PERFORMANCE EVALUATION OF PARABOLIC TROUGH SOLAR COLLECTOR

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ABSTRACT

Solar energy currently represents the most abundant inexhaustible, non- polluting and free energy resources that could be used economically to supply man's increasing energy demands. In the present study, performance evaluation of grade –B type parabolic trough solar collectors (PTSC) was carried out during December-2014, under semi-arid climatic conditions of North-Gujarat. The results showed that an average temperature gain of 53.1^{o}C was achieved during normal day of the season which was directly proportional to the solar insolation. The maximum water temperature at PTSC out let was attained 77.80^{o}C under manual tracking mode. The highest solar insolation of 1150 W/m^{2} was obtained at 13:00 hr. during the study period. The highest thermal efficiency obtained was 35.31 per cent. The efficiency obtained was fairly good considering the use of copper material as absorbing tube. However, the thermal efficiency can be obtained much higher, if the power operated tracking system is used instead of manual tracking.

KEY WORDS: Beam radiation, Parabolic trough solar collector, Thermal efficiency

INTRODUCTION

Energy consumption increases very rapidly with various developmental processes over the world. The sun is one of the richest energy sources and is almost inexhaustible. Energy efficiency and solar technology are important elements in effective utilization of solar energy. Solar energy in the form of radiation can be converted directly or indirectly into other forms of energy such as heat and electricity which has many applications. The solar radiation that reaches the earth's surface without being diffused is called as direct solar radiation. It is also referred to as the solar radiation having UV 6.4 per cent, visible region 48 per cent, Infrared 45.6 per cent are propagating along the line joining the receiving surface and the sun. Parabolic trough solar collectors highly polished metallic surfaces are being used as the reflector. The reflectors normally have a parabolic shape so that the sun rays striking the profile get reflected on its focal point. If a tube carrying a fluid is kept along the focal line, the fluid will be heated to a very high temperature. The parabolic trough solar collector system uses water or thermal oil as heat transfer fluid in industries for either power generation or heating applications or both. In heating applications, mostly water is being used as a heat transfer fluid. Parabolic troughs are one of the cost effective solar thermal systems and have significant potential for further cost reduction and hence, is the best suited for the steam generation. The study was conducted to evaluate performance of laboratory model of parabolic trough solar collector system.

MATERIALS AND METHODS

The study was conducted on laboratory model of parabolic trough solar collector (PTSC) available in the College of Renewable Energy and Environmental Engineering, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India. The experiment was conducted during December 8-14, 2014. During the experimental period, the weather was normal with cool and dry climatic condition (Table 1). Observations were recorded from 9:00 hrs to 17:00 hrs during the day. The tracking system was rotated manually @ 10^0 at an interval of an hour.

The functioning of the system involves the solar radiations reflected from parabola (reflector) concentrate to the focal point, and get absorbed by the fluid inside the absorbing tube. If the reflector is in the form of trough with parabolic cross section, the solar radiation focuses along a line. As shown in Figure 1, the system uses a reflector with a reflectivity of 96 per cent in the shape of a parabola which was anodized aluminum sheet (2100 mm x 1200 mm) to reflect and concentrate the solar radiations towards a receiver tube located at the focus line of the parabola. The absorber tube made up of copper was 2500 mm in lengths and having inside diameter 0.75 mm, coated with a heat resistant black paint for better performance. The receiver absorbed the incoming radiations and transformed into thermal energy, which was collected and transported by a fluid medium circulating within the receiver tube. The heat transfer fluid (water) flew through the absorber tube, heated and thus carried heat.

Schematic diagram of the parabolic trough solar collector with absorber tube, tracking mechanism and support structure is shown in Figure 2. The experiment was performed with water as the heat transfer medium in the absorber tube. An insulated storage tank made up of high density polyethylene (HDPE) of 40 liter capacity was filled with water as working fluid. The water was circulated from the container to the inlet of the absorber tube. After gaining heat from the absorber tube, it was allowed to flow back in the same storage tank and was re-circulated. The inlet and outlet of the absorber tube was connected to the storage tank. The storage tank was kept at 1700 mm above ground level for free flow of water. The instruments used in experimentation are shown in Figure 3.

The main parameters studied include flow rate, useful heat gain, rise in water temperature in the storage tank, thermal efficiency and concentration ratio of solar trough. The following formula were applied to determine amount of heat collected.

$$Q = m_w \times C_{pw} \times \Delta T \qquad \textbf{.......(1)}$$

Where,

Q = amount of heat collected in kw
m_w = mass of water heated in one solar day (sunny hours)
C_{pw} = specific heat of water, 4.18 kJ/kg °C
ΔT = the temperature deference of water, 36°C (60°C –24°C)

$$\text{Collector efficiency} = \frac{Q}{I_s \times A} \qquad \textbf{......(2)}$$

Where

I_s = Solar insolation on tilted surface
A = solar collector surface area.

The concentration ratio was determined as;

$$\text{Concentration ratio} = \frac{\text{Collector surface area}}{\text{Absorber area}} \qquad \textbf{......(3)}$$

RESULTS AND DISCUSSION

The experiment was conducted during December 8, 2014 to December 14, 2014 to operate system and observations were recorded. During the study period, climate was fairly dry and cold with bright sun shine hours (clear sunny day). The PTSC was used to heat up the 40 liter of water. Concentration ratio calculated for the system was 256.94. As shown in Figure 4, the average minimum and maximum ambient air temperature observed during experiment were 19^0 and 29^0 C when measured from 9:00 hours to 17:00 hours. An average duration of bright sun shine hours observed during the experiment was 8.12 hours. The observations recorded at an interval of one hour showed that PTSC out let water temperature was minimum (30^0 C) at 10:00 hrs in the morning, while it was maximum (77.8^0 C) at 14:00 hours.

The results depicted in Figure 5 showed that during the day time, the solar insolation has risen gradually from 9:00 hrs onwards and attained peak (1150 W/m^2) around 13:00 hrs. It declined gradually after 14:00 hrs. onwards till 17:00 hrs. where its value was 402 W/m^2. The reduction was steep after 15:00 hrs. The trend of ambient temperature was similar to that of solar insolation intensity. Hence, it is clear that temperature is directly proportional to the insolation intensity.

The results depicted in Figure 6 showed how water temperature increased with rise in insolation intensity and decreased with insolation intensity during the day. It clearly, revealed that solar insolation intensity plays an important role in performance of solar trough.

The date wise thermal efficiency of PTSC is presented in Figure 7. The efficiency was highest on 12^{th} December, 2014 where average solar insolation was maximum (1150 W/m^2) and it was lowest on 12^{th} September (21.92%) due to lower average solar insolation (570 W/m^2). Hence, it was revealed that thermal efficiency is directly proportional to the insolation intensity. The overall system thermal efficiency found was conducted 28.80 per cent.

The applications of solar collectors have been studied extensively in the past. Eric and Thomas (1989) investigated the thermal performance of parabolic trough solar collector with an innovative porous absorber receiver. Influence of mass flow rate, acceptance angle, receiver dimensions and material properties on the thermal efficiency is determined. Here radial velocity profile is obtained by solving for continuity equation using an implicit solution scheme. The porous absorber consists of several layers of etched stainless steel screen with 50 meshes per inch (20 per cm). The porosity of screen is 0.4. Suction velocity at the absorber surface was fixed at 8.11×10^{-5} m/s, which corresponds to a suction Peclet number of 25 in the inlet channel. Around three hours is required to reach an equilibrium condition at which the maximum liquid temperature condition at which the liquid temperature is 312°C. It was found that as the outlet temperature increases, smaller acceptance half-angle results in higher efficiencies because the losses through the inlet channel are less. Envelop radius at 3.81 cm thermal efficiency is maximum with maximum fluid outlet temperature. Result indicated that the radial dimension of the receiver should be as small as possible to minimize heat loss.

Fadar *et al.* (2009) studied a solar adsorptive cooling system using an activated carbon-ammonia pair, in which the reactor was heated by a parabolic trough collector coupled with a water/stainless-steel annular heat pipe. However, they did not carry on the verification with experimental results.

Ravi Kumar and Reddy (2009) presented 3-D numerical model for thermal analysis of PTC with porous disc receiver. The influence of thermic fluid properties, receiver design and solar radiation concentration on overall heat collection is investigated. The analysis is carried out based on renormalization-group (RNG) K–ε turbulent model by using Therminol-VP1 as working fluid.

Ruby *et al*. (2012) performed through the design, construction, operation and analysis of a high temperature solar thermal system. In this installation, high temperature water is produced by a concentrating solar field, which in turn is used to produce approximately 300 pounds per square inch (20 bar) of process steam. Process steam in the plant is used for cooking, which includes heating edible oil for frying and heating baking equipment. Steam is also converted into hot water for cleaning and sterilization processes.

CONCLUSION

The highest and lowest insolation of 1150 and 402 W/m^2 were observed at 13:00 and 17:00 hrs respectively. Normally, the water temperature varied with insolation intensity. Maximum thermal efficiency (35.31%) was found on 12th December and was lowest (21.92%) on 9th December, 2014. The collector thermal efficiency varied in direct proportion to solar insolation. The overall thermal efficiency of parabolic trough solar collector was obtained as 28.80 per cent.

REFERENCES

Eric, W. G. and Thomas, H. K. (1989). Performance analysis of a parabolic trough solar collector with a porous absorber receiver, *Solar Energy*, **42**(4): 281-292.

Fadar.; Mimet, A.; Azzabakh, A.; Perez-García, M. and Castaing, J. (2009). Study of a new solar adsorption refrigerator powered by a parabolic trough collector. *Appl. Thermal Engg*., 29: 1267-1270.

Ravi Kumar, K. and Reddy, K. S. (2009). Thermal analysis of solar parabolic trough with porous disc receiver. Appll. Energy, **86**: 1804-1812.

Ruby, Steve (American Energy Assets, California L.P.). (2012). Industrial process steam generation using parabolic trough solar collection. California Energy Commission. Publication number: CEC-500-2011-040.

Table 1: Location specific geographical and metrological information

Location Geography	
Longitude	72.3ºE
Latitude	24.3ºN
Altitude	209 m
Weather conditions during the experimental period	
Month of study	Dec. 8-24, 2014
Average maximum temperature	24.65 ºC
Average minimum temperature	8.45 ºC
Average solar radiation	749 W/m^2
Average bright sun shine hours	8.12 hours

Figure 1: experimental setup and main components of PTSC system

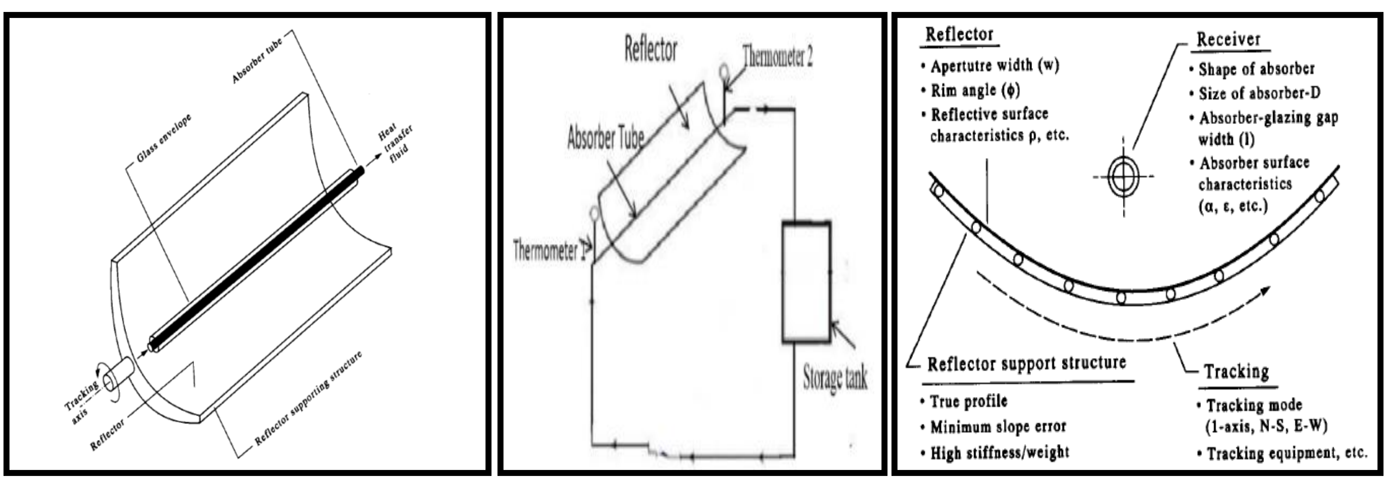

Figure 2: Schematic view of experimental set-up of parabolic trough solar collector system

Solarimeter

Digital Thermometer

Anemometer

Figure 3: Instruments used for meteorological observations

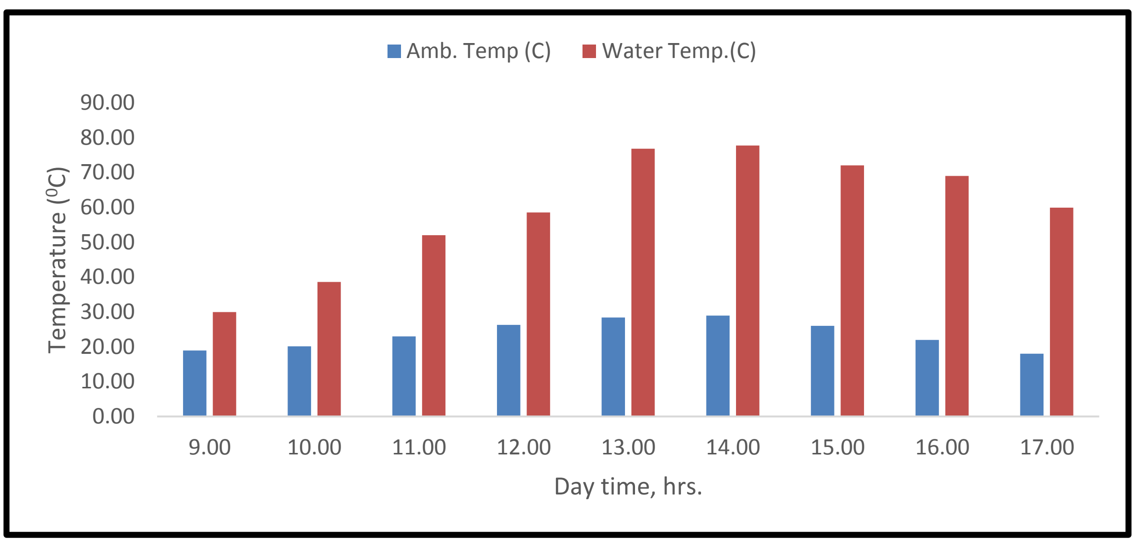

Figure 4: Ambient air temperature and water temperature at trough out let at different time intervals

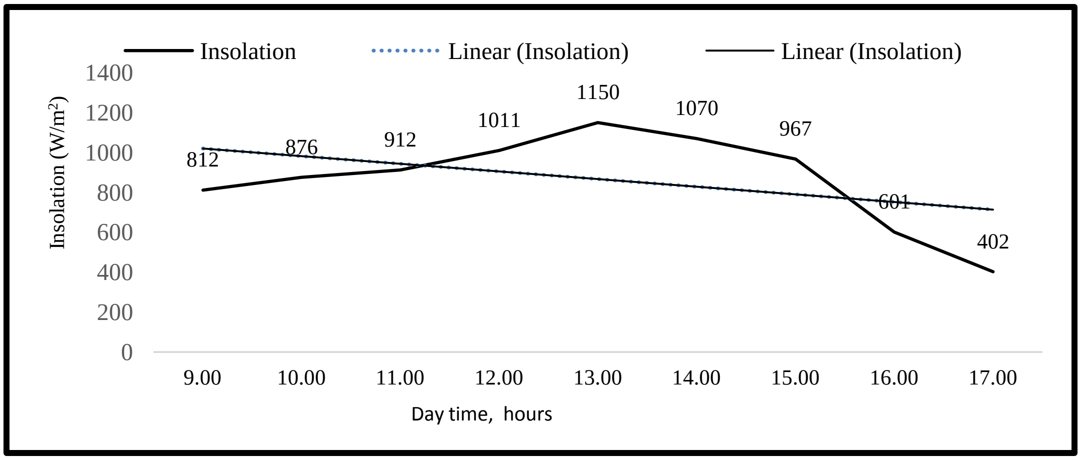

Figure 5: Variation in insolation intensity during the day

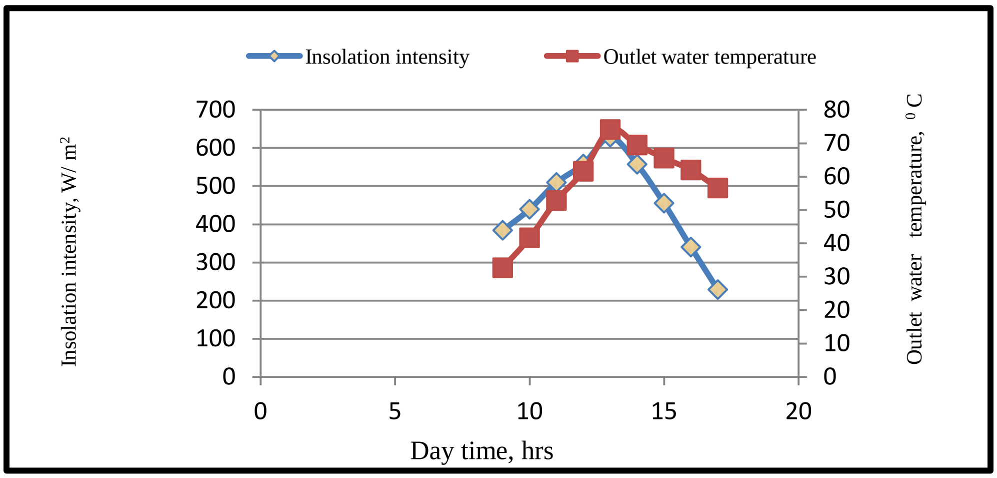

Figure 6: Change in PTSC out let water temperature and insolation intensity

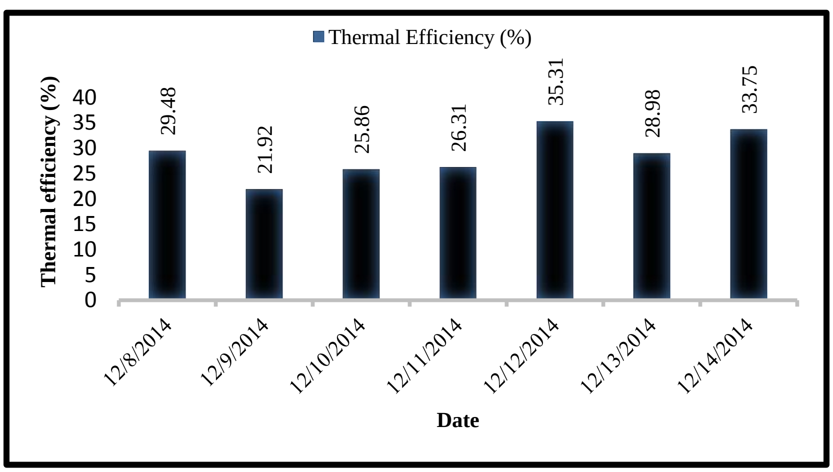

Figure 7: Thermal efficiency of solar trough

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