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Performance Analysis of Scheffler Reflector used for Solar Dry Cleaning

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***Abstract* – Solar energy is the most important non conventional source of energy because of its non-polluting nature. Solar dry cleaning is the simplest, safest and most convenient way to dry clean clothes without consuming any fuel or heating up the appliances which use solar energy. In this Paper the thermal performance of Scheffler Reflector at Gajraj Drycleaners is evaluated. The Experimental investigations were carried out to determine performance of solar scheffler Reflector during summer season in Nagar (18° 20' N, 78° 12' E). In this solar thermal system total 15 dishes of 16 sq. meters Scheffler Reflector are used which generates 150 ^{0}C temp. In this method a primary reflecting parabolic surface concentrates the solar radiation on it and reflects them on to the secondary reflectors. This secondary reflector then focus the incident radiation at the point of interest, thus generated heat/steam can be used for huge dry cleaning purpose. In this work the design of 16sq.m solar reflector is analysed which can be used for dry clean the cloths for 100-110 people every day conveniently by generating steam.**

***Keywords* – Scheffler Reflector, Single Axial Tracking, Solar Energy, Heat Generation, Thermal Efficiency.**

I. Introduction

Solar energy is the most readily available free source of energy. Solar energy production can be divided into two types: solar thermal energy and photovoltaic power production. Among these two methods, solar thermal technology converts solar energy into thermal energy for use. The solar thermal energy thus obtained is mainly used for solar dry cleaning which further includes other applications such as solar home heating, indirect electricity generation etc. Solar dry cleaning provides a very cost-efficient and environment-friendly solution foremost to rural communities of developing countries. The Ministry of New & Renewable Energy (MNRE) Govt. of India has been pursuing a comprehensive program in the country on the development and dissemination of renewable energy technologies. The solar dry cleaning system at Gajraj Drycleaners is established under the MNRE program. In the concentrating type of solar collector, solar energy is collected and concentrated so that higher temperatures can be obtained. The basic idea that leads to the development of the Scheffler reflector is to make solar dry cleaning as comfortable as possible. The solar collector is invented by Wolfgang Scheffler is designed so that dry cleaning is done inside the factory. Because of this there are certain requirements regarding the design and alignment of the building. The building needs to have a north-facing wall, no large buildings or structures close to the dish, and sloping roof to allow the sun to shine on the dish during the daytime and throughout the year. The idea of the Scheffler Collector is to concentrates the solar radiation to one point through absorption onto the black coloured surface of receiver; this concentrated energy is converted into steam used to dry clean the clothes. The main objectives of this paper are:
1) To promote solar energy technologies to meet energy requirements of small scale industry in rural area. 2) To suggest cost effective design & technology for small scale industry applications such as laundry, process heating etc.

Design concepts of the Scheffler Reflector Steam Generator:

Solar steam generation system of this type differ from flat plate solar collector in design and operation as the unit serves for dual operation, to absorb solar radiation as well as reservoir of heated fluid. The designed model of scheffler reflector used at Gajraj Drycleaners is shown in Fig.1. The solar reflector which can heat water of 65 lit per day capacity is designed with dish diameter of 16 m^2.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 and an exit at the bottom of the other side. The SRSG 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. The initial specification for the design of scheffler concentrator is obtained by considering the parabolic equation

$$X^2 = 4fY \quad (1)$$

Where Y is the distance along vertical axis and f is the focal length. X is distance along horizontal axis. The coordinates of scheffler collector is obtained by software called PARABOLA CALCULATOR which is easily available on the internet.

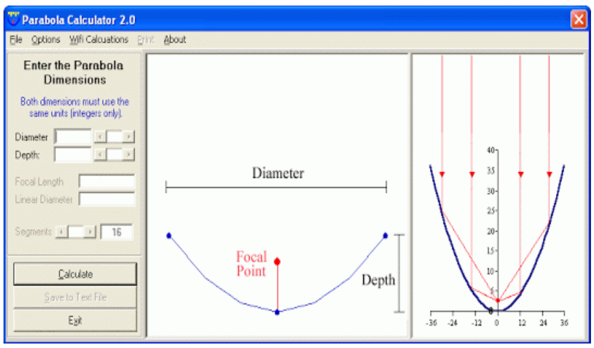

Fig.1. Parabola Dimensions from Parabola Calculator 2.0

We get a parabolic shape at different values of x and y. The initial design of the prototype Parabolic solar collector by the use of software is shown below and the values of different parameters obtained are shown in Table 1.

Table 1: Co-ordinates of designed scheffler reflector from parabola calculator

X	2.50	Y	1.04
X	-2.22	Y	0.82
X	-1.94	Y	0.63
X	-1.67	Y	0.46
X	-1.39	Y	0.32
X	-1.11	Y	0.21
X	-0.83	Y	0.12
X	-0.56	Y	0.05
X	-0.28	Y	0.01
X	0.00	Y	0.00
X	0.28	Y	0.01
X	0.56	Y	0.05
X	0.83	Y	0.12
X	1.11	Y	0.21
X	1.39	Y	0.32
X	1.67	Y	0.46
X	1.94	Y	0.63
X	2.22	Y	0.82
X	2.50	Y	1.04

The design of scheffler dish at Gajraj Dry cleaners is as shown in fig 2.

Fig.2. Solar Thermal system using scheffler collector at Gajraj Drycleaners

The Scheffler reflector used here has an area of 16m^2.The sunlight that falls onto this reflector is reflected sideways to the focal point away from 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. Thus the reflector always maintains its gravitational equilibrium and the mechanical tracking device (clockwork) can be moved easily in position with the sun. Single axis manually tracking system is employed for this system.

The focus is located on the axis of rotation to prevent it from moving when the reflector rotates. During the day, the concentrated light is rotated around its own centre but not in sideways. Thus the focus stays fixed. At the focus it has a container to hold 65 litter water. The parameters measured were: ambient temperature, water temperature, solar radiation and wind speed. K-types thermocouple is used to measure water temperature which has a range of 100 ^{0}C to 1250 ^{0}C. Wind speed is measured by battery operated digital Anemometer with a range 0.3 to 30 m/s and with a facility to show ambient temperature. A pyranometer is used to measure the radiation. The experimentation was carried in the month of May 2015.
The readings were taken at different time zones between 10 AM to 2 PM. All readings were taken at the interval of 5 minutes. More than 200 observations were recorded. The sample observations are shown in Table 3. The solar thermal system at Gajraj dry cleaners is designed as per dimensions mentioned below.

Table 2: Main Specifications of the Parabolic Solar Collector

Description	Specifications
Aperture Diameter(m)	6.5 m^2
Aperture Area (m2)	16 m^2
Reflector Material	Glass-Mirror
Number of receiver sheets	15
Focal Length	4.3m
Concentration ratio	25
Receiver Diameter	0.3m
Receiver Area	0.5m^2
Steam Generated Capacity	800 to 1000 Kg/day
Pressure of Generated Steam	6 to 10 Bar
Maximum Temp Reached at focal point	180 ^{0}C
Maximum Optical Efficiency	72.5%
Maximum Thermal efficiency	69.50%
Maximum Energy Efficiency	68.8%

II. Modelling

The following equations are used for the calculations of Heat generation, Efficiency.
The focal length of parabola

$$f = \frac{h^2}{4 \text{ x } R} \quad (2)$$

The parabola surface area

$$As = \frac{8 \, x \, \pi \, x \, f^2}{3} \quad [((\frac{d}{4 \, x \, f})^2 + 1)^{\frac{3}{2}} - 1)] \quad (3)$$

The concentration ratio

$$C_R = \frac{A_{ap}}{A_{ab}} \quad (4)$$

Power

$$P_s = \frac{Mw \; x \; Cw \; x \; dTw}{dt} \quad (5)$$

Standard Power

$$Ps = \frac{700 \; x \; Mw \; x \; Cpw \; x \; \Delta T}{t} \quad (6)$$

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Thermal efficiency

$$\eta\iota = \eta o - U_\iota \ x \ \frac{A_p \ x \ (T_w - T_a)}{A_a \ x \ I_b} \quad (7)$$

Heat loss factor

$$FU_L = \frac{(M_{POT} \ x \ C_{POT} + M_w \ x \ C_w)}{A_{POT} \ x \ \tau o} \quad (8)$$

Optical Efficiency Factor

$$F\eta_o = \frac{\frac{FUL \ x \ A_{pot}}{A_p} \left[\left(\frac{T_{wf} - T_a}{I_b}\right) - \left(\frac{T_{wi} - T_a}{I_b}\right) x \ e^{\frac{-\tau}{\tau o}}\right.}{1 - e^{-\frac{\tau}{\tau 0}}} \quad (9)$$

The efficiency of a scheffler collector depends on the operating temperature of the collector, the direct normal irradiation I_b and the incidence angle α of the solar radiation. The efficiency is defined as the ratio of the thermal power, absorbed by the heat transfer fluid, to the direct normal irradiation on the aperture area [7-9]:

III. Performance Evaluation

The reflector is a small lateral section of a much larger scheffler. The inclined cut produces the typical elliptical shape of the Scheffler-Reflector. The sunlight that falls onto this section of the Scheffler collector 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 [2,3]:

That way the reflector always maintains it's gravitational equilibrium and the mechanical tracking device (clockwork) 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. The distance between focus and centre of the reflector depends on the selected parabola. During the day the concentrated light will only rotate around its own centre but not move sideways in any direction. That's way the focus stays fixed, which is very useful. The course of the seasons the incident angle of the solar radiation varies + / - 23.5° in relation with the perpendicular to earth-axis. The parabolic has to perform the same change of inclination in order to stay directed at the sun. Otherwise it's not possible to obtain a sharp focal point. But the centre of the reflector and the position of the focus are not allowed to move.

This is only possible by shaping the reflector after another parabola for each seasonal inclination angle of the sun, i.e. for each day of the year. This means the reflector has to change its shape.[9,10,11]

The reflector-frame is build for equinox. By inclining and elastically deforming the reflector-frame all other parabolas can be achieved with sufficient accuracy. Changing the inclination and deforming the reflector are mechanically combined: the two pivots A, at each side of the reflector-frame, and pivot B, in the centre of the reflector, do not form a line, but B is located below. That way inclining the reflector leads to a change in its depth, the centre of the reflector is lifted up (big radius of crossbars) or pressed down (small radius of crossbars) relative to the reflector frame. It's enough to adjust the upper and lower end of the reflector (C and D) to their correct position to obtain a sufficiently exact reflector-shape. The setting is done by a telescopic bar at each end of the reflector. Adjusting the reflector-shape has to be done manually every 2-3 days. When all concentrated light enters the opening of the cooking-place installed at the focal point the correct reflector-shape is achieved.

At the focal-point itself we have measured optical efficiency of up to 75% (with 2mm ordinary glass mirrors). Depending on the season an elliptical reflector of 4.8m x 3.8m (standard size of 16m² Scheffler-Reflector) collects the sunlight of a 12.4m² to 14.4m² area, measured perpendicular to the direction of the incident light (aperture). That way the generated power varies with the season. As an average a 16m² Reflector can bring 50 litres of cold water to boiling temperature within one hour (with 700W/m² direct solar radiation).

IV. Water Heating

The power available from a Scheffler Reflector varies with the amount of direct sunlight available, and with the season of the year. The angle of the reflector towards the sun changes, and so does its intercepting area (aperture).The available power from a 16m² Scheffler Reflector is given in the table 3. Different efficiencies were determined for various setups and temperature ranges. The 16m² reflector is the one of the Scheffler Reflectors used for industries (12.6m² and 8m² are other common sizes).

All data has been normalized for 700 W/m² and 800 W/m² direct solar radiation (typical lower and upper radiation levels).

Table 3: Readings taken for 2kg of water

Time (Min)	T_W ^{0}C	Ta ^{0}C	I_b (W/m^2)
11.00	50.3	36.3	756.38
11.05	63.4	36.9	765.2
11.1	76.4	37.2	782.3
11.15	79.4	37.8	791.4
11.20	86.5	38.5	802.7
11.25	93.5	38.6	816.7
11.30	102.5	38.8	828.4
11.35	110.2	38.9	842.3
11.40	116.4	38.9	852.4

V. Results and Discussions

The heating curves plotted against time as shown below from the cooling curve slope is calculated. The slope of the line drawn between ln(Tw -Ta) vs. time gives the value of $(-1/\tau_0)$. Where τ_0 is time constant for cooling and τ is time interval and it is used to calculate optical efficiency factor. Slope m is calculated and $\tau_0=1/m$.

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Table 4: Readings for Optical Efficiency Factor

Time (Sec)	τ_0	$F'\eta_0$	$I_b(W/m^2)$
11.00-11:10	72.36	0.543	756.38
11.10-11.20	72.36	0.501	784.59
11.20-11.30	72.36	0.486	801.33
11.30-11.40	72.36	0.454	820.36
11.40-11.50	72.36	0.412	835.22
11.50-12.00	72.36	0.385	850.39

The optical The optical efficiencies $F'\eta_0$ were determined after analyzing the sensible heating curves shown in Fig. 4 the values were determined using the equation (9). The overall optical efficiency factors were calculated and shown in table 4. The values were found to be nearly same. Thus, the solar insolation affects the values of the optical efficiency factor very little. The major factors influencing these values are the reflectance of the reflector and the absorptance of the absorber and sun tracking mechanism.

The maximum water temperatures during the tests on the day were found to be 150.45^{0}C water and 38.9^{0}C ambient temperature as shown in figure 4. The temperature increases as solar insolation increases. This high temperature can be utilized cooking, heating, and steaming.

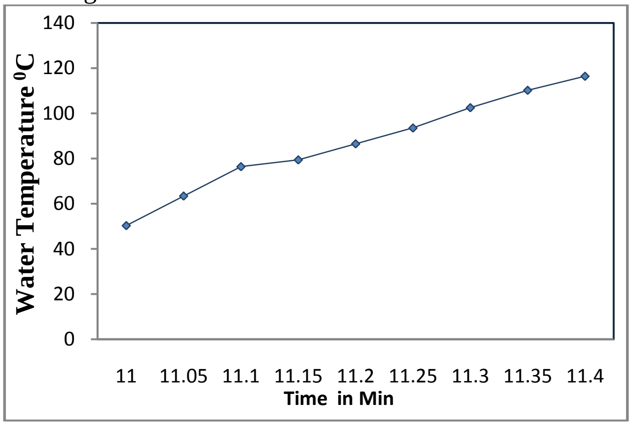

Fig.4. Heating Curve

The maximum Solar beam radiation obtained during the test was 852.4 which depend on local solar time as shown in figure 5.

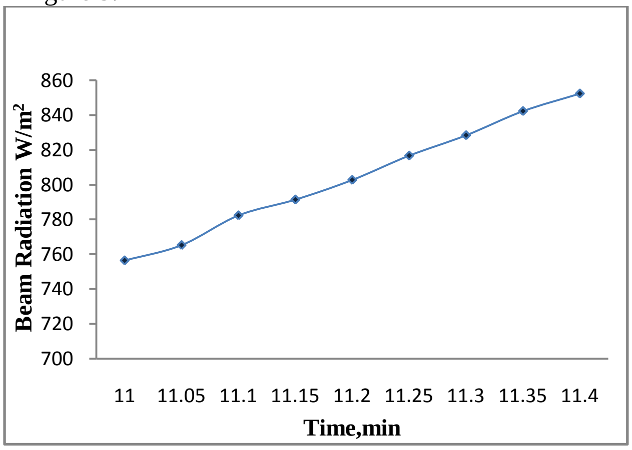

Fig.5. Variation of Solar Isolation with Time

The thermal efficiencies calculated and recorded were found to be 65, 67, 68 and 69.3 for the average solar radiations of 816.7, 828.4, 842.3 and 852.4W/m2 respectively is as shown in fig.5.

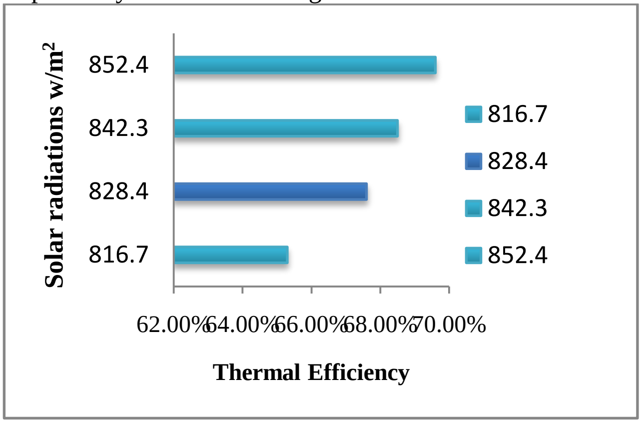

Fig.6. Thermal Efficiency Curve

The Energy efficiency was high during initial time and decreases as the solar radiations increases as it is inversely proportional to radiation. The energy efficiencies obtained are 7.40%, 6.36%, 5.78% and 3.10% for average solar insolation 816.7, 828.4, 842.3 and 852.4 respectively as shown in fig.6.

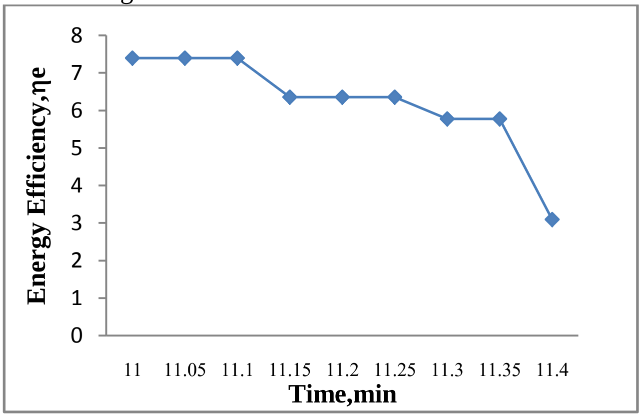

Fig.7. Energy Efficiency Curve

The energy efficiency and solar radiation have different trend with time which are low initially then increases sharply takes peak and then decreases.

VI. Conclusion

The present study was conducted with one of temperature sensitive solar dry-cleaning factory. These types of solar concentrators can open new landmarks in decentralized solar systems. The performance result shows that the low efficiency of the Scheffler reflector is attributed to the optical and thermal losses from the reflector. The thermal efficiency can be increased by increasing the receptivity of the reflectors; proper designing of the parabola with silver coated mirror glass should be preferred for higher efficiency. This study also suggests that such type of solar system must be equipped with necessary mountings and instrumentation to monitor and control the desired thermal parameters during temperature sensitive industrial processing.

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