Design, Development & Performance Evaluation Of Concentrating Monoaxial Scheffler Technology For Water Heating And Low Temperature Industrial Steam Application

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ABSTRACT

This study reveals the Design, Fabrication and Performance Evaluation for 2 bar pressure and 110°C temperature cooking application using 16 m^2 Scheffler reflector. The Scheffler along with mild steel absorber plate of size, 18 cm ø and 2.5 cm thick was evaluated for performance in month of February 2012 at composite climate zone. During the performance it was observed that solar radiation over the day varies from 620 W/ m^2 to 937 W/ m^2. The instantaneous efficiency decreases with increase in radiation. Absorber plate temperature varies from 138°C to 235°C, while maximum steam temperature achieved was 107°C at the outlet of the boiler. The overall efficiency achieved was 57.41 % which appears on higher side as compared to parabolic trough devices. The paper conclude achievement of concentrating solar thermal devices using Scheffler technology for water heating and low pressure, temperature steam applications in industries as textiles, dairies, food industry etc.

Keywords -Concentrating Solar Thermal, Instantaneous Efficiency Overall Efficiency, Performance Evaluation, Scheffler Reflector.

I. INTRODUCTION

India faces formidable challenges in meeting its energy needs in providing adequate energy of desired quantity in various forms in a sustainable manner and at competitive prizes. India needs to sustain an 8% to 10 % economic growth rate over the next 25 years, if it is to eradicate poverty and meet its human development goals. By 2022 power generation capacity must increase to nearly 8, 00,000 MW from the current capacity of 1, 80,760 MW inclusive of all captive plants. The demand must be met through safe, clean, and in a technical efficient, economically viable and environmentally sustainable manner. Presently industrial thermal needs are met by using primary energy fossil fuel like coal, oil and gas. The utilization of these energy sources has limitations. Since solar energy sources is dispersed and thin in nature its application in industrial thermal applications leads to low pressure and temperature applications and shall be ideal as it is a clean source of energy. Scheffler concentrating technology is one of the better utilized one for cooking applications. Industrial needs exist for water heating and steam applications. Fixed focus concentrators developed by Mr. Wolfgang Scheffler have proved to be a mile stone in solar thermal energy utilisation. There is need to develop low cost solar concentrating technology for combined applications of water heating and steam applications. To fulfill the outline of the present paper, a literature review followed with scope of paper is given as follows. R.J.Patil, G.K.Awari and M.P.Singh [1] studied the performance of scheffler reflector having a single drum of 20 litre capacity installed at focal point to serve the dual purpose as absorber tube and storage tank. Using this experiment a generalized data based model is formulated. A.Munir, O.Hensel [2] investigated that Scheffler Concentrators can also be used for Oils Extraction using Laboratory and Solar Distillation Systems. The main object of the research is to investigate optimal thermal parameters and to develop simple and best methodologies for easy adaptation of these techniques for decentralized applications. Ajay Chandak, S.K. Somani and Deepak Dubey [3] designed, developed and tested a multistage evaporation system using scheffler solar concentrators. Total yield obtained in the project was 2.3 times that of single stage distillation. Results of the project are very encouraging for commercial scale application. Joshua Folaranmi [4] designed, constructed and tested a parabolic dish solar steam generator. By Using concentrating collector, heat from the sun is concentrated on a black absorber located at the focus point of the reflector in which water is heated to a very high temperature to form steam. A.R.El Ouedernil, M.Ben Salah, F. Askri, M. Ben Nasrallah and F. Aloui [5] did a experimental study of parabolic solar concentrator having 2.2 m opening diameter. Its interior surface is covered with a reflecting layer, and equipped with a disc receiver in its focal position. An acquisition data system is adapted to measure temperature profile over the receiver in the experiment conditions. A theoretical and experimental study of the thermal transfers is realized for better conception of the solar energy installation. O.Helal, Bechir Chaouachi and Slimane

Gabsi [6] developed and studied a integrated collector storage (ICS) solar water heater with an emphasis on its thermal performance analysis. The suggested design aims to cover the need of hot water of a family composed of four persons during the few sunny days as well as during the night. The details of calculations steps that aim to perform an accurate prediction of the system performance are presented. A.Munir, O.Hensel and W.Scheffler [7] investigated the design principle and calculations of Scheffler concentrator for medium temperature applications in which they presented the design principle and construction details of an 8 m2 surface area Scheffler concentrator. The design procedure is simple, flexible and does not need any special computational setup, thus offering the prospect of potential application in domestic as well as industrial configurations. S.D.Odeh, M. Behnia and G.L.Morrison [8] carried out the performance evaluation of Solar Thermal Electric Generation system in which a unified model of a solar electric generation system (SEGS) is developed using a thermo–hydrodynamic model of a direct steam collector combined with a model of a traditional steam power house. Jose.M. Arenas [9] designed, manufactured and tested a new portable solar kitchen with a large, parabolic solar reflector that folds up into a small volume. Technical trials carried out with a prototype have determined that the solar kitchen reaches an average power scale of 175 W, with an energy efficiency of 26.6%. Anjum Munir [10] has designed and done modeling of a Solar Distillation system for the processing of medicinal and aromatic plants. Most of the agro-based industries can be operated in this medium temperature range. The use of solar energy in agriculture sector can be used to process many perishable agricultural products at farm level. .

As we know Scheffler Technology has been used for cooking for many years. But now-days development in this technology has been made and used in various operations. Thus there is a need of exact technology to be developed with quantitative parameters for low temperature and pressure application with proper design and development of Scheffler reflector.

II. METHODOLOGY FOR PROJECT DEVELOPMENT

The most important industrial processes using heat at mean temperature level are: sterilizing, extraction, pasteurizing, drying, solar cooling and air conditioning, hydrolyzing, distillation and evaporation, washing and cleaning, and polymerization. The ranges of all these processes lie between 60-180°C. The use of solar energy in industrial sector would help to attain the required temperature. At present, various kinds of solar concentrators are in use which has rigid structure and the focus, the hot area where all the light is concentrated and moves with the direction of sun. Despite the high temperature output, such types of concentrators are rarely used for industrial applications due to frequent changes of the focus position and inadequacy of handling approach at the receiver. Therefore there is need for right technology to be developed which is solved by parabolic Scheffler reflectors as they can provide heat for all types of applications such as cooking, steam generation and industrial applications at low pressure & temperature. Thus exact parameters are required to be operated for required application and requirement of proper data for its design and development. By keeping all facts in view, the study has been initiated to design and develop a Scheffler reflector with its installation followed by its Testing and Performance evaluation of the reflector.

2.1 Case study under reference for design purpose & evaluation of parameters

This project work is aimed to establish parametric study of Scheffler technology for water heating and steam generation and its performance evaluation. A case study parallel to the industrial application is hot water requirement for bathing & steam cooking at boy's hostel. A hostel with 500 students and a mess equivalent for 500 students at Shivaji University Kolhapur is considered. For 500 students 10,000 litres of water is required per day at a temperature around 60^{o}C for bathing. Each student consumes approximately 20 litres of water per day. Similarly for cooking for 500 student's quantity of steam required is approximately 200-250 kg with an outlet pressure of 2 bars and 120^{o}C temperature. Therefore, calculated heat energy required to heat 10,000 liter water is 305.23kw/day and quantity of Scheffler required to heat 10,000 liter of water is 12. Similarly for steam cooking 174.41 kw/day heat is required and 7 number of Scheffler are required to heat the water.

2.2 Performance Evaluation Methodology

The heat gain on absorber plate is

$q_u = A_p * I_{sc} – q_L$ (1)

where Ap is the area of absorber plate. I_{sc} is the extraterrestrial solar constant and q_L is the heat loss.

The heat loss from absorber plate is

$q_L = U_L * A_p * (dt)$ (2)

where U_L is overall loss coefficient and dt is the mean temperature difference.

The overall loss coefficient U_L is

$U_L = Ut + Ub + Us$ (3)

where Ut is top loss coefficient. Ub is bottom loss coefficient and Us is side loss coefficient.

Top loss coefficient is

$Ut = [(1/ h_{p-c} + 1/ h_{rc-s}) + (1 / h_{rc-s} + 1 / h_w)]$ (4)

where hp-c is the convective heat transfer coefficient. hrc-s is the radiation heat transfer coefficient and h_w is the wind heat transfer coefficient.

Bottom loss coefficient is

$U_b = K_m / \delta_b$ (5)

where K_m is the thermal conductivity of insulation and δ_b is the thickness of insulation.

Side loss coefficient is

$U_s = [(L_1 + L_2) L_3 K_m] / L_1 * L_2 \delta_b$ (6)

where L_1 is the length of absorber plate. L_2 is the height of absorber plate and L_3 is the width of absorber plate.

Heat loss due to free convection from top of the absorber plate is

$P_{Top} = a_T * [K * Nu * \Delta T] / h_p$ (7)

where a_T is the base area of absorber plate, K is the extinction coefficient, Nu is the nusselt number, h_p is the height of absorber plate and ΔT is the temperature difference.

Heat loss due to free convection from side of the absorber plate is

$P_{side} = \pi d * h_p * [K * Nu * \Delta T] / h_p$ (8)

where d is the diameter of absorber plate

Heat required for boiling water

$Q = m * C_p * \Delta T$ (9)

where m is the mass of water, Cp is the specific heat of water and ΔT is the temperature difference.

Quantity of steam produced

$Q = m_s *$ enthalpy of steam (10)

Thus Efficiency of Schffler system is calculated as

$\square_i = q_u / A_p * I_T$ (11)

where q_u is the heat gain on absorber plate, Ap is the area of absorber plate and I_T is the amount of solar radiation falling.

2.3 System Operation

The water from raw water tank is first passed through the softener where all the impurities and the hardness is removed. This water is then stored in the boiler and passed in the semi hot water tank which is half filled by water. The water from the semi hot water tank is then passed through the inlet of the receivers. The concentrator concentrates sunlight on a receiver, above the receiver is an insulated header pipe filled with water. The cold water enters the receiver through an inlet pipe below the receiver, which gets heated due to the high temperature of the concentrator and the heated water circulates through the semi hot water tank and the cycle continues till steam is generated. The generated steam passes through steam outlet of respective receivers. These generated steam circulate through semi hot water tank which occupies the half portion of it. This generated steam stored in the upper half empty portion of the semi hot water tank building up the working pressure is then sent to the kitchen through an insulated pipeline by passing it through the pressure reducing valve. The receiver and the semi hot water tank is equipped with a drain valve to remove the water which is remained after the completion of the whole process duration.

2.4 Testing & Analysis

A Scheffler System shown in fig.1 fabricated as per specification given was tested. It consists of 16 m^2 surface area that focuses solar energy to receivers that convert water in the pipes to steam. The system produces 4 kg of steam at a pressure of 2 bars at 110 ^oC, gives a maximum output of energy equivalent to 3.5 kW per day and efficiency 60%.

Fig 1: Scheffler Concentrators

Fig 2: Absorber Plate

III. RESULTS AND DISCUSSION

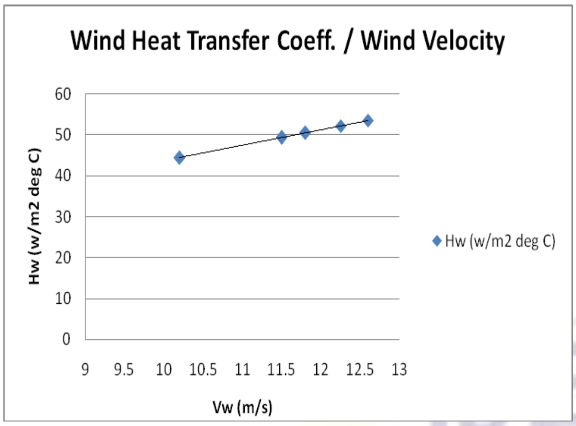

Fig 3: Variation of Wind Heat Transfer Coeff. with Wind Velocity

Figure 3 shows the variation of wind heat transfer coefficient with wind velocity which states that the wind heat transfer coefficient goes on increasing as wind velocity increases which increases the heat loss.

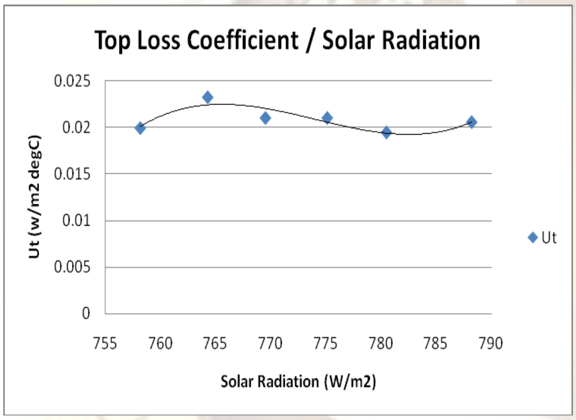

Fig 4: Variation of Top Loss Coefficient with Solar Radiation

Figure 4 states that the top loss coefficient increases with a maximum at 765 W/m^2 and then goes on decreasing as radiation increases with an average upto 0.02085 W/m^2 °C

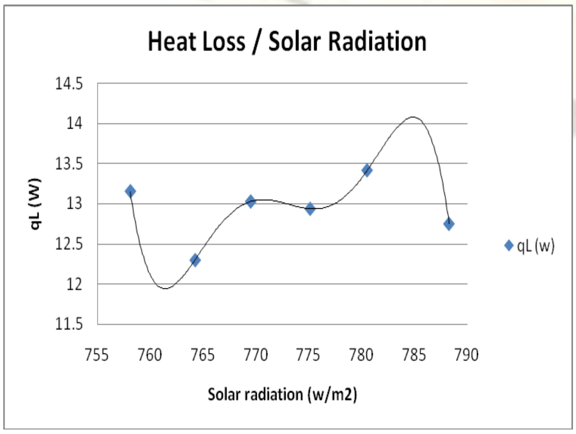

Fig 5: Variation of Heat Loss with Solar Radiation

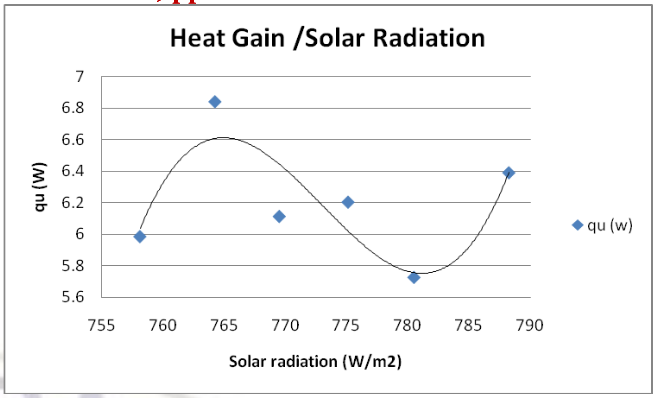

Fig 6: Variation of Heat Loss with Solar Radiation

Figure 5 and 6 shows the variation of heat loss and heat gain against solar radiation. The heat loss goes on incresing as the radiation increases which states that the sloar radiation is not absorbed properly by the receiver which also decreases the heat gain, the increase in the wind heat transfer coefficient may also cause the decrease in heat gain.The heat loss increases with a maximum at 13.41 W with an average upto 12.92 W. Similarly, the heat gain is maximum at 6.83 W with an average upto 6.20 W. This shows a huge difference of 6.72 W which affects the system efficiecny and must be reduced.

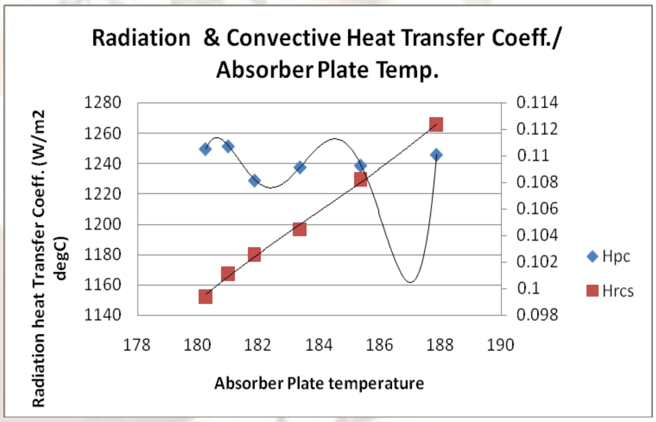

Fig 7: Variation of Radiation & Convective Heat Transfer Coefficient with Plate Temperature

Figure 7 states that radiation heat transfer coefficient goes on increasing as the plate temperature increases with a maximum at 188°C and convective heat transfer coefficient fluctuates as the plate temperature increases with an average of 0.104 W/m^2 °C. The fluctuation in the convective heat transfer coefficient is due to change in the wind velocity. The average heat loss, heat gain, wind heatt transfer coefficient, top loss coefficient, radition and convective heat transfer coefficient varies due to the variable intensity of reflected solar radation.

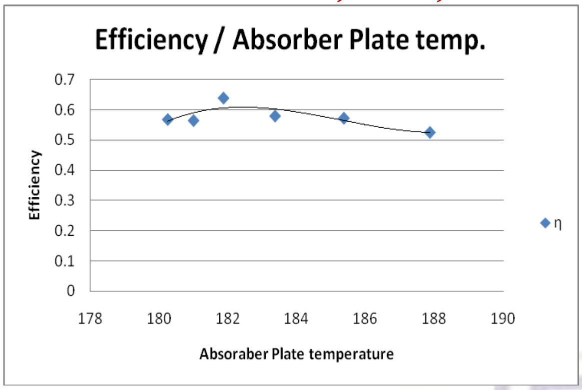

Fig 8: Variation of Efficiency with Plate Temeprature

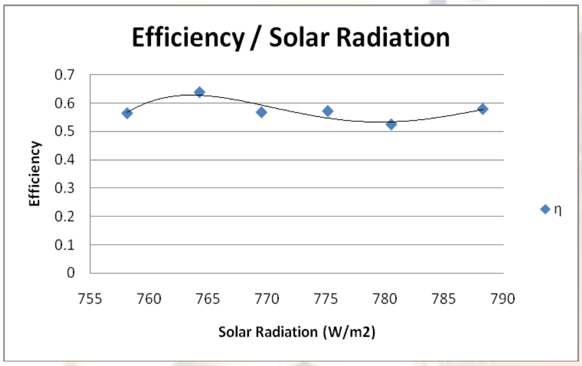

Fig 9: Variation of Efficiency Solar Radiation

Figure 8 and 9 shows the variation of efficiency against solar radiation and absorber plate temperature. The efficiency goes on decreasing as plate temperature as well as solar radiation increases. For plate tempearture the efficiency is maximum at 182^{o}C and for solar radiation at 765 W/m^2 giving an average efficiency of 57.41% which can be thus increased if all the heat losses are minimized

IV. Conclusion

Concentrating solar power has applications in operating and industrial steam generation. India too has declared its best CSP policy through Solar National Mission. The various technologies such as Compound Parabola, Scheffler, Hyperboloid, Fresnel, internally reflecting surfaces etc. have been developed and implied for various applications. The CSP technologies have higher efficiency up to 30 to 35 % as compared to flat plate collectors having efficiency of 20%. This paper has dealt with application of Scheffler technology as they are having better efficiencies than other technologies such as Parabolic trough, Fresnel, ETC. The efficiency of the single Scheffler system decreases with increase in solar radiation and absorber plate temperature and it is in the range of 56.38 % to 63.92%. The average efficiency for a week is worked out to be 57.41 %. As compared to solar water heating system and parabolic trough the efficiencies found are on higher side at least by 25% which means that Scheffler system can be effectively used for industrial applications such as water heating and low pressure and temperature steam.

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