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Performance Evaluation of Solar Parabolic Trough

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Abstract- This paper was concerned with an experimental study of parabolic trough collector designed and manufactured. A parabolic trough solar collector uses Aluminium sheet in the shape of a parabolic cylinder to reflect and concentrate sun radiations towards an absorber tube located at the focus line of the parabolic cylinder. The receiver absorbs the incoming radiations and transforms them into thermal energy, the latter being transported and collected by a fluid medium circulating within the absorber tube.

The Designing and Fabrication of parabolic trough solar water heater for water heating was executed, the procedure employed includes design, construction and testing stages. The model which is made up of reflector surface, reflector support, absorber pipe and a stand with manual tracking arrangement was fabricated using locally sourced material for rural applications point of view. Performance evaluation of this system has been done during the months of November and December (winter season) 2014 at Chandrapur (19.95°N latitude, 79.3°E longitude).

Index Terms- absorber, parabolic trough, receiver, solar water heater

I. INTRODUCTION

Solar energy is the primary source of energy for our planet. The average solar energy reaching the earth in the tropical zone is about 1 kwh/m^2 and total radiation over a day is at best about 7 kwh/m^2. The solar constant Isc is the rate at which energy is received from the sun on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun the value of Isc is 1353 w/m^2. Increased utilization of solar energy in our country would result in all around benefits, both in terms of cleaner environment and monetary gain. The energy from the sun is used for various purposes mainly as power generation known as solar electricity generation system and industrial process heat applications [1].

The energy consumption in residential sector is substantial as it accounts for approximately one-third of overall delivered-energy use and carbon dioxide emissions of this delivered-energy use, approximately a quarter is for water heating. Water heating is generally provided by burning non-commercial fuels, namely-firewood as in rural areas and for this application rural peoples are cutting trees to partial fulfillment of their daily energy requirements, this creates depletion of forests and thus it effect on climate change and commercial fuels such as kerosene oil, liquefied petroleum gas (LPG), coal; through either their direct combustion or through the use of electricity in urban areas [2], this uses of fossil fuels create air pollution and as the costs of natural resource depletion. In our country use of solar trough is mainly for power generation, industrial process heat applications, and for this applications development of a commercial industry to produce and market these solar trough systems but now it’s time to come use of solar trough for domestic applications and manufactured it by using locally available material.

In the present work, new parabolic trough collector system with manual tracking system which has been developed for hot water generation, Fabrication and design of a solar parabolic trough is done using locally available materials. The great advantage of solar trough is that it is clean, cheaper and can be supplied thermal energy without any environmental pollution. It there by directly substitutes renewable energy for fossil-fuels, non-commercial fuel namely- firewood and also helps to cut utility electricity bills. At rural level and remote areas this system can use for hot water generation, crop drying, Laundries, in dairy, Food preparation and service facilities hence low temperature trough will be a better solar thermal device for the rural area.

Sagade et al. conducted experiment on parabolic trough made of fiberglass-reinforced plastic with its aperture area coated by aluminum foil with a reflectivity of 0.86. This line-focusing parabolic trough with mild steel receiver has been tested with and without glass cover. From Indian conditions, low-cost FRP parabolic trough system proves to be beneficial for industrial heating applications as well as domestic heating [3].

Valan Arasu and Sornakumar explained the design and manufacturing of smooth 90°-rim angle fiberglass-reinforced parabolic trough for water heating application. The total thickness of the parabolic trough is 7 mm. The concave surface where the reflector is fixed is manufactured to a high degree of surface finish. They have found that the standard deviation of the distribution of the parabolic surface errors is 0.0066 radians from the collector performance test according to ASHRAE Standard 93 (1986), which indicates the high accuracy of the parabolic surface [4].

Ruby et al. performed through the design, construction, operation, and analysis of a high temperature solar thermal system at a Frito-Lay snack food plant located in Modesto, California. 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 [5].

Ming Qu et al. developed linear tracking parabolic trough reflector focused on a surface-treated metallic pipe receiver enclosed in an evacuated transparent tube, and obtained fundamental radiative and convective heat transfer and mass and energy balance relations. The experiment is shows that when hot-water at 165°C flows through a 6m by 2.3m Parabolic Trough Solar Collector with 900 w/m^2 solar insulation and 0 incident angles, the estimated collector efficiency is about 55% [6].

Brooks, M.J et al. conducted experiment to measure and testing the performance of components of parabolic trough solar collector and development in a solar energy research programme. Low-temperature testing was performed at Mangosuthu Technikon's STAR lab facility using water as the working fluid. Both an evacuated glass shielded receiver and an unshielded receiver were tested, with which peak thermal efficiencies of 53.8% and 55.2% were obtained respectively. The glass-shielded element offered superior performance at the maximum test temperature, Experiment contain also tracking system. Pumping system provided for feed control quantity of fluid. In this study only low-temperature testing was conducted with receiver inlet temperatures from 20°C to 85°C [7].

Singh B.S.M. et al. conducted experiment of solar parabolic trough collector of equilibrium achieved between the increasing thermal losses with the increasing aperture area, and the increasing optical losses with the decreasing aperture area for the optimization of the long-term performance. Three different types working fluid is used with maximum theoretical concentration ratio are reached to 212. It is found that with increasing concentration ratio, decreasing heat removal factor and efficiency [8].

Singh S.K. et al. designed and fabricates the solar parabolic trough water heater for hot water generation. Aluminum sheet is used for making parabolic trough concentrator which is covered by a cloth on which rectangular mirror strips. Two different absorber tubes were taken and the efficiencies of the plate where compared without glass cover on the absorber tubes. The efficiencies find that when without glass cover: aluminum tube receiver: 18.23%, copper tube receiver 20.25% [9].

II. System Description

The parabolic trough solar collector uses aluminum foil sheet in the shape of a parabolic cylinder to reflect and concentrate sun radiations towards a absorber tube located at the focus line of the parabolic cylinder. The receiver absorbs the incoming radiations and transforms them into thermal energy, the latter being transported and collected by a fluid medium circulating within the absorber tube. The absorber tube is made of aluminum; tube is surrounded by a concentric glass cover. The space between the tube and the glass cover is evacuated, a vacuum can be applied in the space between the glass and the metal pipe to further minimize heat loss [10].

A schematic sketch of the test setup of the constructed parabolic trough concentrator for domestic hot water application is shown in Figures 1 The test setup It consists of a solar collector, storage tank of 40-L capacity, control valve used to regulate the flow rate through the circuit.

Figure : The parabolic trough system with storage tank

The necessary instruments are attached to the apparatus. For performance evaluation of a system, data collection is important, and for the data collection, measuring instrument is needed. The following instruments were used

1. Wind Velocity: digital anemometer
2. Temperature measurements: Digital Multimeter with thermocouple kit. (digital display)/ IR Thermometer (Make-Fluke)
3. Solar radiation: pyranometer
4. Mass flow rate: flow meter

III. Fabrication of the Parabolic Trough -

The material for the fabrication of the device was considering strength, suitability and local availability. For construction of the parabolic trough M.S.sheet is used. Aluminium sheet has been selected as material for collector. The parabolic trough was constructed by the help welding. First, the structure was made of a M.S. sheet material. The accuracy of the parabolic trough surface depends on the accuracy of the mold; On top of these parabolic forms reflector-surface Aluminum sheet was fixed with sticky materials (Fevicol-SR). The absorber tube was made of aluminium tube is surrounded by a concentric glass cover. The space between the tube and the glass cover is evacuated, a vacuum can be applied in the space between the glass and the metal pipe to further minimize heat loss and thus boost the system's efficiency. The storage tank (40 liter capacity) made up of GI sheet and the foam material is stick on the external side of the storage tank it act as insulation. The stand (trough and storage tank) was made up MS angel with the help of welding. The sun tracking arrangement was provided to the system which is manually operated.

Table 1 shows the parameters and dimensions of the terms used in the experimentation.

Parameter	Dimension
Aperture of the concentrator (W)	1.20 m
Inner diameter of absorber tube (D_i)	0.023 m
Outer diameter of absorber tube (D_o)	0.025 m
Inner diameter of glass tube	0.046 m
Outer diameter of glass tube	0.048 m
Length of parabolic trough	1.5 m
Concentration ratio	15 Collector
aperture area	1.8 m^2
Storage tank capacity	40 L
Focal distance	0.2 m
Collector orientation	- Axis in N-S direction
Mode of tracking	- E-W (Manual)
Specular reflectivity of concentrator (ρ)	0.80
Glass cover transitivity for solar radiation(τ)	0.80
Absorber tube emissivity/emissivity (α)	0.80
Emissivity of absorber tube surface (ε_p)	0.15
Emissivity of glass (ε_c)	0.82

The experiment procedure was started by flushing the system. Then, the system was filled with water and the flow rate was adjusted to the required value. And the proper working of all measuring instruments was checked, Cold water from the storage tank enters thel receiver of the parabolic trough collector. The tank was located above the level of the collector to assure the natural flow of water. As water in the receiver tube, which is located at the focal axis of the trough, is heated by solar energy, heated water flows automatically to the top of the water tank and is replaced by cold water from the bottom of the tank. When the water gets heated upon rising to the collector, its density will decrease and the lighter-density water will move up and be stored on top of the storage tank. Higher-density water from the bottom of the tank again enters the parabolic trough and gets heated and moves up and stored in the top of the storage tank. Data of all readings of ambient, fluid, receiver body, and storage tank temperatures and total solar radiations with wind speed every half an hour were collected. The experiment has been performed for 7 h over the day from 0930 hours to 1530 hours. The experiment has been continued with changing input parameters, such as mass flow rate of water.

During the experimentation, a cylindrical parabolic collector has been oriented with its focal axis pointed in the north–south (N-S) orientation so that the focal axis is inclined.(angle of inclination-30°) Sun tracking was provided to the parabolic trough collector. Manual tracking was provided to the parabolic trough collector. E-W direction. The trough was rotated manually to get a good focus on absorber tube so that solar beam makes minimum angle of incidence with the aperture plane at all times.

IV. Thermal Performance Calculations

The useful energy delivered from the concentrator can be given by Equations 1 and 2

$$q_u = mc_p(T_o - T_{in}) \tag{1}$$

$$q_u = mc_p\left[\frac{CS}{U_l} + T_a - T_{in}\right]\left[1 - \exp\left\{-\frac{F'\pi D_o U_l L}{mc_p}\right\}\right] \tag{2}$$

Where, qu is the useful energy delivered from the concentrator (W); m, mass flow rate(kg/s); To, outlet fluid temperature (°C); Tin, inlet fluid temperature (°C); Cp, specific heat of water (kJ/kg°C); C, concentration ratio; S, incident solar flux absorbed in the absorber plate (W/m2); Ul, overall heat loss coefficient (W/m2°C); Ta, ambient temperature (°C); F', collector efficiency factor; Do, outer diameter of the tube (m); and L is the length of the concentrator (m). The useful energy gain per unit of the collector length can be expressed by Equations 3 and 4 in terms of the local receiver temperature Tr.

$$q_{u'} = \frac{q_u}{L} \tag{3}$$

$$q_{u'} = \frac{q_u}{L} = F'\left[S - \frac{U_l}{C}(T_r - T_a)\right](W - D_o) \tag{4}$$

Where qu0 is the useful energy gain per unit of the collector length; Tr, mean receiver surface temperature (°C); W, width of the parabolic reflector (m), and where F0 is the collector efficiency factor defined by Equations 5 and 6

$$F' = 1/U_l\left[\frac{1}{U_l} + \frac{D_o}{D_i h_f}\right] \tag{5}$$

$$q_u = F_R(W - D_o)L\left[S - \frac{U_l}{C}(T_{in} - T_a)\right] \tag{6}$$

Where Di is the inner diameter of the tube (m); hf, heat transfer coefficient on the inside surface of the tube (W/m2°C); and FR is the collector heat removal factor. Heat removal factor is given by Equation 7

$$F_R = \frac{mc_p}{\pi D_o L U}\left[1 - \exp\left\{-\frac{F'\pi D_o U_l L}{mc_p}\right\}\right] \tag{7}$$

and collector efficiency can be obtained by dividing qu by Ib WL. The instantaneous collection efficiency can also be calculated by Equation 8

$$\eta_{in} = \frac{q_u}{IbrbWL} \tag{8}$$

Where, nin is the instantaneous collection efficiency

Overall loss coefficient and heat correlations The calculations of overall loss coefficient were based on convection and re-radiation losses. Heat loss rate per unit length can be given by Equations 9 and 10 [1].

$$\frac{q_l}{L} = h_{pc}(T_r - T_c)\pi D_o + \sigma\pi D_o\left(T_r^4 - T_c^4\right) / \left\{ \frac{D_o}{\frac{1}{\varepsilon_p} + D_{ci}\left(\frac{1}{\varepsilon_c} - 1\right)} \right\} \tag{9}$$

$$\frac{q_l}{L} = h_w\,(T_c - T_a)\pi Dco + \sigma\pi Dco\varepsilon c\left(T_r^4 - T_a^4\right) \tag{10}$$

Where, Tc is the temperature of the cover; hw, wind heat transfer coefficient (W/m2-K); εp, emissivity of absorber surface for long-wavelength radiation; and εc, emissivity of the cover for long-wavelength radiation. Heat transfer coefficient between the absorber tube and the cover The heat transfer coefficient hpc for the enclosed annular space between a horizontal absorber tube and a concentric cover is calculated by Equations 11, 12, and 13

$$\frac{K_{eff}}{k} = 0.317(Ra^*)^{0.25} \tag{11}$$

$$(Ra^*)^{0.25} = \frac{\ln\left(\frac{D_{ci}}{D_o}\right)}{b^{0.75}\left(\frac{1}{D_o^{0.6}} + \frac{1}{D_{ci}^{0.6}}\right)} Ra^{0.25} \tag{12}$$

Where Ra* is Rayleigh's number.

$$h_{pc} = \frac{2K_{eff}}{D_o \times ln\left(\frac{D_{ci}}{D_o}\right)}. \tag{13}$$

Heat transfer coefficient on the outside surface of the cover

$Nu = \mathrm{CiRe}^{n}$ (14)

Heat transfer coefficient on the inside surface of the absorber tube.- For Reynolds number less than 2000, the flow is laminar and heat transfer coefficient may be calculated from the below equation

$Nu = 3.66$ (15)

Table – Experimental measurements and calculation for aluminium receiver with glass cover

Time (hours)	Direct solar radiation on the collector (W/m^2)	T_{amb} (°C)	T_{in} (°C)	T_{out} (°C)	ΔT (°C)	T_r (°C)	Flux absorbed by the receiver (W/m^2)	Useful heat gained by water (W)	Overall heat loss coefficient (W/m^2°C)	Instantaneous collector efficiency (%)
09:30	247	19	22	32	10	41	179.6	203	24.00	27.80
10:30	388	20	24	46	22	59	217.5	245	25.30	27.70
11:30	439	21	25	55	30	68	245.3	299	20.70	30.00
12:30	470	25	26	65	39	85	262.6	340	16.80	32.00
13:30	442	26	27	63	36	81	268.5	341	17.70	31.35
14:30	365	27	28	58	30	71	255.0	317	19.28	30.50
15:30	254	28	28	46	18	56	180.0	192	21.30	26.24
16:00	190	30	30	43	13	53	134.8	156	22.55	26.80

Mass flow rate, 0.0017 kg/s. T_{amb}, ambient temperature; T_{in}, inlet fluid temperature; T_{out}, outlet fluid temperature; ΔT, temperature gradient; T_r, receiver temperature.

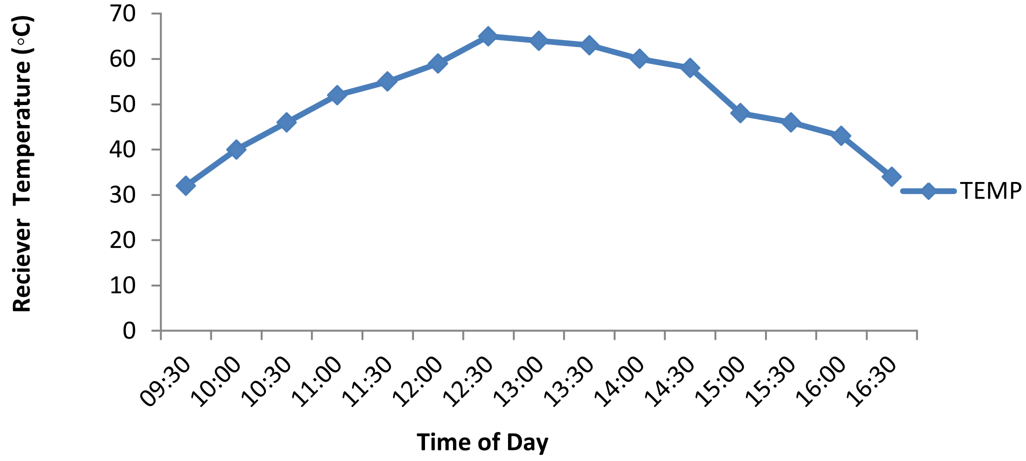

Figure - Variation of receiver temperature throughout the day

V. Conclusion

In the present work, the performance of a new parabolic trough collector with hot water generation system is investigated through experiments over one full day in winter period. The maximum value of each of those parameters is observed around noon, when the incident beam radiation is at its peak. The fabrication and design of a solar parabolic trough using locally available materials is possible hence low temperature trough will be a better solar thermal device for the rural and remote area. From the result It has been seen that the parabolic trough is better option during winter season to reducing the water heating cost. This research has its own special features Maintenance cost is minimum and hence economical, running cost is nil, the labour cost is minimized on account of its simple design. As other forms of energy are fast depleting and polluting the atmosphere, non-conventional energy resources like solar energy are best suited to use. The solar Parabolic Trough is among the best way to use solar energy efficiently due to its advantages to convert abundantly available solar energy into effective and convenient form of heat energy which can be used for various purposes.

References

[1] Sukhatme S.P. (2007) principles of thermal collection and storage. McGraw Hill, New Delhi

[2] Sambo, A.S.(2005) “Renewable Energy for Rural Development : the Nigerian Perspective” proceedings of the ISESCO Science and Technology Vision, Vol.1,12-22.

[3] Sagade et al., “Performance evaluation of low-cost FRP parabolic trough reflector with mild steel receiver”, International Journal of Energy and Environmental Engineering, pp 3-8, 2013

[4] Valan Arasu, A, Sornakumar, T: Desiggn, manufacture and testing of fiberglass reinforced parabolia trough for parabolic trough solar collectors. Sol. Energy. 81(10), 1273-1279 (2007)

[5] 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.

[6] Qu.M., Archer D.H. and Masson S.V. (2006) A linear Parabolic Trough Solar Collector Performance Model. Renewable Energy Resources and a Greener Future, Vol.VIII-3-3, USA

[7] Brooks, M.J., Mills, I and Harms, T.M. (2006) Performance of a parabolic trough solar collector. Journal of Energy in Southern Africa, Vol-17, page 71-80 Southern Africa

[8] Singh B.S.M. and Sulaiman (2003) Examination of designing a solar thermal cylindrical parabolic trough concentrator by simulation. International Rio3 Congress, World Climate and Energy Event, Rio de Janeiro, page 1 -6, Malaysia

[9] Singh S.K., Singh A.K. and Yadav S.K. (2012) Examination of design and fabrication of parabolic trough solar water heater for hot water generation. Vol-1, page 1-9, India

[10] Administration, U. E. I., 2010. International energy outlook. Tech Rep. DOE/EIA-0484(2010), Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC.

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