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DESIGN AND THERMAL ANALYSIS OF FIXED AND TRACKING FLAT PLATE COLLECTORS

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KEYWORDS: Fixed Flat plate collector, Tracking flat plate collector, Thermal efficiency.

ABSTRACT
This paper focuses on Thermal efficiency analysis of flat plate collectors. The instantaneous efficiency for a collector over a day is calculated. Application of solar energy for domestic and industrial heating purposes has been become very popular. However the effectiveness of presently used fixed flat plate collectors is low due to the moving nature of the energy source. In the present work, an attempt has been made to compare the performance of fixed flat plate water heater with that of heater with tracking by conducting experiments. A flat plate water heater, which is commercially available with a capacity of 100liters/day is instrumented and developed into a test-rig to conduct the experimental work. The analysis is carried during which the atmospheric conditions were almost uniform and data was collected both for fixed and tracked conditions of the flat plate collector. The results show that there is an average increase of 400C in the outlet temperature. The efficiency of both the conditions is calculated and the comparison shows that there is an increase of about 21% in the percentage of efficiency.

INTRODUCTION
Solar energy is the energy from the sun. The sun radiates an enormous amount of energy in the form of heat and light resulting from nuclear fusion reaction in its core. Some Solar systems utilises heat energy for heating and others converts sunlight energy into electrical energy. Solar energy is a renewable energy source and inexhaustible in nature. Only a small part of the solar energy that the sun radiates into space ever reaches the earth, but that is more than enough to supply all our energy needs. The sun constantly delivers 1.36 kW of power per square meter to the earth. Solar energy is mainly used to heat buildings and water and to generate electricity. The major component unique to passive systems is the Flat plate collector. This device absorbs the incoming solar radiation, converting it into heat at the absorbing surface, and transfers this heat to a fluid (water) flowing through the Flat plate collector. The warmed fluid carries the heat either directly to the hot water or to a storage subsystem from which can be drawn for use at night and on cloudy days. There are different type of solar collectors like flat-plate collectors, Focusing type collector and evacuated type collector.

FLAT PLATE COLLECTORS
The main components of a flat plate solar collector are:

- ***Absorber plate*** made of copper material, which is black coated to absorb maximum sun radiations falling on it
- ***Tubes or fins*** for conducting or directing the heat transfer fluid from the inlet header or duct to the outlet.
- ***Glazing***, this may be one or more sheets of glass or a diathermanous (radiation transmitting) plastic film or sheet.
- ***Thermal insulation***, which minimizes downward heat loss from the plate.
- ***Cover strip***, to hold the other components in position and make it all Watertight.
- ***Container or Casing***, which surrounds the foregoing components and keeps them free From dust, moisture, etc

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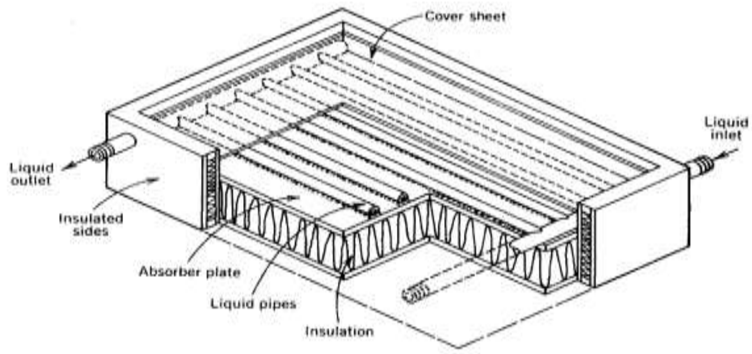

Figure 1 Components of a flat plate solar collector

THE DESIGN PROCEDURE OF FLAT PLATE COLLECTORS

TECHNICAL SPECIFICATIONS

Collector specifications:-

- Solar frame : Width 93mm thickness 1.2mm with powder coating.
- Back sheet : Aluminum sheet 0.45 mm.
- Insulation : Fiber glass wool 25mm thick 18kg density.
- Fins : 9 fins of 56mm, 1/2 inch copper pipe, 0.12mm copper Sheet with black coating ultrasonic weld.
- Front glazing : Toughened glass 4mm thick.
- Bonding between Riser And Absorber sheet : Continuous ultrasonic welding.
- Assembly : assembled under pneumatic technology.
- Bonding between Riser And Header : Brazing.
- Aluminum foil : 0.05 mm
- Gromets : EPDM
- Packing : Corrugated sheet
- Collector size : 1030mm X 2030mm
- Collector beading : EPDM Rubber beeding

Storage tank specifications

- Storage tank : Stainless steel 304 Grade.
- Insulation : Rockwool / Min / puff.
- Tank outer cladding : Powder coated sheet / Stainless steel.
- Inter connecting pipes : Stainless steel 304 Grade.
- Electrical backup : 2 KW thermostats controlled
- Storage tank stand & Hose pipe: Mild steel & 25/35 EPDM Rubber

TESTING OF FLAT PLATE COLLECTORS

For the testing of solar collectors there are two basic procedures, the instantaneous procedures and the calorimetric procedure. Each of these two procedures will allow determination of the fundamental characteristics of the collector. The most widely used procedure for testing collectors is the instantaneous procedure. In this procedure it is only necessary to measure simultaneously under steady state conditions the mass flow rate of the working fluid through the collector, the fluid temperature rise between the collector inlet and outlet, and the isolation on the plane of the collector. The instantaneous efficiency can then be calculated from the following expressions.

$$\eta_i = Q / (A_P \times I_T)$$

Where,

η_i = Instantaneous efficiency

A_P = Area of the collector Plate

I_T = Radiation on tilted surface

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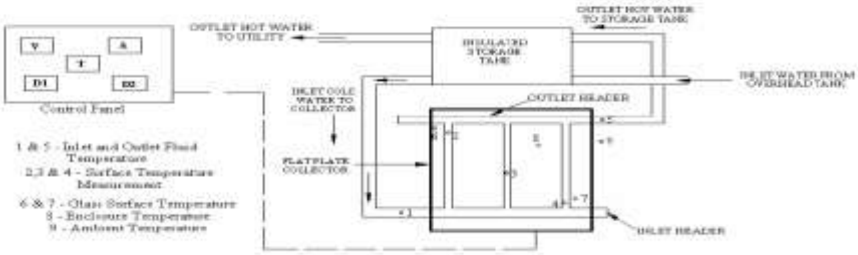

Figure 2.Experimental setup.

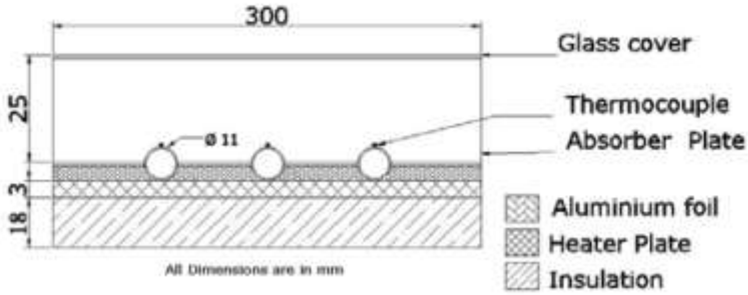

Figure 3. Cross sectional view of the experiment setup.

Figure 4.Test Console

Figure 5. flat plate collector

Calculation of Instantaneous Efficiency

Observations

Constant Terms:-

- Length of the absorber plate 'L' = 2.03 m
- Breadth of absorber plate 'B' = 1.03 m
- I.S.T (Indian standard time) When reading was taken = 11.00 Hrs
- Location of Bangalore = 77.59 °E ,12.96 °N
- I.S.T Longitude = 82.5° E
- Date on which the
- Experiment was conducted = 2nd November 2010
- Collector is facing due south
- Mass flow rate = 0.5 LPM

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Variable Terms:-

- Inlet temperature of water = 27º C
- Outlet temperature of water = 42º C
- Angle of tilt = 60º C

Sl no	I.S.T hours	Temperature of the inlet fluid T_i	Temperature of the outlet fluid T_o
1	8.00	24	25
2	9.00	24	29
3	10.00	26	35
4	11.00	27	42
5	12.00	27	45
6	13.00	28	48
7	14.00	28	45
8	15.00	30	40
9	16.00	29	35
10	17.00	28	31

Table 1. Observation of Test Set up

Calculations

Trial 1 – 11 AM

a)Incident angle θ:-

$\cos\theta = \cos(\Phi - \beta)\cos\omega\cos\delta + \sin(\Phi - \beta)\sin\delta$

Here,

$\Phi = 12.96^\circ$ for Bangalore

δ = Declination angle = $23.45 \sin[360(284+n)/365]$

Here, n = 336 for december 2

$\delta = -22.11^\circ$

ω = Hour angle $= 15(12 - LST)$

Where,

$$LST = IST - 4\frac{(82.5^\circ - \text{longitude of location})}{60} + \text{Equation of time}$$

$$= 11.00 - 4\frac{(82.5^\circ - 77.59^\circ)}{60} + 11'.14''$$

$$= 11.00 - 20' + 11'.14''$$

$$= 10.51 \text{ hrs}$$

$$\omega = 15(12.00 - 10'.51'')$$

$$= 16.5^\circ$$

Substituting all the values in the above equation we get ,

$\cos\theta = \cos(12.96^\circ - 60^\circ)\cos(16.5^\circ)\cos(-22.1^\circ) + \sin(12.96^\circ - 60^\circ)\sin(-22.1^\circ)$

$\theta = 28.258^\circ$

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b) $\cos\theta_Z = \cos\Phi \cos\omega \cos\delta + \sin\Phi \sin\delta$

$= \cos 12.96^{o} \cos 16.5^{o} \cos -22.1^{o} + \sin 12.96^{o} \sin -22.1^{o}$

$\theta_Z = 18.18^{o}$

c) $R_b = \cos\theta / \cos\theta_Z$

$= 0.927$

d) Air mass La :-

$La = 1 / \cos\theta_Z$

$La = 1 / \cos 18.8^{o}$

$= 1.05$

e) $I_n = A\ e^{-B\ La}$

$= 1196\ (e^{-0.143 \times 1.730})$

$= 1028.1\ W/m^2$

f) $I_b = I_n (\cos\theta_Z)$

$= 977.1\ W/m^2$

$I_d = 0.105 \times 1028.1$

$= 107.94\ W/m^2$

g) $Ig = I_b + I_d$

$= 977.1 + 107.94$

$= 1084.94\ W/m^2$

h) Radiation on tilted surface I_T

$I_T = I_b R_b + I_d(1+ \cos\beta /2) + Ig.\ \rho(1- \cos\beta /2)$

$= 977.1(0.927) + 107.94(0.75) + 1084.94(0.6)(0.25)$

$= 1149.37\ W/m^2$

i) $\eta = \dfrac{m\ C_P\ (T_o - T_i)}{A_P \times I_T}$

$= \dfrac{0.00833 \times 4184\ (42 - 27)}{2 \times 1149.37}$

$= 22.98\ \%$

Similarly Hourly global radiations and efficiencies are calculated for all the trials up to 17.00 hrs and are tabulated

Sl no	I.S.T Hours	Radiation on tilted surface $I_T(W/m^2)$	Thermal efficiency η (%)
1	8.00	669.33	5.2
2	9.00	888.977	9.7
3	10.00	1030.13	15.17
4	11.00	1149.37	22.98
5	12.00	1188.75	26.29
6	13.00	1166.33	30.60
7	14.00	1047.21	28.19

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8	15.00	877.41	19.47
9	16.00	687.852	15.14
10	17.00	485.3	10.73

Table 2 Calculated efficiency and global radiation

The average efficiency Over a day is given by $\eta = \frac{\int_0^t m\, C_P\, (T_o - T_i)\, dt}{\int_0^t (A_P \times I_T \times dt)}$

$= 29.11\ \%$

Test Procedure

Two identical single cover flat plate collector were placed with an angle at 28º to the horizontal towards south facing. One collector is fixed and other one is tilted manually for every two hours with an angle of 30º for improving collector efficiency. Inlet temperature of the water and temperature of the hot water in the storage tank were tabulated on hourly basis, both the collector efficiency of the collectors were calculated.

Specification of Flat Plate Collector

- Length of the collector = 2m
- Width of the collector = 1m
- Length of the absorber plate = 1.95m
- Width of the absorber plate = 0.95m
- Material of the absorber plate = Copper
- Thermal conductivity of the plate material = 386 W/mK
- Density of the plate material = 8954 kg/m3
- Plate thickness = 34 gauge
- Diameter of the tube = 6.35m
- Tube center to center distance = 100mm
- Number of tubes used = 9
- Glass cover emissivity/absorptivity = 0.85
- Refractive index of glass relative to air = 1.5
- Diameter of header pipes = 12.7mm
- Insulating material used = Glass-wool
- Thermal conductivity of insulating material = 32.2*10.3 W/mK
- Density of insulating material = 200 kg/m3
- Material of collector tray = Mild steel
- Thermal conductivity of collector tray = 53.6 W/mK
- Density of collector tray = 7833 kg/m3

Efficiency Calculation

Average Solar radiation received by earth in terms of energy R = 900 W/m2/Hr.
Solar radiation received by earth in 7 hours in terms of energy R = 900*7 W/m2/day
R = 6300 Wh/m2
R = 22680000 W Sec/m2, where
A = Area of Flat plate collector in m2
A. T1 = Temperature of water at inlet in ºC
B. T2 = Temperature of water at outlet in ºC
Mass of water taken in the storage tank = 100 kg
Specific heat of water = 4.182 KJ/KG ºK
Area of the flat plate collector,
A = L*W m2

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= 1.95*0.95
= 1.8525 m2
Radiation receive by collector,
R1 = R*A
= 22680000*1.8525
= 43014700 Joules
Output of the Stationary Collector
Q = M*Cp*(T2 – T1)
= 100*4.187*103*(42 – 22)
= 8374000 Joules
Output of the partially rotating Collector
Q = M*Cp*(T2 – T1)
= 100*4.187*103*(46 – 22)
= 10048800 Joules
Efficiency of fixed flat plate collector
η = Output of the collector / Input Radiation
η = M*Cp*(T2 – T1) / R*A
= 8374000 Joules / 43014700 Joules
= 19.93%
Efficiency of the partially rotating Collector
η = Output of the collector / Input Radiation
η = M*Cp*(T2 – T1) / R*A
= 10048800 Joules / 43014700 Joules
= 23.92%

RESULT AND DISCUSSIONS
Average global Radiation 878 WH/m2
Average Wind Speed = 5.1 Km/hr

Time in Hours	Outlet temperature of stationary collector (T_2°C)	Outlet temperature of tracking collector (T_2°C)
9:30	30	30
10:30	33	34
11:30	37	37
12:30	41	42
13:30	44	46
14:30	47	50
15:30	48	52
16:30	48	51
Average Temperature	**41**	**42.75**

Table 3 Results

Average global Radiation 1089 WH/m2
Average Wind Speed = 5.3 Km/hr

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Time in Hours	Outlet temperature of stationary collector (T_2°C)	Outlet temperature of tracking collector (T_2°C)
9:30	30	30
10:30	33	34
11:30	37	37
12:30	42	42
13:30	46	46
14:30	48	50
15:30	50	52
16:30	51	55
Average Temperature	42.12	43.25

Table 4 Temperature distribution

COMPARISON OF EFFICIENCIES OF FIXED AND PARTIALLY ROTATING FLAT PLATE COLLECTORS

Efficiency of fixed flat plate Collector	Efficiency of the partially rotating Collector *C.*	Increase in Percentage of efficiency due to tracking *D.*
E. 19.93%	23.92%	*F.* 21%

Table 5 comparison

From the above calculation, we can conclude that by providing the manual tracking system to the collector with respect to solar beam we can improve the efficiency of the system and it can also be concluded that if we provide the continuous automatic tracking system to the collector, in terms of azimuth angle and altitude, we can still improve the efficiency of the system.

VARIATION OF EFFICIENCY OF THE COLLECTOR WITH THERMAL EFFICIENCY

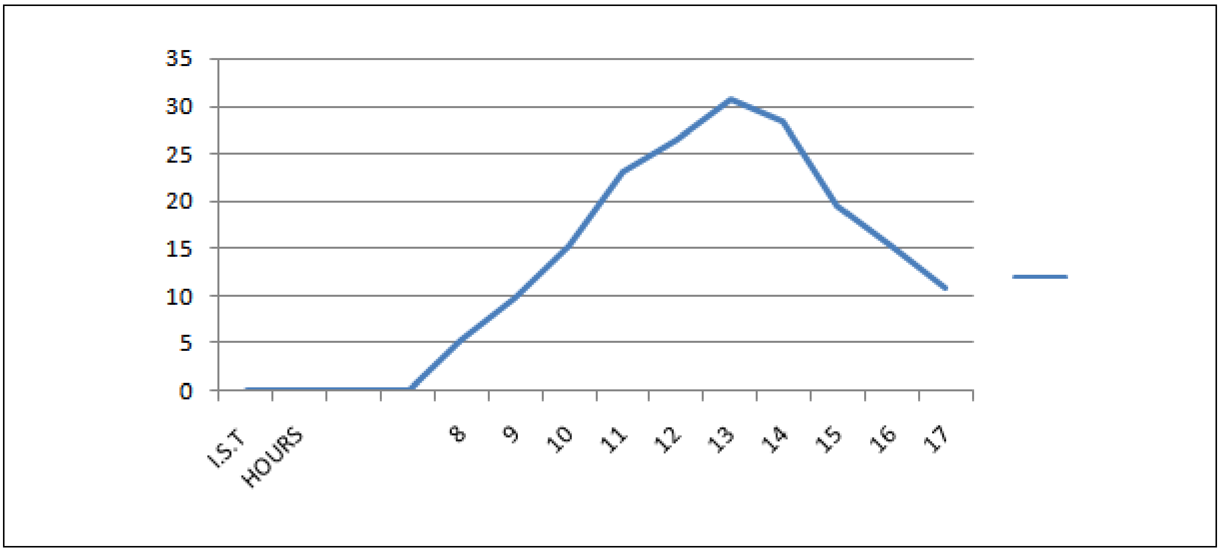

Figure 6.Efficiency versus Time

Figure 6 shows the variation of efficiency of the collector with time .It is evident that the efficiency increases with the time up to 1300 hrs due to the availability of intense beam radiation and slowly decreases during the sunset

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VARIATION OF EFFICIENCY WITH THE CALCULATED RADIATION

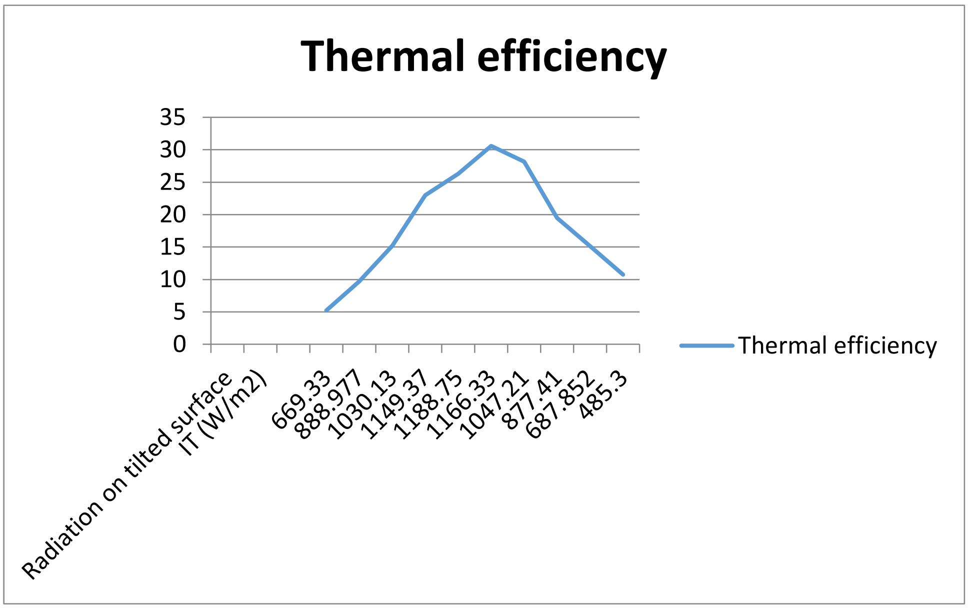
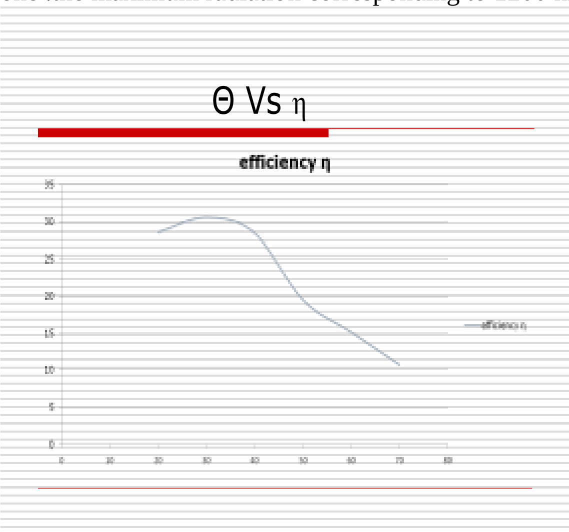


Figure 7.Efficiency versus Tilted radiation

Figure 7 shows the variation of efficiency with the calculated radiation I_T .The curve is similar to the previous one .the maximum radiation corresponding to 1200 hrs.



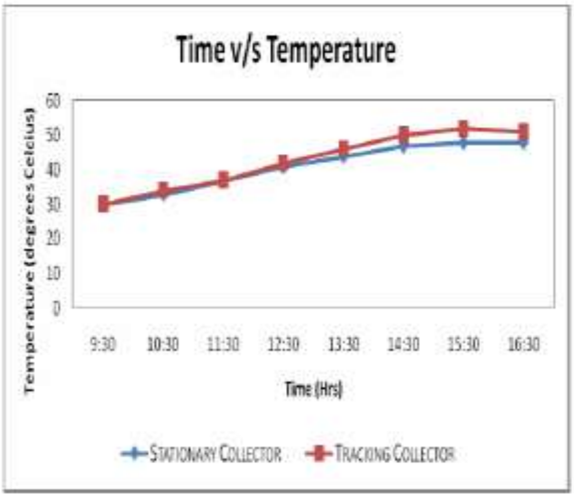


Figure 8 Incident angle θ v/s efficiency ***figure 9.Time v/s Temperature***

The figure 8 shows the variation of efficiency with incident angle θ and figure 9 shows how temperature varies with respect to time for both stationary collector and tracking collector. The tracking collector utilizes maximum beam radiation. So the rise in temperature is high with respect to time in tracking collector compare to stationary collector and gives higher efficiency

CONCLUSIONS

The Conclusions can be drawn based on the analysis of the collector. The instantaneous efficiency is assumed to be a function of only the temperatures of the fluid and the radiation I_T. A more precise and detailed analysis

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should include the fact, that the overall heat loss coefficient (U_L) and other factors such as wind are not constants. Initially due to the transient effects the useful energy received is less. Efficiency decreases with increasing angle of incidence. Efficiency decreases with increasing ratio of diffuse to beam radiation.From the above results, it has been found that the system provided with manually tracking has got higher efficiency than the fixed flat plate collector by 21%. Hence Flat plate collector with tracking method utilizes maximum beam radiation and gives high efficiency when compared to fixed flat plate collector.

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