

Performance Analysis of Scheffler Reflector Using Approximate Generalized Model

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ABSTRACT

The performance of Scheffler reflector has been studied. In this system storage reservoir was installed at Focus point. It has a single large diameter drum which serves the dual purpose of absorber tube and storage tank. The drum is sized to have a storage capacity of 2 liter for experiment. The tests were carried out with this set up and were repeated for several days. Performance analysis of the collector has revealed that the average power and efficiency in terms of water boiling test to be 1.30 kilowatts and 21.61 % respectively against an average value of beam radiations of 742[Wm⁻²]. The maximum water temperature in the storage tank of 89 °C has been achieved on a clear day operation and ambient temperature between 28 °C to 31 °C. Using the experimental database a generalized data based model is formulated.

Key words: *Scheffler Reflector, Thermal Performance, Energy In Sensible Heat, Generalized Model Doe, Experimental Data Based Modeling.*

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INTRODUCTION

This paper German Scientist Wolfgang Scheffler has devised a parabolic reflector set up 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, water heating[1-5].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. Many methods are suggested to keep water temperature at a satisfactory level. Among them, the use of a selective absorber that reduces radiation thermal losses and double glazing, transparent insulation and inverted or evacuated absorber to suppress convection thermal losses are suggested methods that preserve water storage heat. In the literature, few works are referred to Scheffler Reflector with cylindrical water storage tanks mounted at Focal point. 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 most of the above systems the part of the cylindrical absorber is thermally insulated in order to reduce storage tank thermal losses. [6] Considering that this reflector systems aim to cover domestic

needs of about 100-200 liter per day, the aperture area of this can be up to about 2.0-2.5 m² which corresponds to use of cylindrical storage tank with diameter 0.2 m to about 0.4 m. [7] In the present work experimental study of Scheffler Reflector water heater (SRWH) consisting single storage tank as an absorber mounting in side curved reflector trough has been carried out. The solar reflector for 5 liter water per day capacity to heat is designed [8]. In this design the thermal insulation on storage tank is not provided to lower down the cost of Water Heater and for its wide applications in domestic sector. The paper is focused on the performance analysis of Scheffler Reflector water heater for average power and efficiency in terms of water boiling test conducted at Pune in India. [1-9]

DESIGN CONCEPTS OF THE SRWH

Solar water heating system of this type defer to flat plate solar collector in design and operation as it consists of an unit with dual operation, to absorb solar radiation and to preserve the solar heat, instead of the absorbing solar radiation and the heating only the circulating fluid. The designed model for experimentation is shown in fig. 1. The solar reflector water heater of 5 liter capacity per day capacity is designed with dish diameter of 2.7 m².

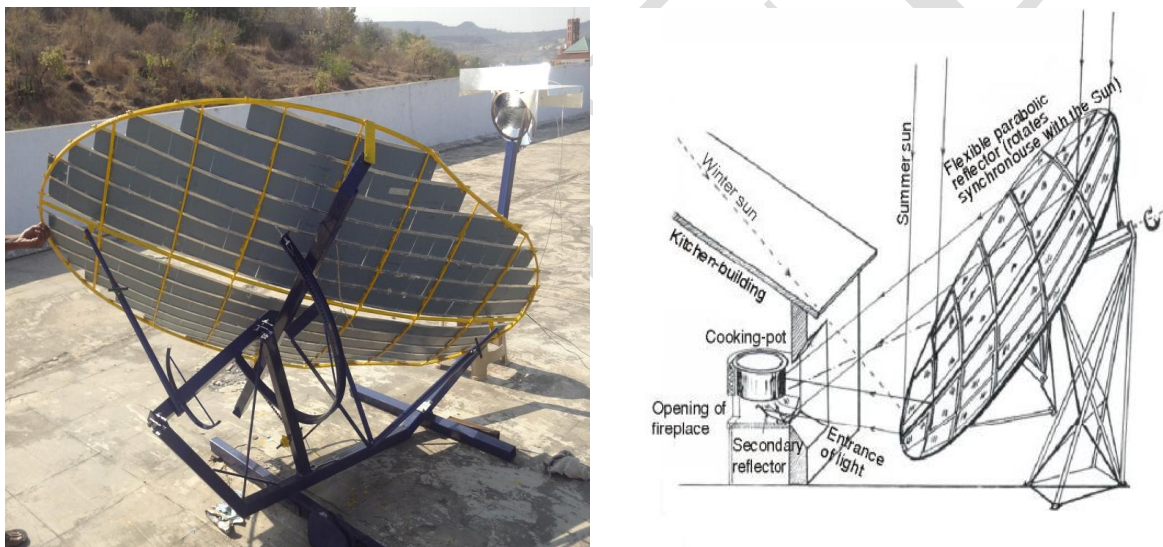


Fig. 1 : (a) A model of SRWH system, (b) Schematic of SRWH

The storage tank painted black is so positioned that its periphery lies on the focus of the parabolic reflector. Non return valve was fitted at the inlet line and air vent, pressure relief valve at the outlet line. For analysis and testing purpose, Al-Cr thermocouples were located at different positions in the heater. 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. The storage tank has an entrance for the water at the top of one side of it and an exit at the bottom of the other side of it. The SRWH inlet is connected directly to the overhead or supply tank and its out let is regulated by the valve. It is naturally circulated type water heater. The storage tank is hydraulically tested for fluid pressure of 0.588 MPa.

TESTING PROCEDURE AND EXPERIMENTATION

The Scheffler reflector used is having an area of 2.7m². 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 2 litres of 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. Around 80 observations were recorded. The sample observations are shown below in table 1.

Sr. no	Area (A)	V T	Wind Speed (km/hr)	Humidity (Y) %	Time	Atm.Temp °C	Acc Due to gravity (g)	Water Temp °C	Altitude Angle (Degree)	Radiations On Dish (W/m ²)	Heat Gain (KJ)
1	2.7	2	1.08	10	9:30	32.3	9.81	33	18.5	787	0
2	2.7	2	1.8	10	9:35	32.4	9.81	39	18.5	780	50.244
3	2.7	2	11.88	10	10:00	33.4	9.81	61	18.5	781	242.854
4	2.7	2	12.24	10	10:05	32.9	9.81	62	18.5	784	251.228
5	2.7	2	23.2	10	12	36.7	9.81	90	18.5	860	485.700
6	2.7	2	5.2	10	12:05	36.5	9.81	89	18.5	873	477.326
7	2.7	2	15.5	10	2:00	39.8	9.81	88	18.5	825	468.95
8	2.7	2	2.6	10	2:05	39.4	9.81	85	18.5	815	443.83
9	2.7	2	4.7	10	3:30	36.1	9.81	80	18.5	741	401.96
10	2.7	2	9.8	10	3:35	35.1	9.81	79	18.5	735	393.586
11	2.7	2	0.8	10	4:00	36.4	9.81	78	18.5	748	385.212
12	2.7	2	1.6	10	4:05	36.3	9.81	78	18.5	745	385.212

Table 1: Test Readings

PERFORMANCE EVALUATION :

- The efficiency was calculated with the following equations:

$$\eta = \frac{10^3 \cdot E_p}{\int_{t=0}^{t_p} [(G_{bave}) \times A_s \times dt]} \times 100$$

where, E_p the total heat energy, t – the time; G_{bave} – the beam radiation at time t , and A_s – 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

$$\text{Aperture area} = \text{Reflector area} \times \cos\left(\frac{43.23^\circ - \text{seasonal angle deviation of the Sun}}{2}\right)$$

seasonal angle deviation of the sun which in our case 9° , 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:

$$E_p = m_w c_w (\Delta T / 3600)$$

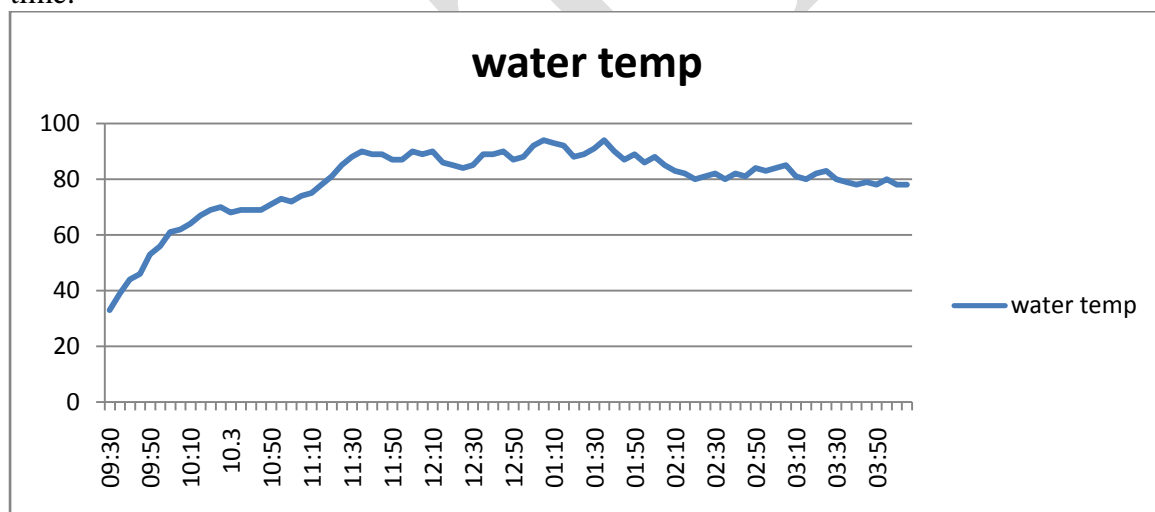
Where m_w is mass water which in our case in 2 ltr. C_w is the specific heat at constant pressure (for water 4.187 kJ/kgK). ΔT is the difference between two consecutive temperatures of water recorded.

Power is Evaluated by :

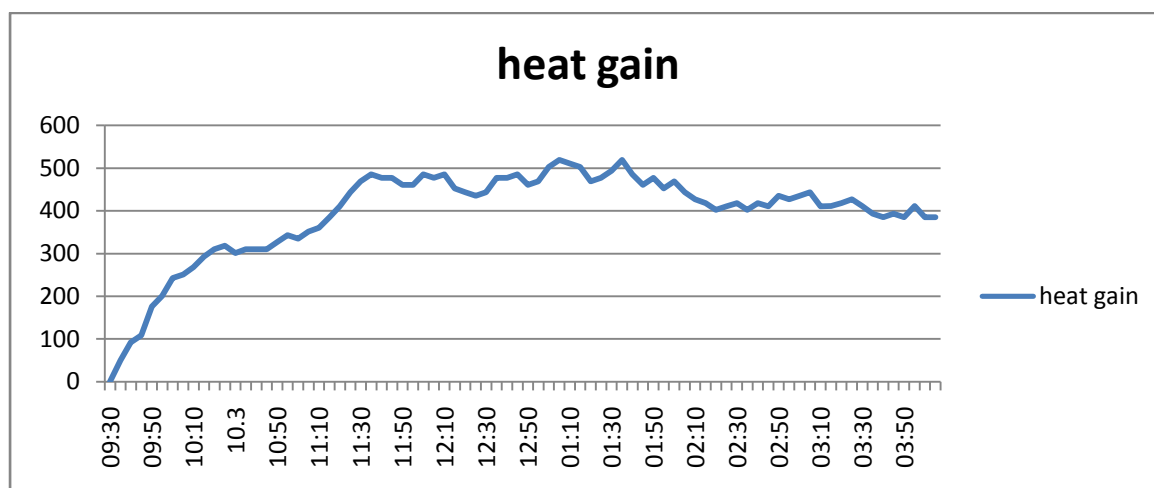
$$P_{ave} = E_p / t_p$$

Where t_p time for which temperatures are recorded.

In between the beam radiation range of 700 to 900 W/m^2 , Scheffler reflector showed that about half of the solar power collected by the reflector becomes finally available in the cooking vessel. Following are the graphs of water temperature and Heat gain with respect to time.



Graph no. 1: Water temp. Vs time.



Graph no.2 : Heat Gain Vs Time

From the above test evaluation it can be observed that heat gain is maximum during the period from 12 pm to 2pm, where sun being at its topmost position at 1 pm allowing us to achieve maximum power and efficiency.

MODEL FORMULATION

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 where as 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
- Test planning comprising of determination of test envelop, test points, test sequence and experimentation plan.
- Physical design of an experimental set up.
- Execution of experimentation
- Purification of experimentation data
- Formulation of model

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. The field of fluid mechanics and heat transfer were greatly benefited from the application of this tool. Almost every major experiment in this area was planned with its help. Using this principle modern experiments can substantially improve their working techniques and be made shorter requiring less time without loss of control. 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 (Hibert, 1961). 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.

- $\pi_1 = \text{Tank Volume} / A = \text{Dish area}^{1.5}$
- $\pi_2 = \text{Wind Speed} \times \text{Time} / A^{0.5}$
- $\pi_3 = g \times A^{0.5} / \text{Wind Speed}^2$
- $\pi_4 = \text{Angle} \times A^{0.5} / W$
- $\pi_{D1} = \text{Water Temp} / \text{Atmos. Temp}$
- $\pi_{D2} = E = m \text{ cp} (\text{Water Temp} - \text{atmos Temp})$
- $\pi_{D3} = E / (\text{Radiation} \times A)$

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, E) = 0
- $\pi (\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7) = 0$
- $N = 11, m = 4$
- No of π terms ($n - m$) = $11 - 4 = 7$

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 pi terms ($\pi_1, \pi_2, \pi_3, \pi_4$) and two dependent pi terms (π_{D1}, π_{D2}) have been in the design of experimentation and are available for the model formulation.

Independent π terms = ($\pi_1, \pi_2, \pi_3, \pi_4$), Dependent π terms = (π_{D1}, π_{D2})

Each dependent π is assumed to be function of the available independent π terms,

$$\theta = f(\pi_1, \pi_2, \pi_3, \pi_4)$$

Where, $\theta = \pi_{D1}$, Dependent pi term “ $f(\pi_{D1}) = \text{function of } (\pi_1, \pi_2, \pi_3, \pi_4)$ ”

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.

$$\pi_{D1} = k_1 \times (\pi_1)^{a_1} \times (\pi_2)^{b_1} \times (\pi_3)^{c_1} \times (\pi_4)^{d_1}$$

In above equation, k_1, a_1, b_1, c_1, d_1 , are unknowns whose value are to be find out.

In this way the matrix can be generated for all the values of π referred from table no 8.2 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 k_1, a_1, b_1, c_1 and d_1 .

k1	0.812369
a1	-0.03
b1	-0.0088
c1	-0.3345
d1	0.5475

By substituting the above unknown coefficients equation generated is:

$$\pi_{D1} = 0.812369 \times \pi_1^{-0.03} \times \pi_2^{-0.0088} \times \pi_3^{-0.3345} \times \pi_4^{0.5475}$$

Similarly, unknown coefficients for all the independent π terms ($\pi_1, \pi_2, \pi_3, \pi_4$) is found out for other two dependant π terms (π_{D2}, π_{D3}) and following table is generated:

Dependant π_{D} terms	k	a	b	c	d
π_{D1}	0.812369	-0.03	-0.0088	-0.3345	0.5475
π_{D2}	3.63533	-6.8093	-0.0605	0.4869	-1.3933
π_{D3}	33.48173	-5.1805	-0.062	1.7168	-3.8323

Hence, after substituting values of k, a, b, c, d equations of dependant π_{D} terms in terms of dependant π values are formulated.

FINAL MODEL FORMULATED

$$\pi D1 = 0.812369 \times \pi 1^{-0.03} \times \pi 2^{-0.0088} \times \pi 3^{-0.3345} \times \pi 4^{0.5475}$$

$$\pi D2 = 3.63533 \times \pi 1^{-6.8093} \times \pi 2^{-0.0605} \times \pi 3^{0.4869} \times \pi 4^{-1.3933}$$

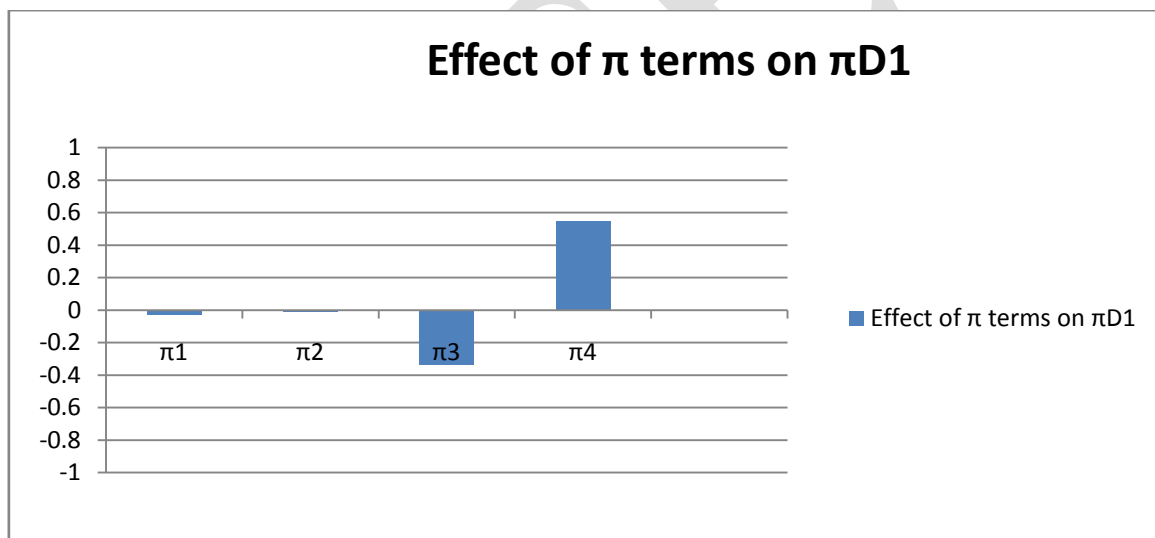
$$\pi D3 = 33.48173 \times \pi 1^{-5.1805} \times \pi 2^{-0.062} \times \pi 3^{1.7168} \times \pi 4^{-3.8323}$$

Above are the equations generated for dependant π terms which were ultimately denoted for the parameters i.e. $\pi D1$ for generated water temperatures (Water Temp/ Atmos. Temp), $\pi D2$ for Heat gain E, $\pi D3$ for efficiency (E/(Radiation*A)).

SENSITIVITY ANALYSIS

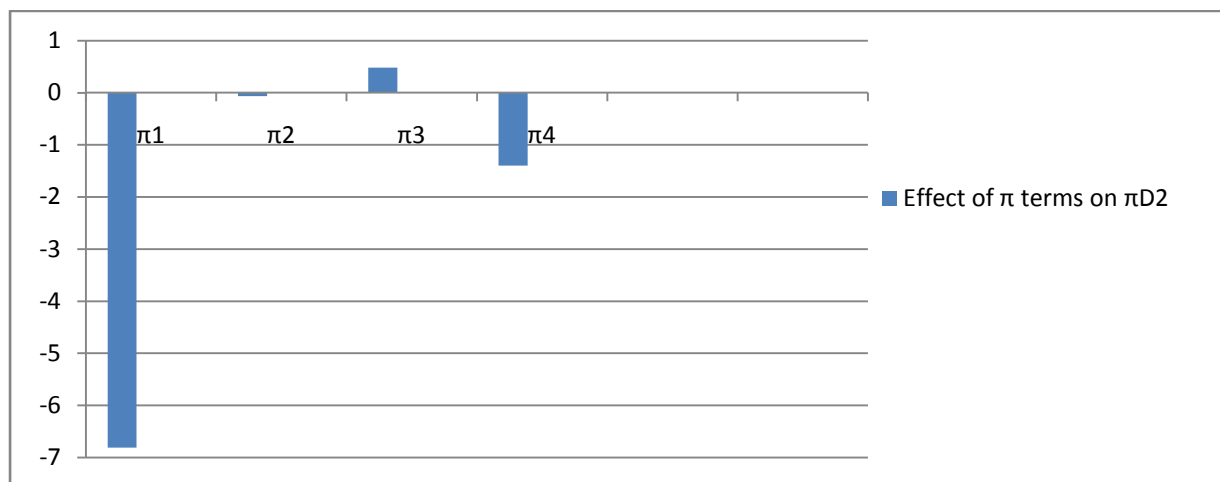
The influence of the various independent π term has been studied by analyzing the indices of the various π term in the models. This will help us find out which parameter has the most effect on the Dependant variable πD .

Following is the Graph showing effect of independent π terms on the dependant $\pi D1$ term indicating generated water temperature.



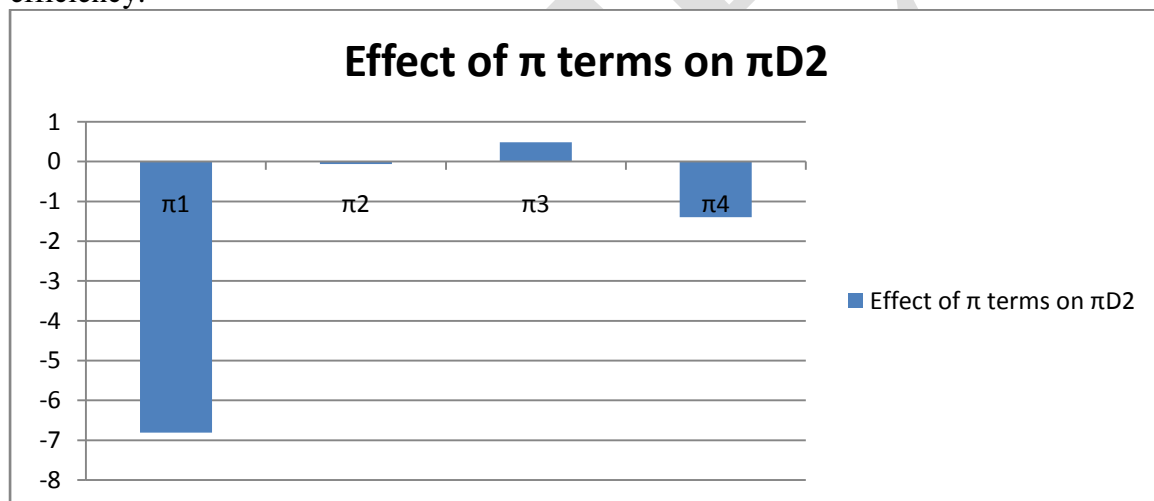
Graph no.3 Effect of π terms on $\pi D1$

From the above analysis it can be clearly observed that $\pi 1$ and $\pi 2$ has very negligible effect on dependant $\pi D1$ term indicating generated water temperature. Whereas, $\pi 4$ shows maximum effect on it. Following is the Graph showing effect of independent π terms on the dependant $\pi D2$ term indicating generated heat.



Graph no,4: Effect of π terms on $\pi D2$

From the above analysis it can be observed that π_2 has very negligible effect whereas, π_1 shows maximum effect on the dependant $\pi D2$ term indicating generated Heat. Following is the Graph showing effect of independent π terms on the dependant $\pi D3$ term indicating efficiency.

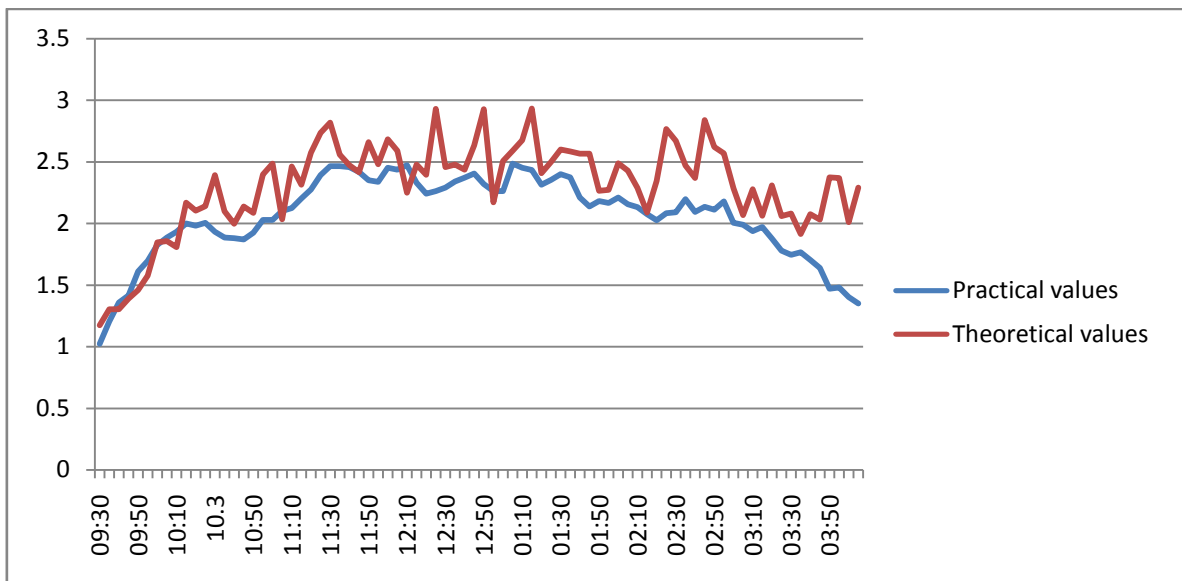


Graph no 5: Effect of π terms on $\pi D3$

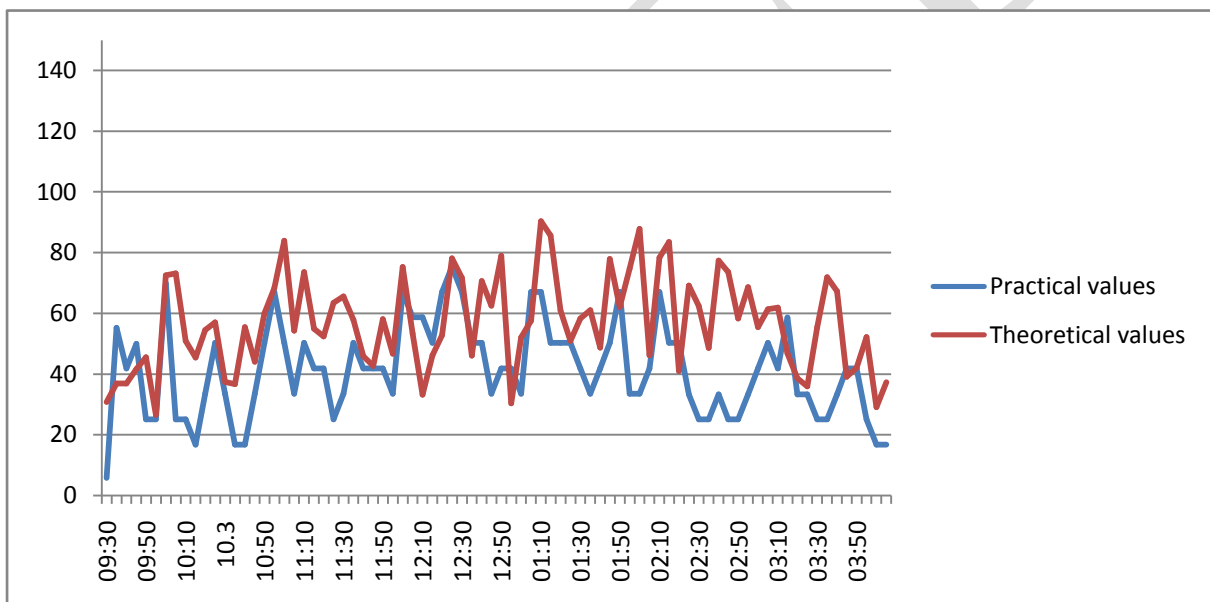
From the above analysis it can be observed that π_2 has very negligible effect and π_1, π_4 shows maximum effect on the dependant $\pi D3$ term indicating efficiency.

COMPARATIVE ANALYSIS BETWEEN THEORETICAL AND PRACTICAL VALUES

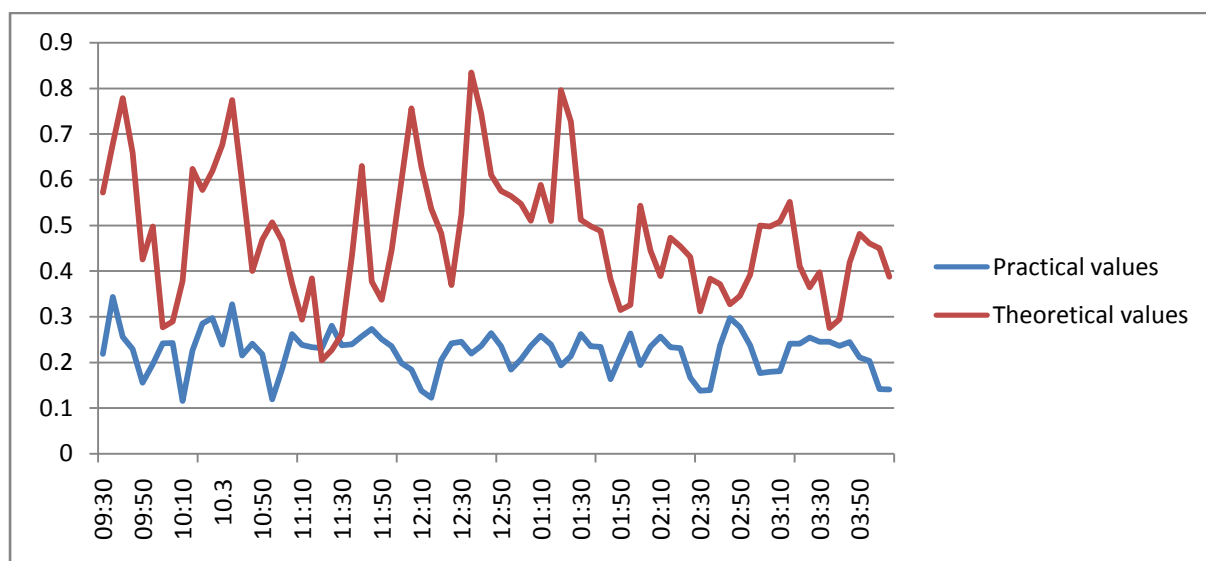
Following are the graphs for comparison between practical dependent values and theoretical dependent values



Graph No.6 : Graph of Time Vs Temperature for Practical and theoretical $\pi D1$ terms



Graph No.7: Graph of Heat Gain vs Temperature for For Practical and theoretical $\pi D2$ Terms



Graph No.8 : Graph of Efficiency Vs Time For Practical and theoretical πD^3 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 is 19%. Power generated in the experimentation is 350 watts.

CONCLUSION

In order to utilize the nonpolluting and freely available source of reversible nature i.e. solar energy, its intensity must be maximum. In order to maximize its effectiveness, the 2.7m^2 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 100°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.

NOMENCLATURE

A_s – aperture area of the Scheffler reflector
 C_w – specific heat at constant pressure,
 – $[\text{kJkg}^{-1}\text{K}^{-1}]$
 E_p – total heat energy
 G_{bave} – beam radiation at time t , $[\text{Wm}^{-2}]$
 m_w – mass of water used

P_{ave} – the average power available
 DT – change in temperature for a specific
 – time, $[\text{K}]$
 t – time, $[\text{hour}]$
 tp – total process time, $[\text{hour}]$

REFERENCES

- [1] Scheffler, W., Introduction to the Revolutionary Design of Scheffler Reflectors, 6th International Conference on Solar Cookers, Granada, Spain, 2006, e-mail: Info@Solare-Bruecke.org
- [2] Scheffler, W., Development of a Solar Crematorium, 6th International Conference on Solar Cooker, Granada, Spain, 2006

- [3] Jayasimha, B. K., Application of Scheffler Reflectors for Process Industry, 6th International Conference on Solar Cocker, Granada, Spain, 2006
- [4] Rupesh J. Patil, Gajanan K. Awari , Mahendra P. Singh, Comparison of performance analysis of Scheffler reflector and model formulation Indian Journal of Science and Technology, Vol 4, No.10, 2011, 0974- 6846
- [5] Vishal R. Dafle, Prof. N.N.Shinde / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 2, Issue 6, November- December 2012, pp.848-852.
- [6] Munir, A., Hensel, O., Solar Distillation for Essential Oils Extraction – A Decentralized Approach for Rural Development, International Solar Food Processing Conference, Indore, India, 2009
- [7] Deepak Gadhia ,Shirin Gadhia Gadhia Solar Energy Systems Pvt. Ltd. 86, old GIDC Gundlav Valsad 396035 India
- [8] Ajay Chandak & Dr. Sunil K. Somani, International Solar Food Processing Conference 2009.
- [9] Modak, J. P. & Bapat, A. R. “Formulation of Generalized Experimental Model for a Manually Driven Flywheel Motor and its Optimization”, Applied Ergonomics, U.K. Vol. 25, No. 2, pp 119-122, and 1994.