Experimental Investigation on PTSC Hot Water Generation System

Vijayan Gopalsamy, Karunakaran Rajasekaran
Assistant Professor / Mechanical Engg, KSK College of Engg. & Tech., Tamilnadu, India
viji_laker@yahoo.co.in
Associate Professor / Mechanical Engg, University College of Engg., Tamilnadu, India
karuna30722@yahoo.com

ABSTRACT

In this work, the performance of the parabolic trough solar collector with hot water generation system is investigated for three days daytimes. The difference in temperature is observed in the range of 6.7°C to 24°C. The average beam radiation during the testing period is 658 W/m^2. The temperature difference, useful heat gain, wind velocity, direct beam radiation, absorber temperature and solar flux are found in the test period from 9.00 a.m to 16.00 p.m. For the maximum outlet and inlet temperature difference of 24°C, the recorded quantities are, beam radiation (763 W/m^2), solar flux (580 W/m^2), and useful heat gain (574.17 W/m^2). The useful heat gain, inlet temperature, outlet temperature, solar flux, and the efficiency of the system as a whole are evaluated an hourly basis. All these parameters are strongly influenced by the incident beam radiation and found to observe its variation. The maximum value of each of those parameters is recorded around noon when incident beam radiation is at its peak level.

Keywords

Parabolic solar collector, Beam radiation, Hot Water Reservoir Tank

1.0 INTRODUCTION

Carbon dioxide introduced the global warming has now become a vital issue and needs to be handled very carefully and tackled effectively. Efficient utilization of a renewable source of energy, mainly solar energy become a focusing area to fight against the global warming issue, it means making the solar energy utilization as a promising one for the sustainable development of human beings. They detailed about the availability of conventional resources (coal, oil, and gas), in terms of source wise and state wise in India. The capacity of the power plant using conventional fuel as an energy source is a major one [1]. The power generation level, the status of power distribution, peak hour demand were discussed. In sector wise, the domestic field utilizes maximum share of power production and followed by commercial, agricultural along with the production capacity of conventional and non-conventional [2]. They provided the grid-connected solar power plant, their capacity of production, and wind energy available in region-wise using MERRA re-analysis method. They concentrated on solar Photovoltaic, solar thermal and wind energy. Factors affecting the exploration of solar energy and problem faced by Indian power sector were also discussed [3,4,5]. Governing agencies, vendors, policies, initiatives for delivering the renewable energy potentials, barriers to implement the projects and future vision were also detailed. The state government capturing 35% shares of Indian renewable energy scenario, with high plant installed capacity [6]. Parabolic Trough Collector currently finds many applications such as power generation [7], steam generation for industries [8] and hot water production for households [9], because of its high-temperature rise between 50°C and 400°C. Even though many different types are available in the market, PTC is mainly preferred for power generation because the effect on the collector's efficiency degradation is very low [10]. The parabolic trough solar collector based thermal power plant nowadays is functioning successfully as which was proved early and right now also.

The author studied different types of solar collector for thermal energy recovery and discussed the energy concerned with atmospheric issues such as acid rain, ozone layer dillution, global climate change and renewable energy technologies due to the usage of conventional energy sources. They studied thermal analysis, optical analysis, and efficiency of all types of the solar collector. For evaluation purpose, they used modeling software, such as TRNSYS, WATSUN, polysun simulation program, "I" chart method cum program and artificial neural network [11]. The author designed and fabricated the integrated storage type solar water heater at ARER (Alternative and Renewable Energy Research), Najah. They conducted the test for one month and attained maximum temperature difference of 36.3^{o}C [12]. They compared the performance of two flat plate collector with and without the tracking system. They maintained the same condition for both the collector and tracking was done 15^o per hour. The temperature enhancement was 4^{o}C and efficiency improvement was 21% [13]. They reviewed the design of PTC, which include structural design, optical sub-system, thermal sub-system. This work discussed the way of enhancing the performance through thermal analysis, optical analysis, error analysis, reflector support system, wind load, collector orientation and tracking mode [14]. Two new PTC were developed, and the performance is compared with LS-2 PTC, linear and convoluted model. The observed efficiency was 70, 78 and 86%. The efficiency enhancement was 10% and 20% for the linear and convoluted model [15]. The author analyzed the geometrical and optical properties of ETSC (Evacuated Tube Solar Collector) by applying various techniques such as collector geometry measurement method, flux measurementmethod, ray tracing method, and thermal performance analysis [16]. They conducted simulation work using solid work to predict the efficiency and heat conduction property [17]. They carried out the experimental work to understand the performance of PTC with thermal energy acquiring system [18,19]. Salgado et al. carried out mathematical modeling, simulation numerical modeling, and experimental work on PTC to study the performance [20].

As a practical example of this type of plant was commissioned and running at Kramer Junction generation in the United States [21]. Based on their study Kalogirou and Lloyd were reported about the feasibility of using the PTC at hotels, restaurants and other places [9]. Parabolic trough collector is to be designed as cost-effective than flat plate collectors. Valan Arasu et al. developed and carried out the simulation work of PTC hot water production set up [22]. They discussed a low-cost method for mass production of parabolic surfaces with fiberglass. Author verified the effect of mold quality on the precision of parabolic surface. Also they detailed the mold production method and the procedure to be followed to develop the parabolic surface was presented [23]. Arasu et al. compared the simulation results with experimental work results and they checked the deviations [24]. They discribed the design and fabrication of a fiberglass-reinforced PTSC for hot water production application. The reflecting material is placed on the parabolic geometry and developed the curved surface to a good level of accuracy as per the designed values and kept the error level as 0.0066 radian conducting the experimental work asper ASHARE standard 93 [25]. Martinez et al. developed a PTC keeping the initial surface as soda lime coated strip type glasses. The parabolic shape was constructed with 16 number of mirror with size of 300mm x 600mm. The specular reflectance of collector was 86%. The focusing test was conducted on concentrator and it produce the focus diameter of 50.8 which faces around 90% of the reflected beam radiation from the reflector surface [26]. Author designed a simple weld type PTC structrue to adopt for certain countries. They studied the deflection property of the structure for different load conditions. The results ensured the slope error of the parabolic geometry support towards the wind loads was under the defined level, and guaranteed that the structure had the capability to handle the extreme wind load conditions [27]. Kalogirou conducted the collector performance test according to the ASHARE Standard 93. The test showed the value slope and intercept was 0.387 and 0.638, respectively [28]. Guven et al had explained and reviewed the design aspects of the PTC structure and subsystems. Method available currently to analyse the performance and technique suggested in the view of improving the performance were also discussed [29].

Gong et al. explained the importance of the air free solar receiver of a PTSC plant set up. They established and optimized the whole system using MATLAB program. They calculated various heat loss of the absorber system and analyze the effect of influencing factors. Under steady condition, variation of heat loss between evacuated and filled receivers were surveyed. Author used CFD (Computional Fluid Dynamics) for further investigation of different heat transfer process of the absorber's end components [30]. Skeiker explained the effect of the tilt angle variation on the quantity of radiation available the collector surface. They proved influence of tilt angle by developing a mathematical model and calculated the optimum tilt angle [31]. Hachicha developed a numerical heat transfer model using finite volume method for parabolic trough collector, to evaluate the performance [32,33]. They carried out the simulation work for temperature distribution of parabolic trough collector receiver by using combination of MCRT and FLUENT software [34]. The author developed optical and thermal 3D model of parabolic trough collector receiver system using MCRT and finite volume method to analyze the non-uniform temperature distribution solar radiation, heat transfer for various receiver surfaces, heat loss and heat gain for the purpose of determining the spectral radiation characteristics of receiver surface and concentrator surfaces [35].

2.0 DESCRIPTION OF PTSC EXPERIMENTAL SETUP

Fig. 1 shows the PTSC experimental setup for water heating purpose. The main parts of the system are a PTSC, hot water reservoir tank (HWRT) and circulating pump. Parabolic trough shape is made up of bending sheet steel and calculation is done by using parabola 2.0. This system is constructed mainly from locally available materials such as a reflective mirror is used as reflector, bare copper tube as an absorber with heat resistant black paint. The circulating pump circulates the water through the receiver tube via flow meter where it is get heated and allowed to the tank. When the concentrator is tilted towards the sun, the sun rays incident on the reflector, is concentrated on the receiver tube. Out of two different system of tracking the sun, it is preferred to rotate the system about north/south axis to get the maximum contact with solar radiation during the daytime. No automatic tracking mechanism was included. Table I indicate the specifications of PTSC. Performance analysis of PTSC system is determined based on the ambient observations of data such as incident beam radiation (I_b), ambient temperature and water inlet temperature. Inlet water temperature (T_{fi}), outlet water temperature (T_{fo}), receiver tube temperature (T_r) and ambient temperature (T_a) of the collector were recorded with the help of PT-100 of resistance temperature device sensors.

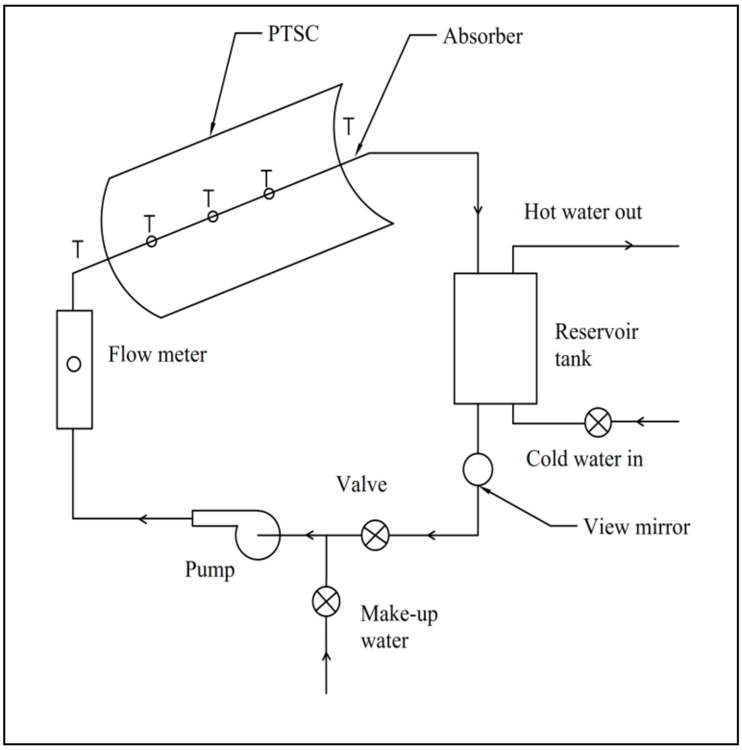


Fig 1 PTSC hot water generation system

Table 1: Specifications of PTSC

Description	Dimension	Description	Dimension
Aperture length(L_c)	1.2 m	Absorber length	1.4 m
Aperture width (W)	0.9 m	Inside diameter (D_i)	0.0254 m
Focal distance (f)	0.3 m	Mode of tracking	Manual
Aperture area (A_a)	1.08 m^2	Working fluid	Water
Rim angle ($Ø_r$)	45°	Mass flow rate	0.017 kg/s
Parabola material	Sheet steel	Absorber material	Copper

The solar beam radiation, mass flow rate, and wind speed are measured by the solar power meter, rotameter and anemometer respectively. Parameters were measured at the one-hour time interval, but tracking of the collector was done by every half an hour, under steady-state conditions. Equation (1) is the governing can be used for calculating thermal performance of PTSC [36-38]. On the other side, this equation will never be used if a transient condition exists, because at transient condition part of solar energy absorbed will heat or cool the collector and its components.

$$\eta_i = Q_u / (I_b R_b W L) \quad (1)$$

The calculation of loss coefficient which includes both the wind loss and radiation loss and overall heat transfer coefficient is done by using (2) and (3)

$$U_L = \left({}^{1}/_{h_{wind}} + {}^{1}/_{h_r} \right) \quad (2)$$

$$U_O = 1 / \left({}^{1}/_{U_L} + {}^{1}/_{h_i D_i} + D_o \ln\left(\frac{D/_o}{D/_i} \right) / 2k \right) \quad (3)$$

Heat removal factor calculated from (4)

$$F_R = \frac{mC_P}{A_r U_L}\left[1 - e^{-\left(A_r U_L F' / mC_P\right)}\right] \quad (4)$$

Solar flux can be calculated from (5)

$$S = I_b R_b \rho\gamma(\tau\alpha)_b + I_b R_b (\tau\alpha)_b \left[{}^{D_o}/_{(W - D_o)} \right] \quad (5)$$

Useful heat gain rate from (6)

$$Q_u = F_R (W - D_o) L \left[S - {}^{U_L}/_{C} \left(T_{f_i} - T_a \right) \right] \quad (6)$$

The experimental work is started from the point of cleaning the PTSC system. Then, the fluid line charged with water and the flow rate is corrected to the specified value. The system is allowed to run for 30 min to attain quasi-steady state before observation is started. To assure the accurate observation, ensure all the connection are to be tight including the connection of the temperature indicator cum controller, digital solar power meter, digital anemometer and manual tracking mechanism of the parabolic trough. The HWRT was located just above the collector level to ensure the natural flow also, even though circulation pump connected. As water in the absorber tube, which is placed at the focal axis of the trough get heated by solar radiation. The heated water flows to the tank and replaced by separate cold water circulation line. When the water obtains heated flows through collector receiver, its density will decrease and light density water will move up and stored in the HWRT. Water from bottom of the tank again enters the receiver with the help of circulation pump. The experiment has been performed for 8 hours over a day from 9.00 a.m to 16.00 p.m. While performing experiments, the PTSC receiver has been oriented with its focal axis pointed towards the north-south horizontal position. Manual tracking was provided and rotated about a horizontal axis and adjusted manually so that solar beam makes a minimum angle of incidence with collector plane at all times.

RESULT AND DISCUSSION

Fig. 2 shows the variation of ambient temperature for the test period of three days. 30°C-34.2°C are recorded as minimum and maximum ambient temperature. Fig. 3 interprets the variation of inlet temperature for the test time. It is observed that the variation of inlet temperature avails in the range of 29°C-33.23°C. This maximum inlet temperature is recorded on the second day of the test period. Fig. 4 shows the maximum outlet temperature of 70°C at 14.00pm of the third day. The Increase or decrease of outlet temperature mainly depends on solar radiation intensity and absorber temperature. The maximum and minimum outlet temperature recorded was 70°C-34°C. Fig. 5 indicates the temperature difference between the outlet and inlet fluid, 6.66°C and 24°C as minimum and maximum range. Fig. 6 explore the variation of absorber temperature for 24 hours of test time. When the receiver is open to the atmosphere there are heavier convective heat losses takes place from the receiver. Receiver temperature is the average of three indicated values over the length not over the time. This temperature is measured at three locations over the length of the receiver. The absorber temperature is in the range of 78°C-145°C. Fig. 7 shows the beam radiation recorded as per the test schedule. The beam radiation for the whole test period is measured using a solar power meter. Recorded beam radiation is in the range of 400-800 W/m^2.

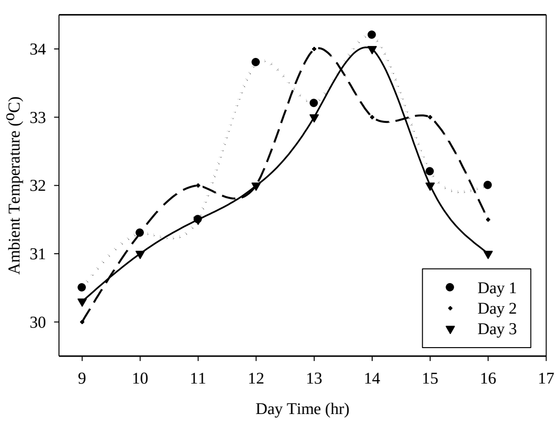


Fig. 2. Variation of Ambient temperature with time

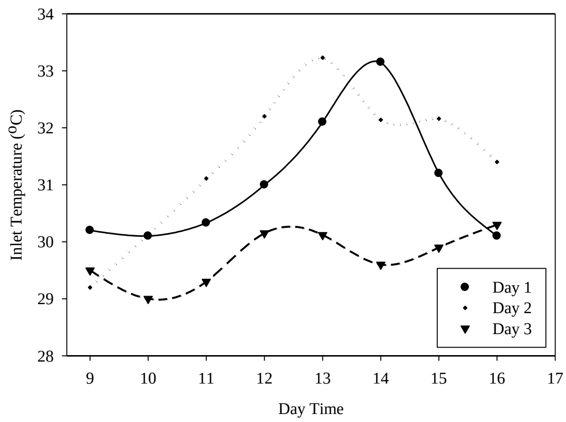


Fig. 3. Trends of inlet temperature with time

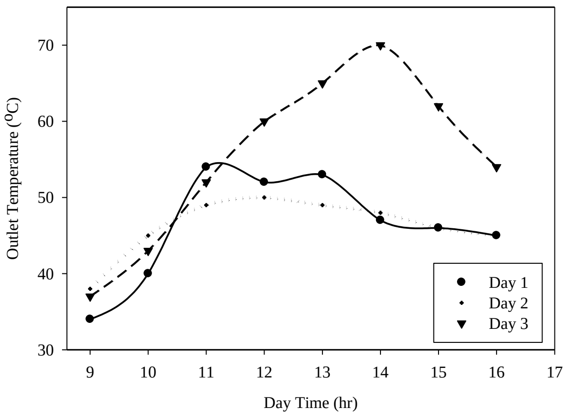


Fig. 4. Outlet temperature vs test period

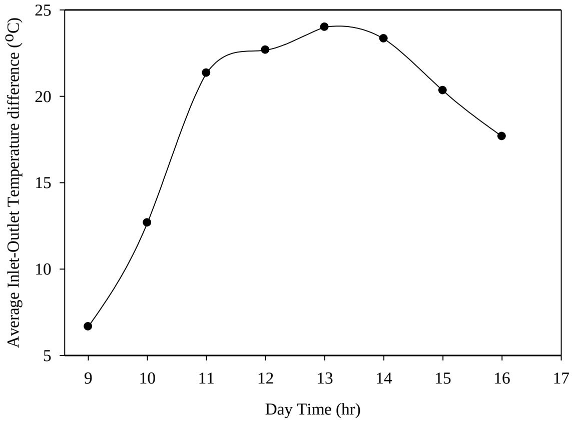
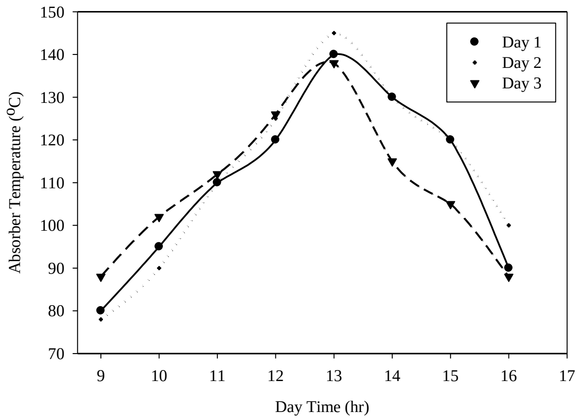


Fig. 5. Average of I/O temperature difference



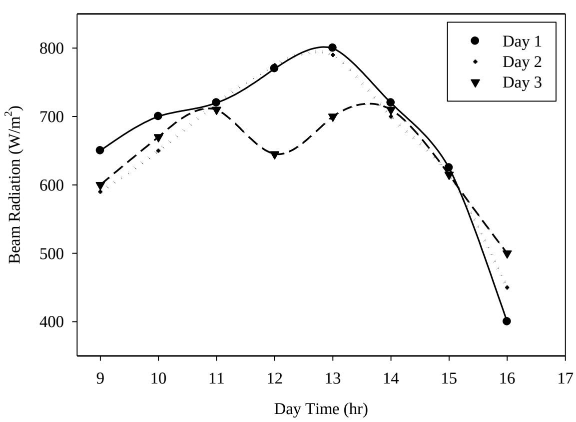
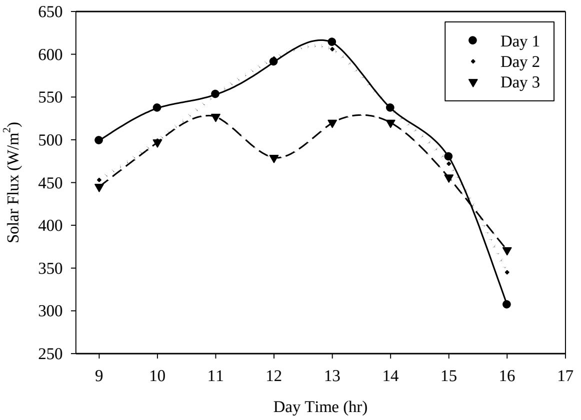


Fig. 6. Availability of Absorber temperature with time

Fig. 7. Status of Beam radiation with time



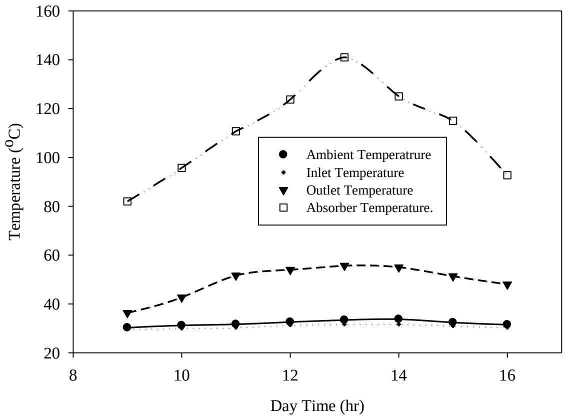


Fig. 8. Changes of solar flux with time

Fig. 9. Variation of different temperature with time

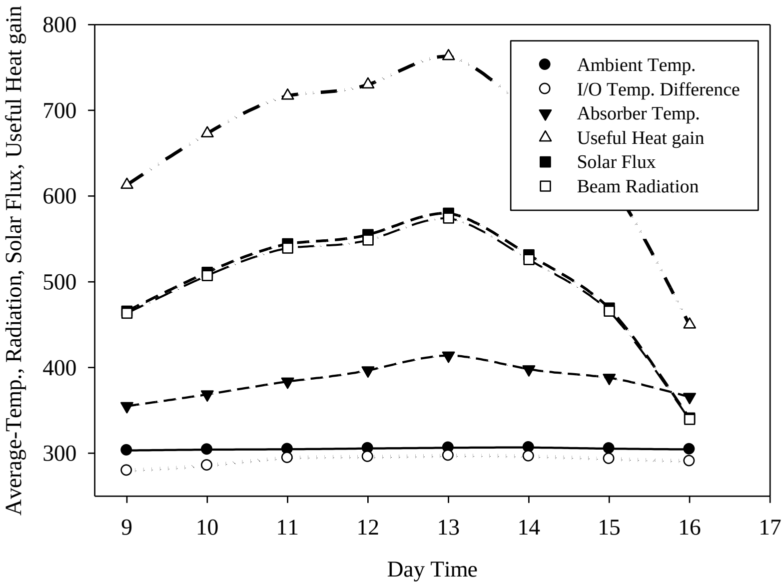


Fig. 10. Parameter variation - temperature (ambient, absorber, difference in Inlet-Outlet), Useful heat gain, Solar flux, Beam radiation (hourly average of 3 days) with time

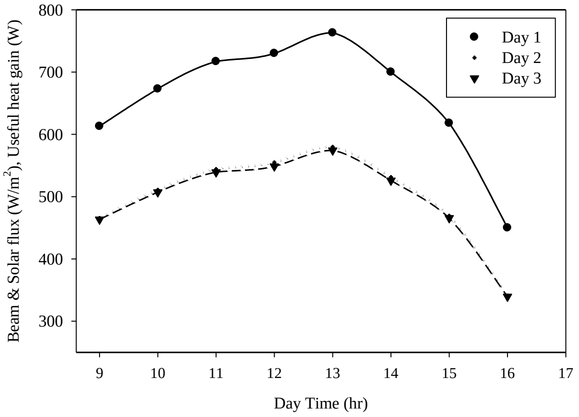


Fig. 11. Average of Beam, Solar and Useful heat gain

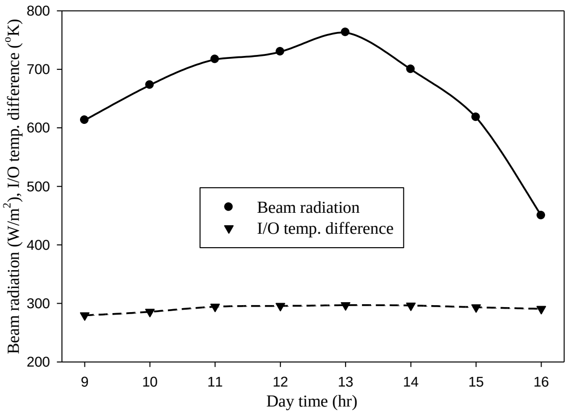


Fig. 12. Average of Beam and difference in I/O temp.

The trend explains that as solar radiation increases up to 13.00 hours and reaches the maximum of 800 W/m^2 and then gradually decreases up to 400 W/m^2 at 16.00 hours for the test day 1. Fig. 8 indicates the solar flux variation for the test period. The solar flux range is between 307-614 W/m^2. Both the beam radiation and solar flux are varied throughout the day. Beam radiation available at the earth depends mainly on the environment conditions. But solar flux depends not only on beam radiation also tilt factor, concentrator reflectivity, an absorbance of the receiver, inner diameter, outer diameter and width of the receiver. The ratio of collector aperture and absorber is known as concentration ratio which is the effective tool in the way of enhancing the collector efficiency. This will probably increase the absorber temperature and useful heat gain parallel to the solar radiation. It is clear that the receiver temperature is increased with increasing solar radiation. It also indicates the useful heat gained by the water, flowing through the receiver throughout the day. The gaining of heat is affected by the various factors, such as receiver temperature, solar radiation, and wind speed. Fig. 9 indicates hourly averages of ambient temperature, inlet-outlet temperature difference, absorber temperature, and beam radiation. This gives the relationship between various abovesaid parameters on hourly as well as a daily basis. Fig.10 shows the bonding across various temperatures, beam radiation, solar flux, and useful heat gain. It is observed that wind velocity having the influence on outlet temperature quantity. Due to the air velocity, it captures the considerable amount of heat, in turn, the absorber temperature is reduced. The heat loss due to this air velocity is known as wind loss coefficient. Fig. 11 and 12 provide the data observed in terms of beam radiation, solar flux, useful heat gain and the outlet temperature of the fluid. Especially the fig.12 shows the graphical representation of initial input (beam radiation) and final output (outlet temperature of the fluid).

CONCLUSION

In the present work, the experimental investigation is carried out on parabolic trough solar collector hot water generation system over three full days in the summer period. This system is operated in closed loop mode by the way of circulating the water through hot water reservoir tank. For the maximum outlet and inlet temperature difference of 24°C, the various quantities recorded are, beam radiation (763 W/m^2), solar flux (580 W/m^2), and useful heat gain (574.17 W/m^2). The useful heat gain, inlet temperature, outlet temperature, solar flux, and the efficiency of the system as a whole are evaluated an hourly basis. All these parameters are strongly influenced by the incident beam radiation and found to accompany its variation. The maximum value of each of these parameters is recorded around noon when incident beam radiation is at its peak.

NOMENCLATURES

PTC	: Parabolic Trough Collector
PTSC	: Parabolic Trough Solar Collector
ARER	: PTAlternative and Renewable Energy Research
HWST	: Hot Water Resevoir Tank
ETSC	: Evacuated Tube Solar Collector

REFERENCES

1. G.C.Manna. 2017. Energy status 2017, central statistics office, Ministry of statistics and programme implementation, office of India.
2. Rajeev Ranjan. and Jyothi Arora. 2016. Power for all - Tamilnadu, a joint initiates of Government of India and Government of Tamilnadu.
3. Savita lolla., Somnath Baidya Roy. and Souranghu Choudury. 2015. Wind and solar energy resources in India, Energy Procedia 76: 187-192
4. Vikas Khare., Savita Nema. and Prashant Baredar. 2013. Status of solar, wind renewable energy in India, Renewable and Sustainable Energy Reviews, 27: 1-10
5. Sharma, N.K., Tiwari, P.K. and Sood, Y.R. 2012. Solar energy in India: Strategies, policies, perspectives and future potential, Renewable and Sustainable Energy Reviews, 16: 933-941
6. Jeslin Drusila Nesamalar, J., Venkatesh, P. and Charles Raja, S. 2017. The drive of renewable energy in Tamilnadu: Status, barriers and future prospect, Renewable and Sustainable Energy Reviews, 73: 115-124
7. Lippke, F. 1996. Direct steam generation in parabolic trough solar power plants: Numerical investigation of the Transients and the Control of a Once-trough system, Journal of Solar Energy Engineering, (118): 9-14
8. May, E.K. and Murphy, L.M. 1983. Performance benefits of the direct generation of steam in line focus solar collector, Journal of Solar Energy Engineering, 105: 126-133
9. Kalogirou, S. and Lloyd, S. 1992. Use of solar parabolic trough collectors for hot water production in Cyprus-A feasibility study, Renewable Energy, 2: 117-124
10. Kalogirou, S., Lloyd, S., Ward, J. and Eleftheriou, P. 1994. Design and performance characteristics of a parabolic-trough solar-collector system, Applied Energy, 47: 341-354
11. Kalogirou. 2004. Solar thermal collectors and applications, Progress in Energy and Combustion Science, 30: 231–295
12. Dhafer Manea, H. and Al-Shamkhi. 2016. Experimental study of the performance of low cost solar water heater in Najaf city, International Journal of Mechanical & Mechatronics Engineering, 16(1): 109-121
13. Rhushi Prasad, P., Byregowda, H.V. and Gangavati. P.B. 2010. Experiment analysis of flat plate collector and comparison of performance with tracking collector, European Journal of Scientific Research, 40(1): 144 -155
14. Thomas, A. and Guven, H.M. 1993. Parabolic trough concentrators-Design, construction and evaluation, Energy conservation and management, 34(5): 401-416
15. Omid Karimi Sadaghiyani, Mohammad Bagher Sadeghi Azad, Sharam Khalilaria. and Iraj Mirzaee. 2014. Two New Designs of Parabolic Solar Collectors, Thermal Science, 18(2): 323-334
16. Eckhard Lüpfert, Klaus Pottler, Steffen Ulmer, Klaus Riffelmann, Andreas Neumann. and Björn Schiricke. 2007. Parabolic trough optical performance analysis technique, Journal Solar Energy Engineering, 129: 147-152
17. Tzivanidis, C., Bellos, E., Korres, D., Antonopoulos, K.A. and Mitsopoulos, G. 2015. Thermal and optical efficiency investigation of a parabolic trough collector - Case Studies in Thermal Engineering 6: 226–237
18. Govindaraj Kumaresan, Rahulram Sridhar. And Ramalingom Velraj. 2012. Performance studies of a solar parabolic trough collector with a thermal energy storage system, Energy, 47: 395-402
19. Rosado Haua, N. and Escalante Soberanis, N.A. 2011. Efficiency of a parabolic trough collector as a water heater system in Yucatan, Mexico, Journal of Renewable and Sustainable Energy, 3: 063108
20. Salgado Conrado, L., Salgado Conrado, A.N., Rodriguez Pulido, B.G. and Calderón, A. 2017. Thermal performance of Parabolic Trough Solar collectors, Renewable and Sustainable Energy Reviews, 67: 345–1359
21. Cohen, G. and Kearney, D. 1994. Improved parabolic trough solar electric system based on the SEGS experience, Proceedings-ASES Annual Conference USA, Solar 94: 147-150
22. Valan Arasu, A. and Sornakumar, T. 2006. Performance characteristics of parabolic trough solar collector system for hot water generation, International Energy Journal, 7(2): 137-145
23. Kalogirou, S., Lloyd, S., Ward, J. and Eleftheriou, P. 1994. Low-cost high accuracy parabolic troughs construction and evaluation, Renewable Energy, 5(4): 384-386
24. Arasu, A.V. and Kumar T.S. 2005. Design and simulation analysis of a parabolic trough solar collector hot water generation system, International Energy Journal, 7(2): 13-25
25. Arasu A.V. and Kumar, T.S. 2007. Design, manufacture and testing of fiberglass reinforced parabola trough for parabolic trough solar collectors, Solar Energy, 81(10): 1273-1279

26. Martinez, I., Almanza, R., Mazari, M. and Correa, G. 2000. Parabolic trough reflector manufactured with aluminum first surface mirrors thermally sagged, Solar Energy Materials and Solar Cell, 64(1): 85-96

27. Thomas, A. 1994. Simple structure for parabolic trough concentrator," Energy Conversion Management, 35(7): 569-573

28. Kalogirou, S. 1996. Parabolic trough collector system for low-temperature steam generation: Design and performance characteristics, Applied Energy, 55(1): 1-19

29. Thomas, A. and Guven, H.M. 1983. Parabolic trough concentrators-design, construction and evaluation, Energy Conversion Management, 34(5): 401-416

30. Gong, G., Huang, X. and Wang Hao, M. 2010. An optimized model and rest of the China's first high temperature parabolic trough solar receiver, Solar Energy, 84(12): 2230-2245

31. Skeiker, K. 2009. Optimum tilt angle and orientation for solar collectors in Syria, Energy Conversion Management, 50(9): 2439-2448

32. Hachicha. and Rodriquez. 2013. Heat transfer analysis and numerical simulation of a parabolic solar collector, Applied Energy, 111: 581–592

33. Changfu you. 2013. Modeling of fluid flow and heat transfer in trough solar collector Applied, Thermal Engineering 54: 247-254

34. Zhiyong Wu. 2014 Three-dimensional numerical study of heat transfer characteristics of parabolic trough receiver, Applied Energy, 113: 902–911

35. Men Wirz. and Mathew Roesle. 2012. Three dimensional optical and thermal Numerical model of solar tubular receiver in parabolic trough concentrators. Journal of Solar Energy Engineering, 134

36. Duffie, J.A. and Beckman, W.A. 1991. Solar energy of thermal process, John Wiley and Sons, New York, USA.

37. Sukhatme, S.P. 1999. Solar energy principles of thermal collection and storage, Tata Mc Grow Hill Publishing Company, New Delhi

38. Tooraj, Y., Farzad, V., Shojaeizaden. and Sirus Zinadini. 2012. An experimental investigation on the effect of Al_2O_3-H_2O nanofluid on the efficiency of flat plate collectors, Renewable Energy, 39: 293-398