PERFORMANCE EVALUATION OF PARABOLIC SOLAR CONCENTRATOR WITH CARBON CREDIT ASSESSMENT

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Abstract - The large number of developments are continuously being carried out in the field of cover materials, absorber materials and glazing coating etc. along with the changes in the design and circulating fluid. The studies have been carried out on thermal performance evaluation of solar water heater and found more increase in the thermal efficiency in comparison to conventional solar water heater. In this paper energy equation for heat transfer of two-dimensional fluid flow of the cylindrical parabolic collector have been considered and collector efficiency factor, collector heat removal factor, and collector overall heat loss coefficient are used to evaluate the thermal performance of collector and to study the effect of fixed mass flow rate with variation of incident solar radiation. The experimental study was conducted at Department of Mechanical Engineering, Poornima University, Jaipur to analyzed the effects of all the operating parameters on the system performance in order to obtain the optimum performance of the system. The system gives the maximum efficiency of 48.26 % with outlet temperature of 83°C of water and 53°C of storage tank water. Number of Carbon Credits that we can earn by saving monthly 5046506565 kWh of Electricity i.e. saving 5298831.89 tonnes of CO2. The results obtained can help engineers in the evaluation of the existing real systems and design of future system.

Keywords: Thermal performance, cylindrical parabolic solar collector, carbon credits, Renewable energy, solar energy

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1. INTRODUCTION

As we know that in present time energy crisis is on the global scale. The impact of energy crisis is mainly on the developing countries such as India. Developing countries mainly depend up on conventional fuel resources which are going to end in nearby future. Thus, they have to promote their non-conventional energy resources such as solar and wind. Energy can be conserved by two ways: one is by using renewable sources of energy and the other is by using energy management techniques. Solar energy is the energy derived from the sun through the form of solar radiation. Solar powered electrical generation relies on photovoltaic's and heat engines. A partial list of other solar applications includes space heating and cooling through solar architecture, daylighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Energy can be conserved in the areas such as heating and cooling. A lot of energy is required in the heating of water in many part of the world mainly in the countries having colder climate. This energy consumption can be minimized by using solar energy as the source for heating water application. Today a lot of techniques and designs are being evolved in the field of solar heating techniques. There are basically two types of solar water heating system one is flat water heating system and the other one is concentrated water heating system. Flat water heating system is an effective way of cooling water and cost effective also, on the other hand concentrated water heating system can be used for obtaining a higher temperature, which can be further utilized for producing electricity. Thus, concentrating water heater gives us an edge over the flat plate collector for the heating of water as well as can provide as a source for power generation. For experiment purpose parabolic reflector is utilized for making the solar water heater. The solar water heater was fabricated by using water tank, storage tank, insulated water flow pipe, meter, temperature sensor. This concentrated heating system is basically works on the principle of thermosyphon.

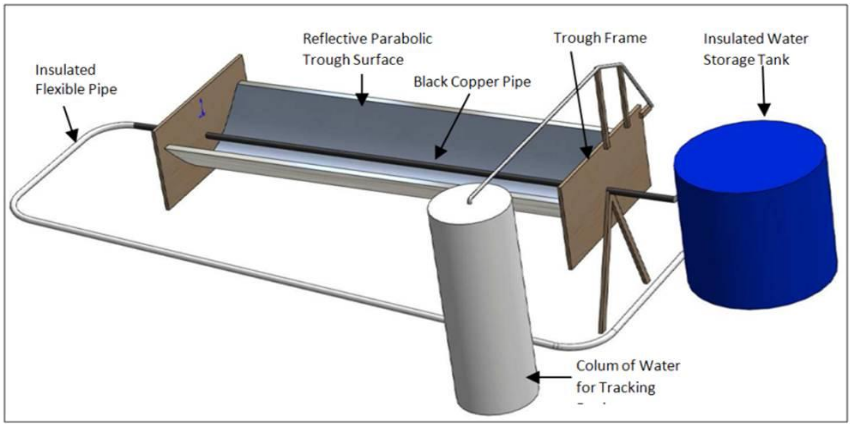

Figure 1.1. Cylindrical Parabolic Solar Water Heater

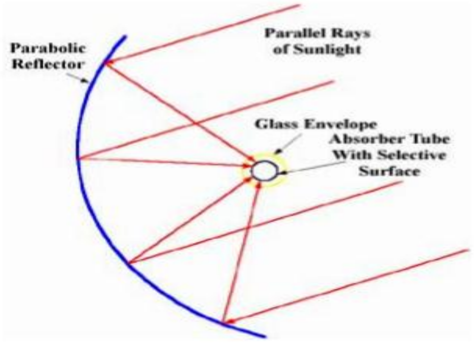

Figure 1.2. Cross Section of Cylindrical Parabolic Concentrating Collector

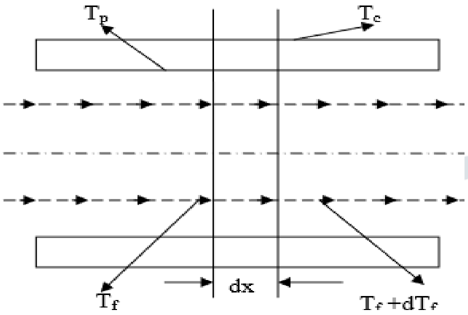

Figure 1.3. Energy Flow Diagram of Cylindrical Parabolic Concentrating Collector (Sukhatme, 2007).

2. METHODOLOGY

The efficiency of cylindrical parabolic solar water heater can be calculated by:

$$\boldsymbol{\eta = mC_p(T_e - T_i) \times 100 \Big/ A_c.[H_b].t}$$

We now consider the performance analysis of a cylindrical parabolic concentrating collector whose concentrator has a aperture W, length L and rim angle ϕr. The absorber tube has an inner diameter Di and an outer diameter Do , it has a concentric glass cover of inner diameter Dc1 and outer diameter Dco around it. The fluid being heated in the collector has a mass flow rate m, a specific hear Cp, an inlet temperature Tfi and an outlet temperature Tfo. The collector is operated in any one of the modes and the beam radiation normally incident on its aperture is Ib rb, whose value can be calculated from the equations derived. In some of the tracking modes, the sun's rays are incident at an angle and will, therefore, come to a focus a little beyond the length of the concentrator. We assume that the absorber tube is long enough to intercept this image. In practice this would mean that the absorber tube might be a longer (say about 10 percent) than the concentrator and that the flux falling on the absorber tube would not be uniform along the length. For the purposes of analysis, however, we will not radiation flux is the same all along the length. We will also make the assumption that the temperature drop across the temperature drop across the absorber tube and the glass cover are negligible.

The concentrator ratio of the collector is given by

$$C = \frac{Effective\ aperture\ area}{Absorber\ tube\ area} = \frac{(W - D_0)\mathrm{L}}{\pi D_0 L} = \frac{(W - D_0)}{\pi D_0}$$

An energy balance on an elementary slice dx of the absorber tube, at a distance x from the inlet, yield the following equation for a steady state:

$$dQ_u = [I_b R_b (W - D_o)\ \rho r (\tau\alpha)_b + I_b R_b D_o (\tau\alpha)_b - U_l \pi D_o (T_p - T_a)]dx$$

We define absorbed flux S as follows,

$$S = I_b R_b \rho r (\tau\alpha)_b + I_b R_b (\tau\alpha)_b \left(\frac{D_o}{W - D_o}\right)$$

Equation thus becomes,

$$dQ_u = \left[S - \frac{U_1}{C}(T_p - T_a)\right](W - D_o)dx$$

The useful heat gain rate dQu can also be written as

$$dQ_u = h_f \pi D_i (T_p - T_f)\, dx$$

$$= \dot{m} c_p dT_f$$

$$dQ_u = F'\left[S - \frac{U_1}{C}(T_f - T_a)\right](W - D_o)dx$$

Where, F' is the collector efficiency factor defined by,

$$F' = \frac{1}{U_l\left[\frac{1}{U_l} + \frac{D_o}{D_i h_f}\right]}$$

$$\frac{dT_f}{dx} = \frac{F'\pi D_o U_l}{\dot{m}C_p}\left[\frac{CS}{U_l} - \left(T_f - T_a\right)\right]$$

Integrating and using the inlet condition at x = 0, Tf = Tfi we have the temperatue distribution

$$\frac{\left(\frac{CS}{U_l} + T_a\right) - T_f}{\left(\frac{CS}{U_l} + T_a\right) - T_{fi}} = \exp\left\{-\frac{F'\pi D_o U_l x}{\dot{m}C_p}\right\}$$

The fluid outlet temperature is obtained by putting, Tf = Tfo and x = L. Making this substitution and subtracting both sides of the resulting equation from unity, we have

$$\frac{\left(T_{fo} - T_{fi}\right)}{\frac{CS}{U_l} + T_a - T_{fi}} = 1 - \exp\left\{-\frac{F'\pi D_o U_l L}{\dot{m}C_p}\right\}$$

Thus, the useful heat gain rate

$$Q_u = \dot{m}c_p(T_{fo} - T_{fi})$$

$$Q_u = \dot{m}c_p\left(\frac{CS}{U_1} + T_a - T_{fi}\right)\left[1 - \exp\left(-\frac{F'\pi D_o U_1 L}{\dot{m}c_p}\right)\right]$$

$$= F_R(W - D_o)L\left[S - \frac{U_1}{C}(T_{fi} - T_a)\right]$$

Where FR is the heat removal factor defined by

$$F_R = \frac{\dot{m}c_p}{\pi D_o L U_R}\left[1 - \exp\left(-\frac{F'\pi D_o U_1 L}{\dot{m}c_p}\right)\right]$$

The instantaneous collection efficiency ηi is given by

$$\eta_i = \frac{Q_u}{(I_b R_b + I_d R_d)WL} \times 100$$

The instantaneous efficiency can also be calculated (by neglecting ground-reflected radiation) on the basis of beam radiation alone, in this case,

$$\eta_{ib} = \frac{Q_u}{(I_b R_b)WL} \times 100$$

3. RESULTS AND DISCUSSION

3.1. PERFORMANCE EVALUATION OF PARABOLIC SOLAR WATER HEATER

The experiments were carried out at Poornima University, Jaipur (latitude of 26.91ºN; longitude of 75.78ºE) India. Various parameters were measured during the experiment such as Parabolic Trough inlet temperature, Hot Water Tank outlet temperature, Hot water Tank output Temperature, Ambient Temperature, Radiations received on the focal axis of the parabolic trough etc. The parameters were measured in every 30 minutes from 09.00 a.m. in the morning to 04.00 p.m. in the evening. Test data for August 01, 2014 (Tuesday).

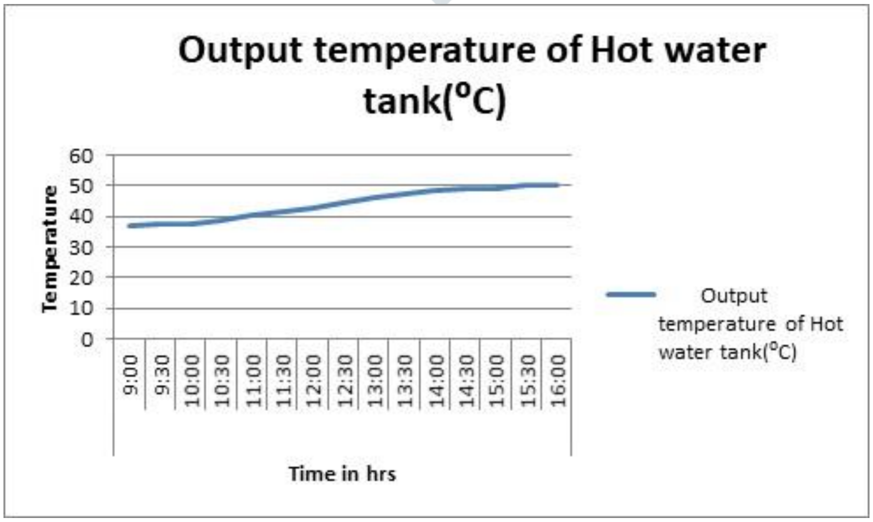

Figure 3.1. Output temperature of hot water tank on 01/08/2017

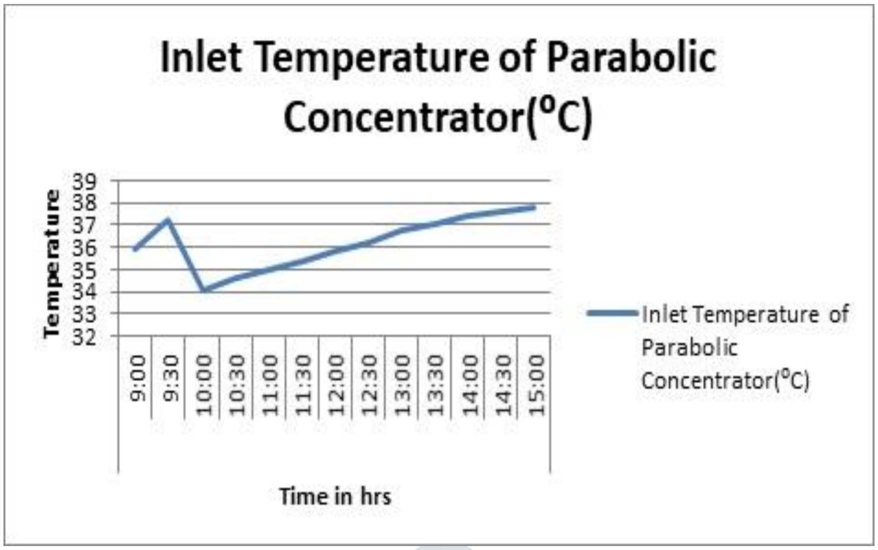

Figure 3.2. Inlet temperature of Parabolic concentrator on 01/08/2017

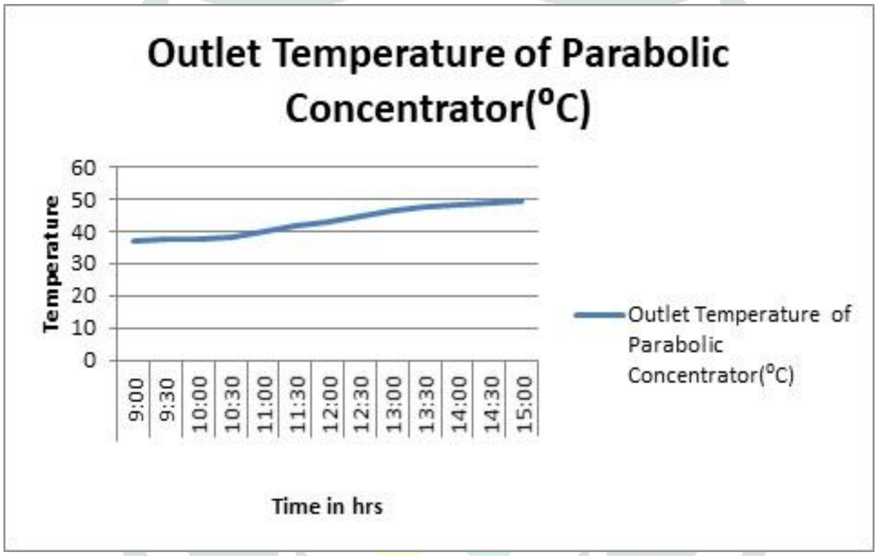

Figure 3.3. Outlet temperature of Parabolic concentrator on 01/08/2017

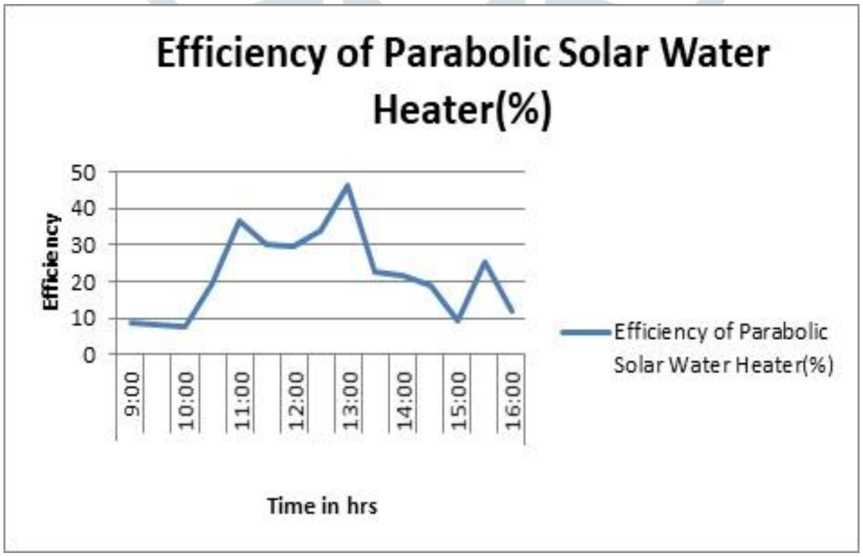

Figure 3.4. Efficiency of Parabolic solar water heater on 01/08/2017

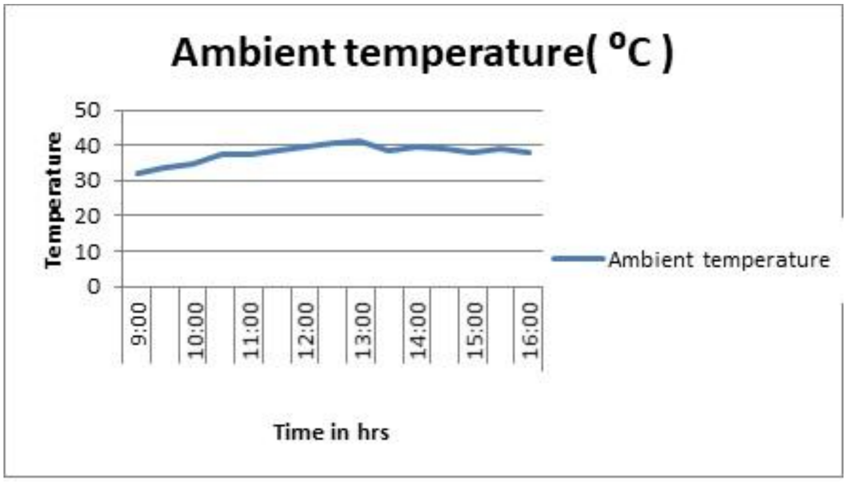

Figure 3.5. Ambient Temperature on 01/08/2017

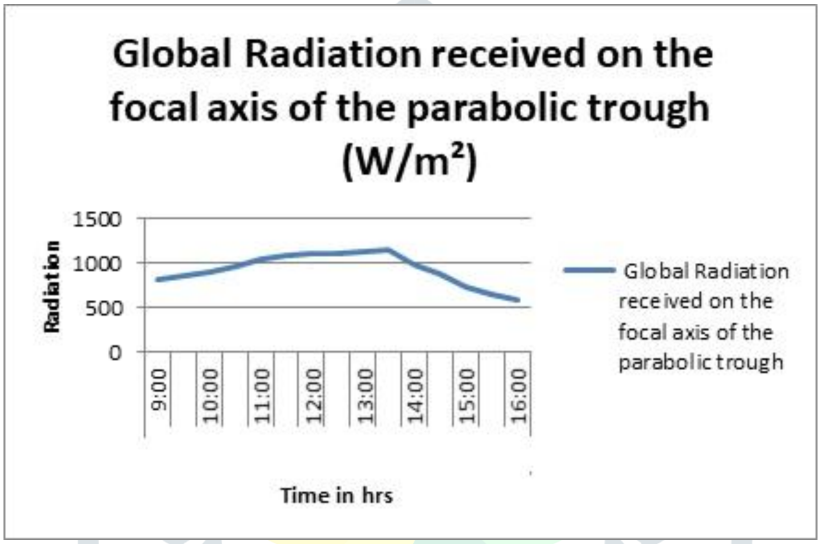

Figure 3.6. Global radiation received on focal axis of Parabolic concentrator on 01/08/2017

3.2. CALCULATION OF CARBON CREDITS

As per the Latest population figures based on data from the 2011 census of India the total population of India is = **1,210,193,422**

Out of the total population of India according to the latest 2011 census share of the Urban population that is people living in the towns and the developed cities is about **27.8%** of the total.

Urban population of India = 27.8% of 1,210,193,422 = 336433771

Assuming the average number of persons in one family i.e. family size = 4

Total number of families residing in the Urban areas of India = 336433771/4 = 84108443

Assumption: Water Heating System (Electric Geyser) Specifications for each family:

Capacity = 2000 Watts = 2kW
Time of run = 60 minutes per day

Now Electricity Requirement for water heating daily for 1 family = (2kW * 60) / 60 = 2 kWh

Total Electricity Requirement for water heating monthly for 1 family = 60 kWh

Hence, Electricity Requirement for water heating monthly for total families of India (residing in Urban Areas) = (84108443 * 60) kWh = 5046506565 kWh

As 1 kWh = 1 Unit of Electricity and 1 Unit costs around Rs 6 /- as per the State Electricity Board's Tariffs

Total Electricity Bill for water heating monthly for all families of India (residing in Urban Areas) = 3027.903 crores

3.3. CARBON CREDIT ANALYSIS

For Coal based Power Plant and including the Life Cycle Analysis for all the processes involved in the Electricity Generation, Transmission the equivalent amount of CO2 emissions produced for the generation of 1 Unit (1 kWh) of Electricity is approximately equal to 1.050 kg of CO2.

As 1 Carbon Credit = 1 tonne CO2 emissions saved

Amount of CO2 produced for production of 1 kWh of Electricity = 1.050 kg = .00105 tonne

Electricity Requirement monthly for water heating for total families of India (residing in Urban Areas) = (84108443 * 60) kWh = 5046506565 kWh.

If for all the families of India as above the Electric Water Heating Systems are replaced by the Solar Water Heating Systems then above shown total Electricity Requirement can be avoided and we will be able to save monthly this much Electricity = 5046506565 kWh.

Hence, as for 1 kWh of Electricity we emit CO2 = 0.00105 tonne.
Now for this total monthly Electricity Savings of 2018602620 kWh the amount of CO2 emissions saved
= 5046506565 * 0.00105 = 5298831.89 tonne.
As 1 Carbon Credit = 1 tonne CO2 emissions saved. Therefore, Number of Carbon Credits that we can earn by saving monthly 5046506565 kWh of Electricity i.e. saving 5298831.89 tonne of CO2

CONCLUSION

The experiments were carried out at Department of Mechanical Engineering, Poornima University, Jaipur (latitude of 26.91ºN; longitude of 75.78ºE) India. Various parameters were measured during the experiment such as Parabolic Trough inlet temperature, Hot Water Tank outlet temperature, Hot water Tank Output Temperature, Ambient Temperature, Radiations received on the focal axis of the parabolic trough etc. The system gives the maximum efficiency of 48.26 % with outlet temperature of 83°C of water and 53°C of storage tank water. Number of Carbon Credits that we can earn by saving monthly 5046506565 kWh of Electricity i.e. saving 5298831.89 tonnes of CO_2. The results obtained can help engineers in the evaluation of the existing real systems and design of future system.

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