Performance analysis of Parabolic Trough Collector using TRNSYS® - A case study in Indian coastal region

Y Krishna¹,4, M Faizal², R Saidur³, P P Manihalla⁴ and S Karinka⁵

¹Taylor’s University, School of Computer science and Engineering, Jalan Taylors, 47500 Subang Jaya, Selangor, Malaysia.
²Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
³Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Science and Technology, Sunway University, No. 5, Jalan Universiti, Bandar Sunway, Petaling Jaya 47500, Selangor Darul Ehsan, Malaysia.
⁴P A College of Engineering, Nadupadav, Mangalore, Karnataka, India 574153.
⁵NMAM Institute of Technology, Nitte, Udupi District, Karnataka, India 574110.

E-mail: yathinkrishna3030@gmail.com

Abstract: A solar water heating system incorporating parabolic trough collector (PTC) with Phase change material (PCM) is simulated using TRNSYS® software. The simulation is carried out to predict the hot water availability during the peak hot water demands of the morning and evening hours. Lauric acid (LA) is used as the primary heat transfer fluid (HTF) to extract the sun’s energy in PTC whereas, water is used as the secondary heat transfer fluid to extract heat from the primary heat transfer fluid. The study models a medium temperature, concentrating parabolic trough collector without any solar tracking components. TRNSYS® simulation components have been studied completely using Type 1245 parabolic trough collector with Type 533 horizontal storage tank with heat exchangers, which fulfils daily hot water demands of domestic and industrial applications. The storage tank is vertically stratified to regulate the temperature of HTF coming out of the collector. The results showed that LA having a thermal conductivity of 0.975 KJ/hr-mK provides a peak energy gain of 18500 KJ/hr in February and 5000 KJ/hr in July along with a 100°C rise in temperature for the city of Mangalore, India. The weather condition of the city provides an average annual collector efficiency of 26%.

1. INTRODUCTION

The global energy demand is continuously rising due to the growth in technology, increase in population, and a modern lifestyle. Fossil fuels are continuously depleting for the past five decades and in turn, polluting the natural environment by the emission of CO2 and other harmful gases [1]. Therefore, researchers and scientists are working hard in the field of renewable energy on exploring new and renewable energy sources [2-9]. Among renewable energy, solar energy is abundantly available across the globe. Solar energy is a more convincing alternative energy source because of its sustainability and environmental friendliness. With a 10% efficient solar energy conversion system, if 0.1% of the solar energy is harnessed i.e. 1.08 ×1014 kW of energy, 3 TW of energy can be obtained, which is fourfold of global installed capacity [10].

Due to the limited resources of fossil fuels and increasing awareness of environmental pollution and
damage, solar energy is expected to play an important role in the fulfillment of world energy demand [11, 12]. The drawback of effective utilization of solar energy is the availability of the sun’s radiation on a seasonal and daily basis throughout the year. Also, sometimes the direct beam radiation may not reach the earth’s surface due to the presence of clouds. This sporadic nature of solar energy has made its usage in the commercial and domestic sectors less effective, especially in the standalone systems and solar domestic hot water supply (SDHWS) [13]. Solar water heating system faces similar issues while delivering hot water during late night and in the early morning when the demand for hot water is at its peak.

Solar energy is broadly classified into solar PV and solar thermal energy. The solar thermal energy conversion system is further classified into flat plate collector, evacuated tube collector, parabolic troughs collector (PTC), linear Fresnel lenses, solar dish collector, and solar power tower systems [5]. PTC consists of a reflective concentrator that is placed behind an evacuated tube absorber through which the HTF is made to flow. The sun’s radiation gets concentrated on the absorber and heats the HTF flowing inside it [14]. The hot HTF is made to exchange heat with cold water for domestic or industrial usage. Jean et al. experimentally investigated the feasibility of using PTC as micro combined heat and power system (micro-CHP) and obtained conversion efficiency up to 38% for 19kW thermal power output [15]. Onder et al. designed and analyzed the PTC system for generating hot water for an ice-cream factory and found an energy savings of 98.56% by replacing a conventional heating system. The payback period of the system is found to be 8.6 years [16]. Boukelia et al. compared and investigated the energy-environmental-exergy-economic analysis of parabolic trough collectors with and without PCM storage. Therminol VP-1 and molten salt are utilized for this study. The PTC-PCM system was also integrated with fossil fuel for energy backup. The results showed that the configuration based on molten salt HTF with energy storage was better in terms of economic and environmental friendliness [17]. Hang et al. investigated the performance of medium temperature PTC with a length of 4.2m and aperture area of 6.72m2 and concluded that shading effect, cosine effect, incidence angle modifier (IAM) and end losses require substantial attention during the design of PTC. The experimental results obtained a peak efficiency of 72% [18]. Fuwang et al. simulated the performance of PTC using TRNSYS® for hot water supply and space heating for the winter season in Tianjin University, China. The results of the simulation showed that solar radiation plays a significant role in providing the ratio of useful energy by PTC. The results also showed the higher instantaneous solar fraction and lower average solar fraction during the sunshine hours indicating the requirement of thermal storage to enhance the system performance [19]. Monica et al. coupled PTC to an organic Rankine cycle to directly utilize the useful energy to charge the thermal storage and to feed the power block. TRNSYS® simulation was carried out to emulate the system and results showed that the system is a promising alternative for a low-temperature industrial process where heat generation and electricity are primary requirements [20].

Mangalore is a port city with a maximum number of residential apartments in the state of Karnataka, India. A solar water heating system is the most suitable way to save energy in residential apartments. In the present study, to overcome the challenges in SDHWS for apartments in the city of Mangalore, a parabolic trough collector is simulated using LA PCM as HTF and storage material, using TRNSYS® software. This primary HTF exchanges the heat with cold water which is a secondary HTF. The secondary HTF extracts the heat and delivers it to the end-user load at the setpoint temperature. The objective of the study is to determine the feasibility of PTC to deliver hot water at desired temperature during the late-nights and early morning hours. The study is made to deliver SDHW at 45°C for a community apartment with a dwelling of 100 people.

2. METHODOLOGY

India has a great potential for solar energy production because it has about 300 to 350 days of sunshine and an average of 1500 to 2000 sunshine hours which depends on the location [21]. In this investigation, Mangalore is chosen as the location for the simulation which is located at the latitude of 12.9141° N, longitude 74.8560° E, and an altitude of 22m above mean sea level. Mangalore is a port
city with an average of 2500 sunshine hours with January as the most and July as the least sunshine hours [22]. The process of designing a theoretical model and optimizing it requires interpolation with quite a number of iterations. A detailed parameter setting is necessary for practical models. Sometimes it is challenging to create an actual setup in the laboratory due to extreme run time, socio-financial issues, and trade off. Therefore, simulation modelling tools are used to design and simulate the behavior of practical systems [23]. The meteorological data of Mangalore is loaded as TM3 (Typical Meteorological Year 3) external data file to replicate the weather condition in TRNSYS®. The external weather data file is obtained from meteonome data which is shown in Figure 1. The inclination of the plane is set to the latitude of the region which is the optimal tilt angle for the region [24].

2.1. TRNSYS® simulation model
The TRNSYS® simulation model consists of two thermal loops. The first loop consists of PTC, HTF pump, PCM storage tank with heat exchanger, and a differential controller to turn the pump on and off. The second loop consists of water draw forcing function to imitate water draw profile, heat exchanger coils, flow diverter, and a temperature-controlled flow diverter to set the outlet temperature. The first loop extracts the sun’s energy using PTC and stores the energy in the LA PCM storage tank. The second loop extracts the stored energy, heats the water, and delivers to the outlet. System components in TRNSYS® environment are shown in Figure 2. The detailed description of the components is presented as follows.

Figure 1. Meteorological data of Mangalore. (a) Radiation data, (b) Global radiation data, (c) Sunshine hour data, (d) Daily temperature data [22].
2.1.1. Parabolic Trough collector

Parabolic Trough Collector (Type 1245) is selected in this simulation from the standard TESS solar thermal collector library. The type 1245 PTC is a medium temperature concentrated PTC without sun tracking parameters. It has an external reflective concentrator placed behind an evacuated glass tube that contains the absorber and HTF. The end-user has an option to control the HTF flow rate through the collector to maintain outlet temperature. The collector array consists of a concentrator connected in series or parallel, in the current simulation a single PTC is connected to the storage tank [14]. The collector efficiency is obtained from Hottel-Whillier steady-state condition equation, and reduced to equation (1) and equation (2) as follows[25]:

\[
\eta = a_0 - a_1 \frac{\Delta T}{I_T} - a_2 \left( \frac{\Delta T}{I_T} \right)^2 
\]

(1)

\[
\eta = \frac{Q_{\text{useful}}}{A_a I_T} 
\]

(2)

Equation (1) is the general collector efficiency equation where, \(a_0\), \(a_1\), and \(a_2\) are thermal efficiency parameters which are available for solar collectors according to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards and rated by Solar Rating & Certification Corporation (SRCC) [14]. The technical details of the PTC input to the simulation are presented in Table 1. The useful energy gain, \(Q_{\text{useful}}\), of the collector is obtained using equation (2), where ‘\(A_a\)’ is the area of the collector in m\(^2\) and ‘\(I_T\)’ is incident beam radiation in W/m\(^2\).

### Table 1. Specification of PTC

| Parameter                          | Specification of the component |
|------------------------------------|-------------------------------|
| Number in series                   | 1                             |
| Number of parallel flow loops      | 1                             |
| Total aperture area                | 46.5 m\(^2\)                  |
| Concentration ratio                | 18.9                           |
Two system components are used to pump HTF and draw water in the current simulation. Type 110 variable speed pump is used to pump liquid PCM to the collector. Type 14b water draw forcing function is used to draw fresh cold water into the heat exchanger inside the storage tank. The PCM flow rate is set to 500 kg/hr to maintain the outlet temperature of the HTF well below the degradation temperature of Lauric acid [3]. The differential controller controls the flow rate of the variable speed pump. The pump is turned ON only when there is a 20°C difference between the inlet and outlet temperature of PTC.

The hot water draw profile is set to 100 kg/hr for three times a day as shown in Figure 3 according to the Indian standard of individual bathing water requirement for residential buildings [26]. Depending upon the bathing requirements in Indian cities the hot water draw is set to ON with the flow rate of 100 kg/hr during the morning, afternoon, and evening hours.

![Figure 3. Water Draw load profile using forcing function in Type 14b component.](image)

2.1.3. Tempering valve and Tee piece connector

To deliver hot water to the end-user, tempering valve and flow mixer are used. The tempering valve is a temperature-controlled flow diverter (Type 11b). The hot water load will flow through the temperature-controlled flow diverter and depending on the temperature of the cold water coming in and hot water coming out of the top of the tank, it diverts the flow to either mix with the hot water load or replace the water at the bottom of the tank. The tee piece connector is a flow mixer to mix hot and cold water to deliver the preset hot water to the hot shower outlet. The working of the tempering valve is shown in Figure 4. “\( m_{\text{mix1}} \)” is the mass flow rate of cold water which is set up by the user in the water draw load profile which is represented as “Make-up” in the figure. It gets divided into “\( m_{\text{mix1}} \)” and “\( m_{\text{mix2}} \)” flow rate to the storage tank and mixer respectively. In the mixer, “\( m_{\text{mix2}} \)” mixes with hot water coming out of the tank to deliver the desired temperature to the load with the same flow rate as to make up inlet. The control signal of the tempering valve operates on the following conditions as in equation (3) to get the set temperature output [27].

For \( T_i = T_o \)

\[
\gamma = \frac{(T_{\text{set}} - T_o)}{(T_h - T_i)}, \text{ if } T_i > T_{\text{set}}
\]
2.1.4. Weather data processor
The metrological data file is loaded from the weather data reader and processor unit (Type 15), built-in meteonorm files with the extension .tm3 [14]. The weather data is provided to other TRNSYS® components at the time pace below 60 minutes at steady time gaps, with the help of a weather data processor. The ambient temperature and beam radiation data for the Mangalore region are presented in Figure 5 for February, Figure 6 for July, and Figure 7 for December. The simulation is carried out for February, July, and December because these three seasons resemble three different climatic conditions of the region (Figure 1c). February 1 to 28 is depicted as hot weather data, July 1-31 is shown as rainy season data and December 1-31 is read as cold-weather data.
2.1.5. PCM horizontal storage tank with internal heat exchanger

The storage tank component (Type 533) is a constant volume horizontal cylindrical storage tank, consisting of immersed heat exchangers filled with energy storage fluid. The tank is filled with LA PCM material which interacts with water flowing in heat exchanger coils. The tank is stratified into isothermal temperature nodes where the end-user controls the degree of stratification at each node. The component provides the user to use three different types of heat exchangers i.e. coiled type, tube type, and serpentine heat exchangers. The user defines the magnitude of flow rate, temperature, specific heat capacities, fluid density, fluid thermal expansion coefficient, thermal conductivity, and viscosity of the storage tank fluid and heat exchanger fluid. The LMTD (Log Mean Temperature Difference) of heat exchangers are calculated iteratively. The natural convection co-efficient $h_o$ is calculated using equation (4) [14].

$$h_o = \frac{N_uD(k)}{d_o} \quad (4)$$

Where $d_o$ is the outer diameter of the heat-exchanger tube and $N_uD$ is the Nusselt number for flow around a tube with diameter $D$ and $k$ is the thermal conductivity of the HTF in W/mK [14].

2.1.6. Differential controller

The differential controller produces a control function $\gamma \gamma 0$, which may have the value of 1 or 0. The difference between the upper-temperature limit (Th) and lower temperature limit (Tl) compared with temperature difference dead bands ($\Delta TT_h \ aaaaaa \Delta TT_l$) determines the value of $\gamma \gamma 0$. The control signal during the previous time step (on/off) determines the new value of $\gamma \gamma 0$. The value is set to zero if the condition exceeds the upper set limit. Mathematically, the expression of the control function is shown in equation (5) to (8): If the previous condition is ON ($\gamma \gamma_i = 1$):

$$\text{if } \Delta TT\leq (TT_h-TT_l) \text{ then } \gamma \gamma 0=1 \quad (5)$$

$$\text{if } \Delta TT> (TT_h-TT_l) \text{ then } \gamma \gamma 0=0 \quad (6)$$

If previous condition is OFF ($\gamma \gamma_i = 1$):

$$\text{if } \Delta TT\leq (TT_h-TT_l) \text{ then } \gamma \gamma 0=1 \quad (7)$$

$$\text{if } \Delta TT> (TT_h-TT_l) \text{ then } \gamma \gamma 0=0 \quad (8)$$

Where $C_p$ is the specific heat capacity of liquid LA, $CC_{\gamma^w}$ is the specific heat capacity of the ideal gas, R is the value of universal gas constant, w is the acentric factor, and $T_r$ is the reduced temperature. The $w$ value is taken as 0.8422 for LA. The values of the specific heat of LA obtained by the Rowlinson-Bondi equation are presented in Table 2.
Table 2. Comparison of standard specific heat capacity of LA with specific heat capacity obtained by Rowlinson-Bondi equation

| Temperature (°C) | Standard Cp at 25 °C (J/gK)[29] | Rowlinson-Bondi correlation value (J/gK) [28] | Error % |
|------------------|----------------------------------|-----------------------------------------------|---------|
| 5                | 1.901                            | 2.091                                         | 10      |
| 25               | 2.019                            | 2.727                                         | 25      |
| 27               | 2.141                            | 2.462                                         | 15      |

The specific heat values are obtained for higher values of reduced temperature using the Rowlinson-Bondi correlation and plotted as the function of temperature. The equation of the curve is obtained by the polynomial curve fitting method which is shown in Figure 8. The polynomial curve equation is utilized to run the transient simulation in TRNSYS® environment.

![Figure 8. Variation of specific heat capacity of LA as the function of Temperature, and polynomial fitting of obtained specific heat curve.](image)

3. TRNSYS® SIMULATION PROCESS

To witness the effect of HTF on domestic hot water loop with Parabolic trough collector, thermal properties of LA are loaded in the primary loop, and thermal properties of water are loaded to the secondary loop in TRNSYS®. The input and output for different components used in the simulation are shown in Table 3.

Table 3. Details of parameters used for TRNSYS® components

| Inputs to the components       | Outputs of the components                   |
|--------------------------------|---------------------------------------------|
| **Parabolic trough collector** |                                             |
| Inlet temperature °C           | Outlet temperature °C                       |
| Inlet flow rate (kg/hr)        | Outlet flow rate Kg/hr                      |
| Ambient temperature °C         | Useful energy gain (kJ/hr)                  |
| Incident radiation (kJ.hr.m²)  |                                             |
| **Storage Tank**               |                                             |
| Inlet temperature for the port °C | Temperature at outlet °C            |
| Inlet flow rate for Port (kg/hr) | Flowrate at outlet (kg/hr)              |
| Inlet temperature for heat exchanger °C | Heat exchanger outlet flow rate (kg/hr) |
| Inlet flowrate for heat exchanger (kg/hr) | Temperature at heat exchange outlet °C |
| **Pump**                       |                                             |
| Inlet fluid temperature °C     | Outlet fluid temperature °C                |
| Inlet mass flow rate (kg/hr)   | Outlet mass flow rate (kg/hr.)              |
4. RESULTS AND DISCUSSION

The current simulation on SDHW fulfillment is investigated for the city of Mangalore. The simulation is carried out for February, July, and December months. PTC inlet temperature, outlet temperature, the mass flow rate of the LA, and beam radiation data for February, July, and December are presented in Figure 9, Figure 10, and Figure 11 respectively. The outlet temperature of PTC is well below the degradation temperature of LA which is 250°C, meanwhile, the inlet temperature is above 34°C which is above the phase change temperature of LA[3]. The mass flow rate of HTF is turned ON only when there is a 20°C difference between the inlet and outlet temperature of PTC which is realized in the mass flow rate curves in the graph.

Figure 9. The graph shows the inlet and outlet temperature of HTF, Beam radiation, and HTF mass flow rate for February.

Figure 10. The graph shows the inlet and outlet temperature of HTF, Beam radiation, and HTF mass flow rate for July.

Figure 11. The graph shows the inlet and outlet temperature of HTF, Beam radiation, and HTF mass flow rate for December.
Plots of solar radiation data and useful energy gain is shown in Figure 12, Figure 13, and Figure 14. The useful energy gain for February and December are 18662 kJ/hr and 16000 kJ/hr. However, the useful energy gain for July is 5145 kJ/hr which is lower compared to the other two months. The values of energy gain for these three months can be justified with the radiation value of 1022 W/m², 519 W/m², and 938 W/m² for February, July, and December respectively. The current simulation assumes a constant optical efficiency value for the PTC. Therefore, when the loss of heat in the absorber tube is higher, the efficiency drops resulting in the drop in energy gain. The monthly efficiency of the collector is shown in Figure 15. From the graph we can infer that July, August, and September has higher efficiency compared to other months, because of the lower ambient temperature during those months. The lower ambient temperature reduces the inlet temperature of PTC resulting in higher temperature difference and hence increasing the thermal efficiency of the collector. The weather condition of the city provides an average efficiency of 26% annually.

The temperature of water from the heat exchanger outlet is more than 150°C, to deliver the hot water to the load at 45°C tempering valve and the Tee piece connector is used. Depending upon the temperature of the water draw and outlet temperature of the heat exchanger, flow is mixed, and the desired temperature of the water is delivered. Figure 16 shows the hot water profile for the representative days in February, July, and December. From the graph we can infer that PTC with the concentration ratio of 18.9 and aperture area of 46.5 m² and PCM storage of 1 m³ can provide hot water in the early morning hours, in the afternoon, and also for late-night demands for critical climatic condition, making PTC feasible, by considering thermal parameters.
5. CONCLUSION

In this paper fulfillment of SDHW for the residential apartment is simulated using TRNSYS® software. Type 1245 PTC component with Type 533 horizontal thermal storage tank with heat exchanger is used to store heat using PCM material. LA thermal properties are used to simulate HTF in PTC and storage tank. Water is made to exchange heat with PCM inside the tank to fulfill hot water
demand. Meteorological data in the present simulation is set for the city of Mangalore, India. The simulation results are obtained for February, July, and December as these months represent the climatic conditions of the other nine months of the year. Results are obtained for representative solar days to reduce the number of iteration and predict results for the entire month. The region experiences lower beam radiation intensity during July and hence the outlet temperature of PTC is lower compared to the other two months. However, the efficiency of the collector is higher during July as the ambient temperature of the region is lower during July, increasing the temperature difference across the collector. From this, we can infer that the lower the temperature at the inlet, higher the thermal efficiency. Since the current system is utilized for residential SDHW fulfillment, multiple heat exchangers are not feasible to lower the inlet temperature of PTC. Results show that due to the usage of PCM for storage, it is possible to deliver hot water even during the morning hours and late-night which is a challenge in other solar water heaters in residential buildings. Therefore, we can conclude that PTC with PCM storage is feasible for residential buildings with a higher number of dwellings.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support provided by Sunway University through the project no# STR-RCTR-RCNMET-001-2019. This work was also supported by Taylor’s University through its TAYLOR’S RESEARCH SCHOLARSHIP Programme”

CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

[1] Abas N and Khan N 2014 Carbon conundrum, climate change, CO2 capture and consumptions Journal of CO2 Utilization 8 39-48
[2] Chen K, Ren Z, Mu S, Sun T Q and Mu R 2020 Integrating the Delphi survey into scenario planning for China's renewable energy development strategy towards 2030 Technological Forecasting and Social Change 158 120157
[3] Krishna Y, Aslfattahi N, Saidur R, Faizal M and Ng K C 2020 Fatty acid/metal ion composite as thermal energy storage materials SN Applied Sciences 2 798
[4] Nam K, Hwabong S and Yoo C 2020 A deep learning-based forecasting model for renewable energy scenarios to guide sustainable energy policy: A case study of Korea Renewable and Sustainable Energy Reviews 122 109725
[5] Krishna Y, Faizal M, Saidur R, Ng K C and Aslfattahi N 2020 State-of-the-art heat transfer fluids for parabolic trough collector International Journal of Heat and Mass Transfer 152 119541
[6] Wang S, Huang Y, Vorushylo I, Chen H, McLarnon D, MacArtain P and Hewitt N 2020 Economic assessment of high penetration energy scenario in 2030 on the interconnected Irish power system Energy Policy 145 111774
[7] Krishna Y, K. A R R and Afzal A 2018 The CFD analysis of flat plate collector-nanofluid as working medium AIP Conference Proceedings 2039 020062
[8] Krishna Y, Saidur R, Aslfattahi N, Faizal M and Ng K C 2020 Enhancing the thermal properties of organic phase change material (palmitic acid) by doping MXene nanoflakes AIP Conference Proceedings 2233 020013
[9] Krishna Y, Saidur R, Faizal M, Aslfattahi N, Ng K, Arifutzzaman A and Karinka S 2019 Effect of Al2O3 Dispersion on Enthalpy and Thermal Stability of Ternary Nitrate Eutectic Salt International Journal of Nanoelectronics and Materials 13 75-84
[10] Panos E, Densing M and Volkart K 2016 Access to electricity in the World Energy Council's global energy scenarios: An outlook for developing regions until 2030 Energy Strategy Reviews 9 28-49
[11] Abas N, Saleem M S, Kalair E and Khan N 2019 Cooperative control of regional transboundary air pollutants Environmental Systems Research 8 10
[12] Echegaray F 2014 Understanding stakeholders' views and support for solar energy in Brazil Journal of Cleaner Production 63 125-33
[13] Sadhishkumar S and Balusamy T 2014 Performance improvement in solar water heating systems—A review Renewable and Sustainable Energy Reviews 37 191-8
[14] Specialists T T E S 2012 TESSLibs 17 Solar Library Mathematical Reference. (USA: TESS) pp 152-61
[15] Bouvier J-L, Michaux G, Salagnac P, Kientz T and Rochier D 2016 Experimental study of a micro combined heat and power system with a solar parabolic trough collector coupled to a steam Rankine cycle expander Solar Energy 134 180-92
[16] Kizilkan O, Kabul A and Dincer I 2016 Development and performance assessment of a parabolic trough solar collector-based integrated system for an ice-cream factory Energy 100 167-76
[17] Boukelia T E, Mecibah M S, Kumar B N and Reddy K S 2015 Investigation of solar parabolic trough power plants with and without integrated TES (thermal energy storage) and FBS (fuel backup system) using thermic oil and solar salt Energy 88 292-303
[18] Qu H and Wang M 2015 Experimental Study of a Parabolic Trough Medium Temperature Solar Thermal System Energy Procedia 70 504-9
[19] Wang F, Feng H, Zhao J, Li W, Zhang F and Liu R 2015 Performance Assessment of Solar Assisted Absorption Heat Pump System with Parabolic Trough Collectors Energy Procedia 70 529-36
[20] Borunda M, Jaramillo O A, Dorantes R and Reyes A 2016 Organic Rankine Cycle coupling with a Parabolic Trough Solar Power Plant for cogeneration and industrial processes Renewable Energy 86 651-63
[21] Sunwatt Soltech (P) Ltd. Sunwatt House M C-, Dr.A.S.Rao Nagar, ECIL PO, Hyderabad - 500062 Andhra Pradesh (INDIA) 2015 Why Solar? ed Sunwatt-India (India)
[22] Cilmate W 2010 Climate in Mangalore (Karnataka), India. ed W Cilmate: weather station: Mangalore, India.) pp Data from weather station: Mangalore, India.
[23] Shrivastava R L, Vinod K and Untawale S P 2017 Modeling and simulation of solar water heater: A TRNSYS perspective Renewable and Sustainable Energy Reviews 67 126-43
[24] Sukhatme S P and Nayak J 2017 Solar energy: McGraw-Hill Education
[25] Duffie J A and Beckman W A April 2013 Solar engineering of thermal processes (USA: John Wiley & Sons, Inc., Hoboken, New Jersey) standards B o I 2010 Indian Standard Code of Basic Requirements for Water Supply, Drainage and Sanitation. ed C Water Supply and Sanitation Sectional Committee (New Delhi, India: BIS)
[26] 18 T 2019 TRNSYS 18 Matheamtical Reference. (Madison, WI 53703 – U.S.A. pp 4-332
[27] Noor Azian Morad, A.A. Mustafa Kamal, F. Panau and Yew T W 2000 Liquid specific heat capacity estimation for fatty acids, triacylglycerols, and vegetable oils based on their fatty acid composition Journal of the American Oil Chemists' Society 77 1001-5
[28] Peter J.; Mallard W G NIST Chemistry WebBook, NIST Standard Reference Database Number 69, (Gaithersburg (MD): National Institute of Standards and Technology)