Testing and Performance of Parabolic Trough Collector in Indian climate

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Abstract— A parabolic trough collector is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal. The energy of sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line, where object is positioned that is intended to be heated. It consists of a tube, which runs the length of the trough at its focal line. The mirror is oriented so that sunlight which it reflects is concentrated on the tube, which contains a fluid which is heated to a high temperature by the energy of the sunlight. The hot fluid can be used for many purposes.

Key words: parabolic trough collector, Focal line

I. Introduction

India is one of the countries where the present level of energy consumption, The estimate of annual energy consumption in India is about 330 Million Tones Oil Equivalent (MTOE) for the year 2004. Accordingly, the per capita consumption of energy is about 305 Kilogram Oil Equivalent (KGOE). By world standards, is very low. But it is very high when compared with available resources.

That's why in the last few decades world has seen a boom in renewable energy systems because of depleting resources of fossil fuels. The depleting sources of fossil fuels have caused world to pay attention to renewable energy systems. The sun, our singular source of energy, emits energy as electromagnetic radiation at an extremely large and relatively constant rate 24hrs per day. Solar radiation is a high-temperature, high-energy source at its origin, the Sun, where its irradiance is about 63 MW/m2. The rate at which this energy is emitted is equivalent to energy coming from a furnace of about 6,000 K (10,340F). However, because of Sun-Earth geometry the solar energy flows down to around 1 kW/m2 on the Earth's surface.[2]

India has tremendous scope of generating solar energy. The geographical location of the country stands to its benefit for generating solar energy. The reason being India is a tropical country and it receives solar radiation almost throughout the year, which amounts to 3,000 hours of sunshine. This is equal to more than 5,000 trillion kWh. Almost all parts of India receive 4-7 kWh of solar radiation per sq meters. This is equivalent to 2,300–3,200 sunshine hours per year. States like Andhra Pradesh, Bihar, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, and West Bengal have great potential for tapping solar energy due to their location. Since majority of the population lives in rural areas, there is much scope for solar energy being promoted in these areas. Use of solar energy can reduce the use of firewood and dung cakes by rural household.

In this paper analysis of parameters such as mass flow rate, outlet temperature, solar intensity, wind velocity on outlet temperature and efficiency is done. Main objectives are as follow

1) Mass flow rate vs. Output temperature.
2) Mass flow rate vs. overall heat loss coefficient.
3) Mass flow rate vs. heat removal factor.
4) Mass flow rate vs. Efficiency.

II. Nomenclature

- PTC - Parabolic Trough Collector
- A - Aperture Area of receiver, m^2
- W- Aperture area of collector, m^2
- CR- Concentration ratio
- T_i- Inlet temperature of water, c◦
- T_o- Outlet temperature of water, c◦
- T_s- Surface temperature of receiver, c◦
- T_a- Ambient temperature, c◦
- F_{R}- Heat removal factor
- S- Solar heat flux, W/m^2
- V- Wind velocity, m/s
- Q- Total useful heat gain, W
- U_l - Overall heat loss coefficient, m^2k
- Q_L- Total heat loss, W

III. Fabrication of PTC

For the manufacturing of PTC test rig following dimensions are taken for ease in handling.

1) Concentration ratio = 20.
2) Receiver diameter (d) = 0.0123m.
3) Dimensions of parabola,
   a) Length of parabolic trough (L) = 1m.
   b) Height of trough (H) = 0.3m.

By the calculations we found out the aperture of Parabolic trough,

W= 0.75 m

Fig .1: Parabolic Trough

For mounting of test rig stand is manufactured with dimensions as follows

a) Length (l) = 1.3m.
b) Width (w) = 0.8m.
c) Height (h) = 0.5m.
d) Bearing support (b) = 0.15m.

Materials are selected according to machinability, availability and cost consideration

Materials selected.

1) Parabolic trough- Mild Steel.
2) Reflector-G.I sheet.
3) Stand-Mild Steel.
4) Receiver-Commercial Copper pipe. [5]

Fig. 2: stand

For solar tracking wiper motor is used for rotation of trough to maintain focus on receiver wiper motor is coupled to trough via chain drive. To control the rotation Photo-diode and electronic circuit is used. [7]

IV. OBSERVATIONS

During the testing on PTC readings were taken for 4 different mass flow rates. For temperature measurement J-type thermocouple is used with digital temperature indicator. Flow control valve is used to maintain flow rate.

Mass flow rate	lux meter reading	wind velocity	T_i	T_o	T_s	T_a
(kg/hr)	(W/m²)	(m/s)	(c◦)	(c◦)	(c◦)	(c◦)
1	1015	0.8	30	100	95	32
1.5	900	0.1	32	100	98	34
2	900	0.3	34	95	95	36
3	920	0.2	31	75	72	34

Table No. 1 observation table

V. CALCULATIONS

To analyze given objective following parameters are calculated. [1]

1) Overall heat loss coefficient (Ul), W/M2K

$Q_l = U_l *A*(Ts-Ta)$, w

Where,

Q_l = Heat loss by conduction and convection, W

2) Heat removal factor (Fr),

$Fr = \{(M_f*C_p)/(\pi* d_o * U_l *l)\}[1-\exp\{(-f'*\pi *d_o * U_l *l)/ (M_f * C_p)\}$

Where,

M_f = Mass flow rate, Kg/sec.

C_p = specific heat of water, J/KgK.

3) Efficiency of collector (η)

$\eta = Q/(I_b R_b*W*l)$

Where,

Q = Total heat gain, W

I_b = Incident solar irradiation, W/m²

R_b = Tilt factor

Mass flow rate Kg/hr	U_l W/m²K	F_r	η
1	103.7073	0.599319	46.31391
1.5	101.0534	0.80274	61.95502
2	94.38856	0.83261	64.25942
3	83.76665	0.898753	68.64213

Table.2: Result table

VI. ANALYSIS.

A. *Mass flow rate (Mf) Vs Outlet temperature (To).*

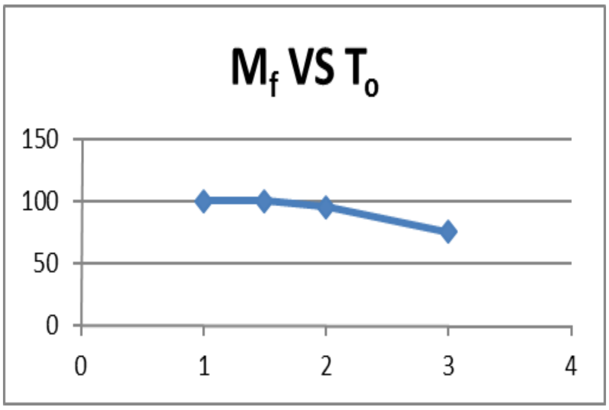

Fig. 3: Graph1. Mass flow rate (Mf) vs. Outlet temperature (To).

We see from the above graph that due to high heat removal factor heat is rapidly supplied to the water so the collector tube temperature is decrease due to which temperature of water is lowered at the outlet.

B. *Mass flow rate (Mf) vs. overall Heat loss coefficient (Ul).*

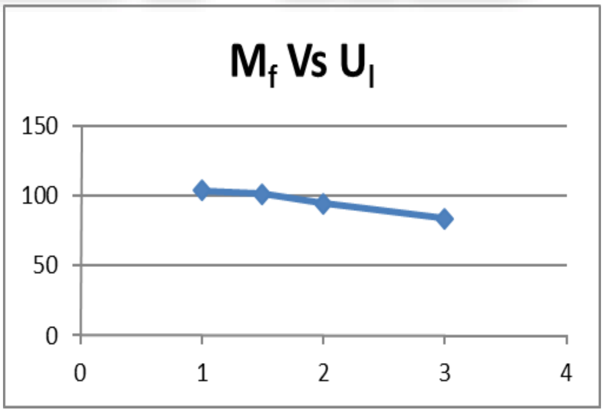

Fig. 4: Graph 2. Mass flow rate (Mf) vs. overall Heat loss coefficient (Ul)

We see from the above graph (mass flow rate vs. overall heat loss coefficient Ul) that due to increase in rate of heat transfer to water the surface temperature is lowered which results into decrease of heat losses by convection and radiation.

C. Mass flow rate (Mf) vs. Heat removal factor (Fr).

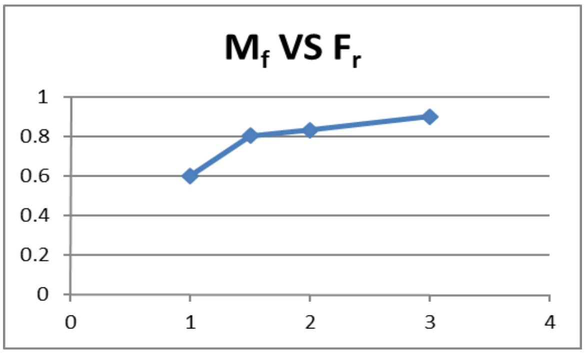

Fig. 5: Graph 2. Mass flow rate (Mf) vs. Heat removal factor (Fr).

We see from the above graph (mass flow m rate vs. heat removal factor Fr) that as the mass flow rate increases heat removal factor increases. Due to increase in hf that is convective heat transfer coefficient between water and copper tube heat removal factor Fr increases. As the flow rate of water increases forced convection increases which results into increase in rapid transfer of heat which results into increase in heat removal factor.

D. Mass flow m rate (Mf) vs. Efficiency (η).

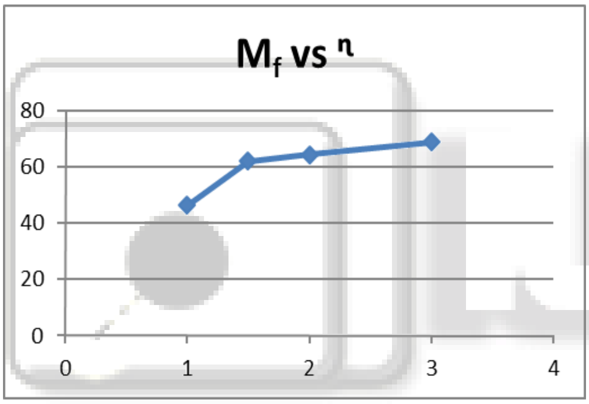

Fig. 6: Graph 4. Mass flow rate (Mf) rate vs Efficiency (η).

We see from the above graph (mass flow m rate vs. efficiency η) that as Fr increases the overall heat transfer increases to water which results into increase in the efficiency. The overall efficiency also increases due to increase in Qu.

VII. CONCLUSION

We have seen form the analysis and testing that, As the mass flow rate increases heat removal factor increases it ranges from (0.53 to 0.90) also efficiency increases it ranges from (41% to 69.39%). While as the mass flow rate increases output temperature decreases it ranges from (100◦c to 60◦c) and over all heat lost coefficient decreases it ranges from (107.69 W/m2-k to 69.07 W/m2-k).

For this design consideration the maximum efficiency achieved is 69.39% for mass flow rate 3kg per hour and overall performance is at its peak.

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