Experimental Analysis of 2.7 m² Scheffler Reflector and Formulation of a Model

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Abstract: **The performance of 2.7 m² Scheffler reflector has been studied. Scheffler Reflector is parabolic dish collector designed to collect energy from sunlight. In this System storage vessel was installed at focus point . Vessel stores 10 ltr of water for the purpose of experimentation. Tests were carried out with this set up for the purpose experimentation. Performance analysis of the reflector revealed that average power and efficiency in terms of water boiling tests to be 550 W and 19%.**
Maximum temperature of water was observed to be 94⁰C. Ambient temperature was observed to be in between 32ᵒC and 40 ⁰C.

Keywords— **Scheffler Reflector, Heat Gain, Performance Analysis**

I. INTRODUCTION

Wolfgan Scheffler, set-up a parabolic reflector to harness solar energy using low cost set-up which can be used in rural areas in India. A concentrating primary reflector tracks the movement of the Sun, focusing sunlight on a fixed place. The focused light heat a very large pot, which can be used for heating, steam generation, cooking, baking breads, and water heating .The Scheffler reflector can be used for the supply of hot water for domestic purposes. These systems can have one water storage tank which performs dual function of absorbing solar radiation and preserving heat of water.

The use of Scheffler reflectors can result in effective water heating by using the non-uniform distribution of solar radiation on the cylindrical absorber surface. In Our System, we have painted the vessel in non reflective black color which will maximize the absorbtivity. The paper is focused on the performance analysis of Scheffler Reflector for average power and efficiency in terms of water boiling test on the domestic 2.7 m² Scheffler Reflector in Pune.

II. DESIGN CONCEPTS OF SCHEFFLER REFLECTOR

Solar energy is a weak source and its maximum energy density is merely about 1000 watts/m² even when the sun is at the zenith. Therefore, for the utilization of solar energy, its efficient concentration is required.

A parabola comprises of a set of points in a plane which are equidistant from the focus and the directrix. In other words, Given a point and a line that lie in a plane, the locus of points in that plane that are equidistant to the said point and the said line is a parabola. A parabola may be characterized as a conic section with an eccentricity of 1. A parabola has a single axis of reflective symmetry. The axis passes through its focus and is perpendicular to its directrix. A parabola spun about this axis in three dimensions traces out a shape known as a paraboloid of revolution.

In our analysis, we have considered experimentation on lying type of Scheffler reflector which gives better efficiency in the season of summer unlike standing type reflector. Manual tracking mechanism has been employed. Non return valve was fitted at the inlet line and air vent, pressure relief valve at the outlet line. For analysis and testing purpose,. This type of compact solar water heater is simple in design, low in cost, easy in operation and maintenance, easy to install and of high efficiency compared to flat plate collectors and tubular type integrated collector storage systems.
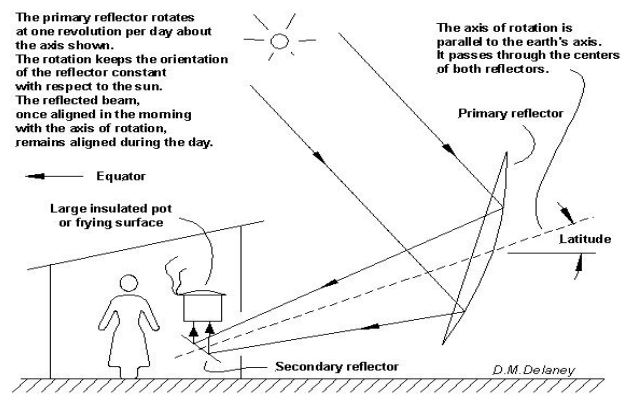
How the Scheffler cooker keeps its area of focus on the cooking place as the sun moves.
Fig1: Schematic of domestic Scheffler

Fig. 2 : A model of Scheffler Reflector system

III. EXPERIMENTAL PROCEDURE

A. Experimental Setup

The Scheffler reflector used is having an area of 2.7m^2. The sunlight that falls on this reflector is reflected sideways to the focus located at some distance of the reflector. The axis of daily rotation is located exactly in north-south-direction, parallel to earth axis and runs through the centre of gravity of the reflector. That way the reflector always maintains its gravitational equilibrium and the mechanical tracking device (Manual) doesn't need to be driven by much force to rotate it synchronous with the Sun. The focus is located on the axis of rotation to prevent it from moving when the reflector rotates. During the day the concentrated light rotated around its own centre but not move sideways in any direction. That way the focus stays fixed. At the focus it has a container to hold 10litres water. The parameters measured were water temperature, solar radiation, wind speed, and ambient temperature. Temperature gun was used to measure water temperature which has a range of –200 °C to 1250 °C. Wind speed is measured by battery operated digital anemometer, it has a range of 0.3 to 30 m/s. Ambient temperature and Humidity is measured using Hygrometer . A Solarimeter is used to measure the radiations. The experimentation was carried in the month of April .This month Covers summer season in India .The readings were taken at different time zones between 9 a. m. to 4 p. m. for various days. All readings were taken at the interval of 5 minutes. More than 300 observations were recorded.

B. Observations

The detail procedure for the test run is as under:

- In the morning With the help of manual tracking mechanism the dish is rotated to follow the sun from morning to evening.
- Water is filled in the Tank which is at focus.
- As soon as dish starts moving the readings were noted at regular interval manually.
- Observations: 80 observations were recorded throughout the day.

Sr. No.	Time	Atm.Temp	Wind vel.	Water temp	Radiations on dish	Heat Gain
1	9:30	32.3	1.08	33	787	0
2	9:35	32.4	1.8	39	780	251.22
3	9:40	32.4	1.8	44	791	460.57
4	9:45	32.5	2.52	46	785	543.7
5	9:50	32.9	3.24	53	779	879.31
6	9:55	33	0.72	56	771	1004.92
7	10:00	33.4	11.88	61	781	1214.27
8	10:05	32.9	12.24	62	784	1256.14
9	10:10	33.1	5.4	64	806	1339.88
10	10:15	33.5	3.24	67	849	1405.5
11	10:20	34.8	5.4	69	857	1549.23
12	10:25	34.9	6.12	70	850	1591.11
13	10.3	35.2	3.24	68	804	1507.36
14	10:35	36.6	1.8	69	850	1549.23
15	10:40	36.7	5.7	69	845	1549.23

Table 1: Sample observations

C. Performance Evaluation

- The efficiency was calculated with the following equations:

$$\eta_{overall} = \frac{(\text{Heat Gain} \times 10^3)}{\int_{tr}^{tp} (\text{Radiation} \times \text{Aperture Area} \times dt)} \times 100$$

where ,E_p is the total heat energy, t – the time; *Radiation* – the beam radiation at time t, and *Aperture area* – the aperture area of the Scheffler reflector which is also a variable function whose value can be determined for any day of the year by the formula

- Aperture area = $\dot{\eta} \times$ Design area $\times$ cos[(43.23 - seasonal angle deviation of the Sun)/2]

Where, $\dot{\eta}$ is the area efficiency (ratio actual area on which mirrors could be placed to the design area) which in our case is 91% , seasonal angle deviation of the sun which in our case 9^0,design area is 2.7m^2.

- We have used water for the evaluation of the cookers in terms of power. For the performance test with water only, following equation was used:
  Heat Gain = $m_w c_w (\Delta T/3600)$

Where m_w is mass water which in our case in 2 ltr. C_w is the specific heat at constant pressure (for water 4.187 kJ/kgK). ΔT is the difference between two consecutive temperatures of water recorded.

- Power is Evaluated by :
  $$P = E_p / t_p$$

Where t_p time for which temperatures are recorded.
In between the beam radiation range of 750 to 900 W/m2, Scheffler reflector showed that about half of the solar power collected by the reflector becomes finally available in the cooking vessel.
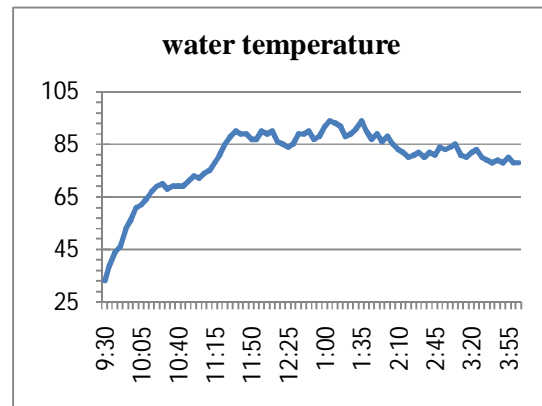
D. Performance Evaluation

Fig. 3: Graph of Temperature vs. Time

During the performance evaluation test with 10 liters of water, 1.000 ml water was evaporated. The average power and efficiency in terms of water boiling test was calculated to be 550 W and 19% respectively, against an average value of beam radiations of 812 W/m2.
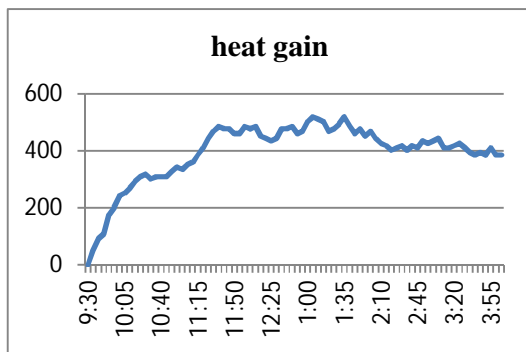

Fig. 4: Graph of Heat Gain Vs. Time

IV. MATHEMATICAL MODEL

A. Need For Formulating Generalized Experimental Data Based Model

While working on the Scheffler Reflector it is necessary to decide the parameters that affect on the temperature at focus point. This would be Possible when a quantitative relationship amongst various dependent and independent variables of the system is established by formulating the mathematical model of Scheffler reflector. It is well known that such mathematical model for Scheffler Reflector cannot be formulated by applying only logic but formulation with an experimental data base is essential. In this experimental approach all the independent variables are varied over a widest possible range, a response data is collected and an analytical relationship is established. Then the technique of optimization is applied to deduce the values of independent variables at which the necessary responses can be minimized. The determination of such values of independent variables is always the puzzle for because of complex phenomena of interaction of various independent variables such as Generated Water Temp, Incident Rays, Water Quantity, Operation time, wind speed, ambient temperature, acceleration due to gravity whereas response variable would be generated water temperature and heat gain. Theta (Generated Water Temperature) and heat gain is considered while developing model.

The Methodology is briefly as follows :
- Identification of independent and Dependent Variables
- Reduction of independent variables adopting dimensional analysis
- Physical design of an experimental set up.
- Execution of experimentation
- Purification of experimentation data
- Formulation of model

B. Design of Experimentation

Reduction of variables through dimensional analysis: The various independent and dependent variables of the system with their symbols and dimensional formulae are given in nomenclature. There are several quite simple ways in which a given test can be made compact in operating plan without loss in generality or control. The best known and the most powerful of these is dimensional analysis. In the past dimensional analysis was primarily used as an experimental tool whereby several experimental variables could be combined to form one.. Almost every major experiment in this area was planned with its help. Deducing the dimensional equation for a phenomenon reduces the number of independent variables in the experiments. The exact mathematical form of this dimensional equation is the targeted model. This is achieved by applying Buckingham's π theorem.When we apply this theorem to a system involving n independent variables, (n minus number of primary dimensions viz. L, M, T) i.e. (n-4) numbers of π terms are formed. When n is large, even by applying this theorem number of π terms will not be reduced significantly than number of all independent variables. Thus much reduction in number of variables is not achieved. It is evident that, if we take the product of the terms it will also be dimensionless number and hence a π term. This property is used to achieve further reduction of the number of variables. Dimensional analysis is used to reduce the variables and following π terms were evolved out of it.

- $\pi 1$ = Tank Volume / A=Dish area$^{1.5}$
- $\pi 2$ = Wind Speed $\times$ Time / A$^{0.5}$
- $\pi 3$ = g$\times$A$^{0.5}$/Wind Speed^2
- $\pi 4$ = Angle $\times$A$^{0.5}$ / W
- $\pi D1$= Water Temp/ Atmos. Temp
- $\pi D2$= Heat gain = m cp (Water Temp - atmos Temp)
- $\pi D3$= E/(Radiation$\times$A)

Buckingham- π theorem in brief
- Generated Water Temperature [θ]
- Water temp =f (Radiation,wind speed, Time, A, W, atmos temp,g)
- f (atmos temp, wind speed, Radiation, Time, A,W, water temp,g,Angle,W, Haet gain) = 0
- π ($\pi 1$,$\pi 2$,$\pi 3$,$\pi 4$,$\pi 5$,$\pi 6$,$\pi 7$) = 0
- N = 11 , m =4
- No of pi terms (n- m) = 11-4 =7

C. Formulation of Experimental Data Based Model

It is necessary to correlate quantitatively various independent and dependent terms involved in this very complex phenomenon. This correlation is nothing but a mathematical model as a design tool for such situation. The mathematical model for all processing operations is given below:
For Generated Water Temperature, Heat Gain and efficiency:

Four independent π terms (π1, π2, π3, π4) and two dependent π terms (πD1, πD2) have been in the design of experimentation and are available for the model formulation.
Independent π terms = (π1, π2, π3, π4),
Dependent π terms = (πD1, πD2)
Each dependent π is assumed to be function of the available independent π terms,
θ = f (π1, π2, π3, π4)
Where, θ = πD1, Dependent pi term
     "f (πD1)= function of (π1, π2, π3, π4) "
A probable exact mathematical form for this phenomenon could be the empirical relationships in between dependent dimensionless ratio and independent dimensionless ratio and are assumed to be exponential.

     πD1 = k1 x (π1) a1 x (π2) b1 x (π3) c1 x (π4) d1
In above equation,k1, a1, b1, c1, d1, are unknowns whose value are to be find out.

     In this way the matrix can be generated for all the values of π and taking log of the above equation. By using Matlab, solution for the above equation is found out by achieving individual values of the unknowns k1, a1,b1,c1 and d1.

k1	0.81236
a1	-0.03
b1	-0.0088
c1	-0.3345
d1	0.5475

By substituting the above unknown coefficients equation generated is:

$$\pi D1 = 0.812369 \times \pi1^{-0.03} \times \pi2^{-0.0088} \times \pi3^{-0.3345} \times \pi4^{0.5475}$$

Similarly, unknown coefficients for all the independent π terms (π1,π2,π3,π4) is found out for other two dependant π terms (πD2,πD3) and following table is generated:

Dependant πD terms	K	a	b	c	d
πD1	0.812369	-0.03	-0.0088	-0.3345	0.5475
πD2	3.63533	-6.8093	-0.0605	0.4869	-1.3933
πD3	33.48173	-5.1805	-0.062	1.7168	-3.8323

Hence, after substituting values of k, a, b, c, d equations of dependant πD terms in terms of dependant π values are formulated.

D.   Final Model Formulated

$$\pi D1 = 0.812369 \times \pi1^{-0.03} \times \pi2^{-0.0088} \times \pi3^{-0.3345} \times \pi4^{0.5475}$$
$$\pi D2 = 3.63533 \times \pi1^{-6.8093} \times \pi2^{-0.0605} \times \pi3^{0.4869} \times \pi4^{-1.3933}$$
$$\pi D3 = 33.48173 \times \pi1^{-5.1805} \times \pi2^{-0.062} \times \pi3^{1.7168} \times \pi4^{-3.8323}$$

Above are the equations generated for dependant π terms which were ultimately denoted for the parameters i.e. πD1 for generated water temperatures (Water Temp/ Atmos. Temp), πD2 for Heat gain E,πD3 for efficiency (E/(Radiation*A)).

E.   Comparative Analysis between Theoretical and Practical values

Following are the graphs for comparison between practical dependent values and theoretical dependent values
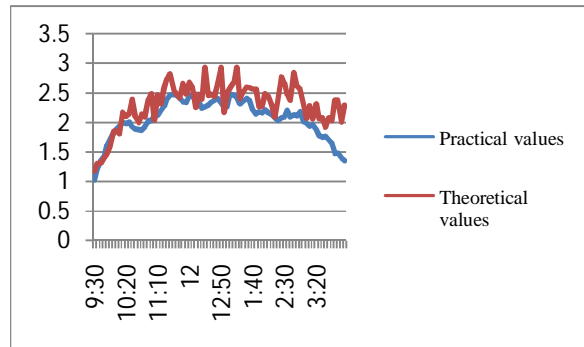

Fig.5: Graph of comparative analysis between practical and theoretical πD1 terms

From the above analysis it can be observed that most of practically attained efficiency is lesser than the Theoretical efficiency attained from the mathematical model. Efficiency achieved from the formulation is 43% and efficiency attained from the practical values of πD terms is 19%.Power generated in the experimentation is 550 watts.
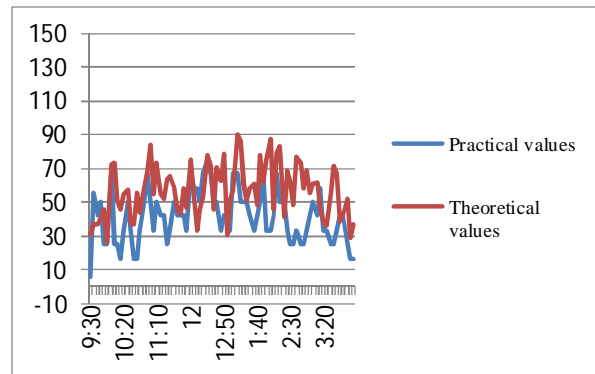

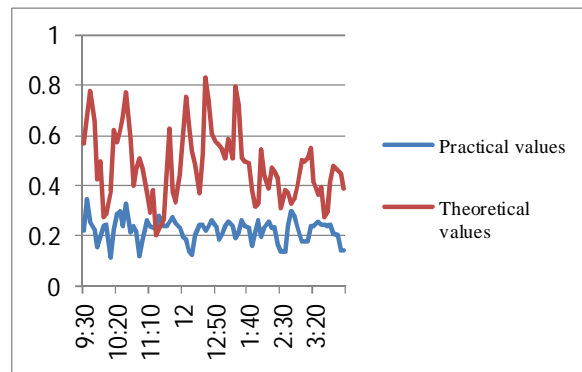Fig.6: Graph of comparative analysis between practical and theoretical πD2 terms

Fig 7: Graph of comparative analysis between practical and theoretical πD3 terms

V. CONCLUSION

In order to utilize the non polluting and freely available source of reversible nature i.e. solar energy, its intensity must be maximum. In order to maximize its effectiveness, the 2.7m2 Scheffler Reflector is one of the most promising sources available. This system mainly finds its application in household cooking. Small systems use a well insulated solid iron-block which is heated to about 400°C at the focal-point which can be used for cooking for a family.

Dimensional correlations for generated water temperature, heat gain, efficiency and various other independent variables have been developed based on experimental results. The dimensional analysis shows that generated water temperature is determined primarily by ratio of product of angle and Dish area to the wind speed.

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