedure:

We followed following steps to obtain the performance data:

- We arranged our dish and found the focal point and placed receiver accordingly.
- After that we started collecting data at intervals of 15 mins.
- Here collection of data refers to reading from IR thermometer pointed towards receiver surface and submerging Bulb thermometer in to water of quantity 8 Liters.
- Also tracking was done time to time after every 15 mins using manual tracking.
- The irradiation data was collected with help of Pyranometer and temperature data was collected with help of IR type & Mercury Bulb type thermometers

2. Observation:

We've collected data with pyranometer as follows:

Table 2: Intensity of Radiation

Time (hr.)	Intensity of radiation (W/m^2)		Time (hr.)	Intensity of radiation (W/m^2)	
	On 16th April, 2018	On 17th April, 2018		On 16th April, 2018	On 17th April, 2018
11:00	816	847	14:00	838	830
11:30	852	872	14:30	767	780
12:00	896	883	15:00	709	735
12:30	875	913	15:30	610	680
13:00	867	900	16:00	513	570
13:30	865	852			

Specifications:

→ **Collector:**
- Frame material: Mild steel
- Supporting material: GI sheet (0.5 mm thick)
  - Thickness = 0.5 mm
- Reflecting material: PET Mylar Sheet
  - Reflectivity: up to 90%
  - Transmissivity: 10 %
- Collector dimensions:
  - Horizontal length, l: 2.4 m
  - Vertical length, b: 1.3 m

→ **Receiver:**
- Material: Aluminum coated with black paint
- Receiver dimensions:
  - H = 0.27 m
  - D = 0.39 m
- Mass of receiver, m_{all} = 1 kg
- Specific heat of aluminum, $C_{PAl} = 0.921 \text{ kJ/kgK}$
- Fluid used in the receiver: Water
- Amount of water in receiver, m_{aw} = 2 liter = 2 kg
- Specific heat of water, $C_{PW} = 4.184 \text{ kJ/kg}$

Table 3: Temperature Readings

Time (hr.)	Temperature (°C)	
	Receiver's Surface (t_R)	Water (t_W)
8:30	60.7	32
9:00	64.3	43
9:30	66	50
10:00	77.5	55
10:30	80	59
11:00	81.3	61
11:30	84.7	65
12:00	88	67
12:30	90.5	70
13:00	92	70
13:30	93.7	70
14:00	94.2	72
14:30	97.3	73
15:00	96.1	72
15:30	93.6	71
16:00	90.3	72
16:30	88.7	72
17:00	87.4	69
17:30	79.5	68
18:00	75	66

3. Calculations:

- Aperture area of collector, $A = l \times b$

$$= 2.4 \times 1.3 = 3.12 \text{ m}^2$$

- Area of receiver, $a = H \times D = 0.27 \times 0.39$

$$= 0.1053 \text{ m}^2$$

- Intensity of radiation, I = 913 W/m^2
- Total incident solar radiation on collector, Q_I = Area of Collector × Intensity of radiation

$$= 3.12 \times 913 = 2848.56 \text{ W}$$

- During time interval 12:00 to 12:30, $Q_I = 2848.56 \times 30 \times 60 \text{ kJ} = 5127.408 \text{ kJ}$
- Heat reflected from collector, $Q = 5127.408 \times 0.90 = 4614.67 \text{ kJ}$
- Heat received at receiver, $Q_R = Q_W + Q_{Al}$

Where, Q_W = Heat absorbed by water

Q_{Al} = Heat absorbed by aluminum vessel

- Heat absorbed by water, $Q_W = m_W \times C_{PW} \times \Delta T_W$

$$= 2 \times 4184 \times (70 - 67) = 25.104 \text{ kJ}$$

- Heat absorbed by aluminum vessel, $Q_{Al} = m_{Al} \times C_{Pal} \times \Delta T_{Al}$

$$= 1 \times 921 \times (90.5 - 88) = 2302.5 \text{ kJ}$$

- Heat received at receiver, $Q_R = Q_W + Q_{Al}$

$$= 25.104 + 2302.5 = 2327.604 \text{ kJ}$$

- Thermal efficiency, $\eta = \dfrac{\text{Heat received } (Q_R)}{\text{Heat reflected by collector} (Q)} = \dfrac{2327.604}{4614.67} = \dfrac{2327.604}{4614.67} = 50.44\ \%$

4. Result Table :

Table 4: Result Table

Time	Intensity of radiation (W/m^2)	Temperature (□C)		Incident Heat (kJ)	Reflected heat (kJ)	Heat at receiver			Efficiency (%)
		Vessel	Water			Heat absorbed by vessel (kJ)	Heat absorbed by water (kJ)	Total (kJ)	
11:00	847	81.3	61	0.00	0.00	0	0.00	0.00	0.00
11:30	872	84.7	65	4897.15	4407.44	3131.4	33.47	3164.87	71.81
12:00	883	88	67	4958.93	4463.04	3039.3	16.74	3056.04	68.47
12:30	913	90.5	70	5127.41	4614.67	2302.5	25.10	2327.60	50.44
13:00	900	92	70	5054.40	4548.96	1381.5	0.00	1381.50	30.37
13:30	852	93.7	70	4784.83	4306.35	1565.7	0.00	1565.70	36.36
14:00	830	94.2	72	4661.28	4195.15	460.5	16.74	477.24	11.38
14:30	780	97.3	73	4380.48	3942.43	2855.1	8.37	2863.47	72.63
15:00	735	96.1	72	4127.76	3714.98	1105.2	8.37	1113.57	29.98
15:30	680	93.6	71	3818.88	3436.99	2302.5	8.37	2310.87	67.24
16:00	570	90.3	72	3201.12	2881.01	2486.7	8.37	2495.07	86.60

5. Graphs & Conclusion:

- As per fig 5 it is clear that intensity of radiation increases with time starting with sunrise, peak at noon time, decreasing with time ending lowest at sunset.

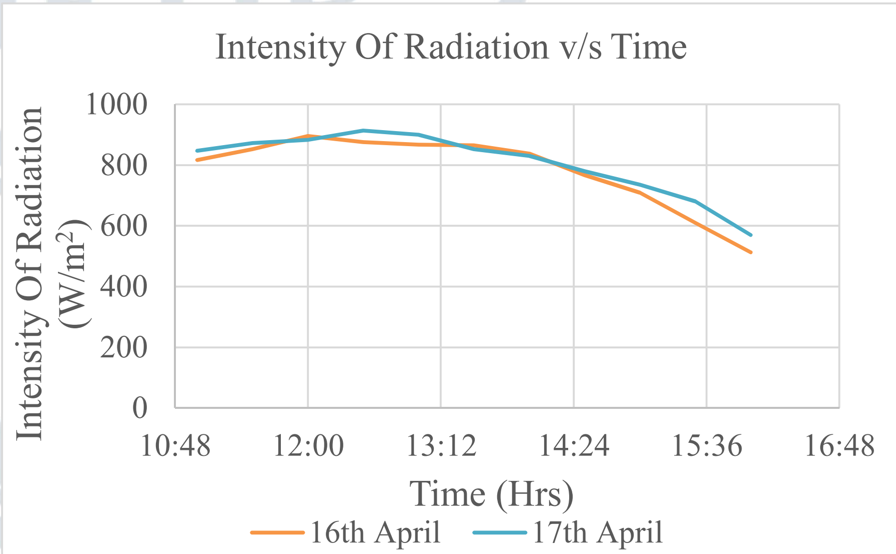


Figure 5

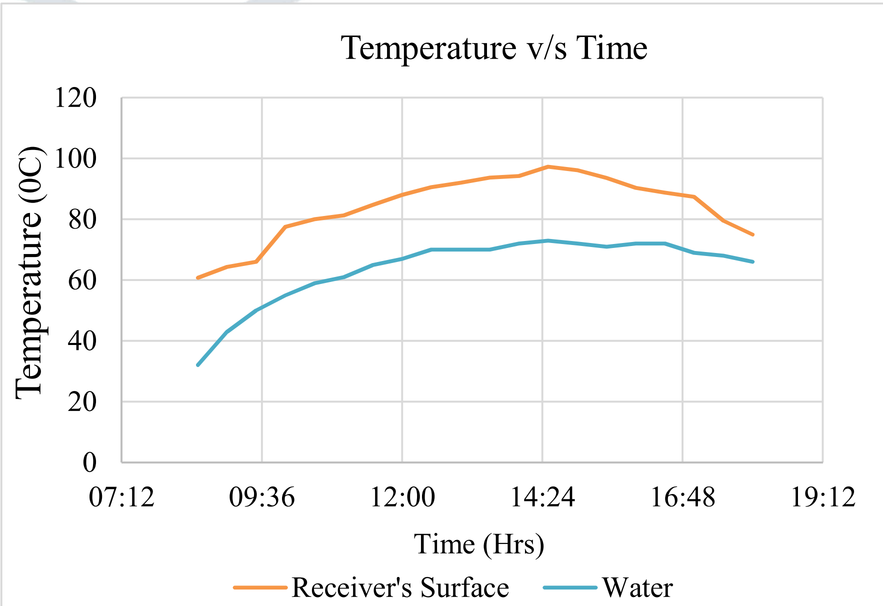


Figure 6

- As per fig 6, temperature of water and receiver surface temperature increase steadily and remains constant some time when solar irradiation is at peak. This is as a result of steam forming in container and also heat loss results as an obstacle in heating of water.

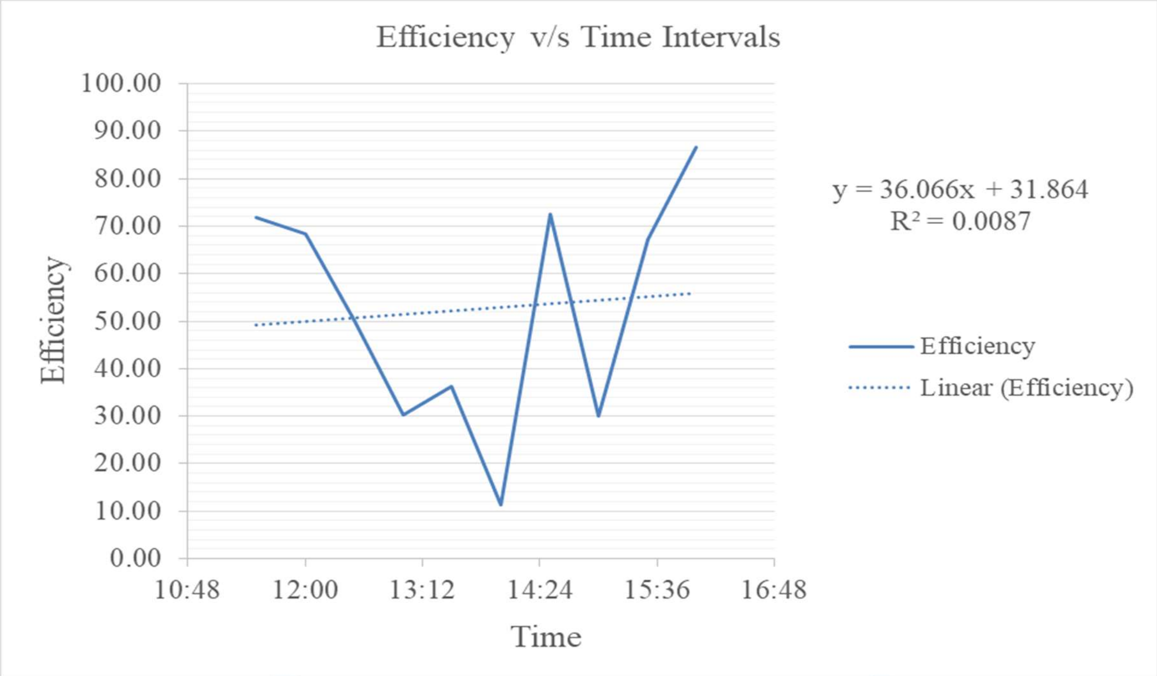


Figure 7

- As per fig 7 the efficiency curve follows equation y=36.066x + 31.8664 and has coefficient of determination 0.0087 which shows comparative less error with linear trendline. This trend of efficiency is due to poor insulation and heat loss due to gloss paint on receiver and some other factors such as aperture area of dish when sun as peak is small.

Following can be concluded:

- From the experiment, a great fall can be seen in the heat efficiency during 12:00 to 14:00 hours because sun has reached on the top and dish aperture area towards sun decreases.
- PET sheet has been used in the experiment and from the experiment carried out, it can be concluded that PET sheet can be used instead of mirror if about 50% efficiency is required as PET sheet is less costly than mirror.
- Also, it is easy to attach and remove PET sheet on dish. Hence, it becomes cost effective and can be maintained easily.
- PET sheet does not get easily oxidized with time as in the case of mirror.
- Because of Scheffler dish heat receiver unit can be placed at a distance from dish.
- Consistent cooking temperature can be obtained from 11:30 to 16:30 hours.
- Scheffler dish solar concentrator setup is developed in such a way that any common man with basic knowledge can easily operate and maintain it.
- Parabolic Dish by TSS, Ahmedabad (having similar area & automatic tracking) will cost Rs.25000 while developed Scheffler dish concentrator setup cost Rs.11000.

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Thesis

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