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Effect of Wind Velocity At different Yaw Angle On Top Loss Coefficient Of Solar Flat Plate collector – An Experimental Study

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Abstract

Solar energy will be more relevant for developing countries whose energy requirements are increasing rapidly as a result of large-scale industrialization and growing population. Solar Flat plate collector is the main part of the solar system for tapping solar energy to some useful energy. The surface area installation of solar collector has been increased astonishingly in India as well as some other countries since last decade. From the present work the experimental data were generated from which effect of wind velocity on top loss coefficient of solar flat plate collector was studied and discussed.

Keywords: Three pedestal fans, Digital voltmeter & Ammeter, Experimental setup, Thermocouples.

Introduction

A measurement of the flat plate collector performance is the collector efficiency defined as the ratio of the useful energy gain to the incident solar energy over a particular time period. The useful energy in terms depends strongly on the energy loss from the top surface of the collector both due to convective and radiative heat transfer processes. The losses from the bottom and from the edges of the collector to an always exist; their contribution however, is not as significant as the losses from the top. Thus, an accurate calculation of the top loss coefficient (U_t) becomes available and desirable. The calculation can be done using thermal network analysis. Thus, however involves an inconvenient iterative solution. Moreover, the calculation of the convective heat transfer coefficient between the absorbing plate and the cover (h_{p-c}) which is obtained from the Nusselt (Nu) and Grashof (G_r) numbers makes the whole task of calculating U_t even more difficult. As an approximation to this iterative analysis an empirical correlation and analytical equation are made.

The overall thermal performance of a flat plate solar collector is strongly influenced by the energy exchange, which takes place between the external environment and the uppermost surface of the collector. For designing or modeling purposes these energy exchanges are usually described in terms of a top surface heat loss coefficient(U_t) which combine both radiative & convective heat transfer processes.

Thus, the wind induced convective heat transfer from the uppermost surface of a flat plate collector can play a significant role in determining magnitude of U_t & therefore overall efficiency of the collector. The choice of the value for h_w is of major importance to input into the equations for calculating top loss coefficient U_t. Most convective model of flat plate collector for performance, which neglects thermal capacitance effect, was proposed by [1].

[1] Equation was valid only for collector tilt s = 45^o which must be corrected for other tilt angles. Afterward – new parameter is introduced which physically accounts for convective heat losses from top or the absorbing plate and was function of tilt angle. The choice of this parameter did not predict the expected behavior of convective losses with tilt angle and its validity found restricted to only $0^o \leq s \leq 34^o$.

In order to resolve this discrepancy and presumably, to have better agreement of U_t values with iterated ones [2] has proposed relation. [3] Has suggested a new equation based on [2] equation. It was somewhat simple equation to determine U_t with an accuracy of 0.25 W/m^2C with respect to iterated values. This equation was modified to allow for a correct variation of parameter with s for 0^o – 90^o. This yields the expected decrease of parameter and hence U_t with increasing tilt angle.

[3] Tested validity of equation over a wide range of parameter and the U_t value so obtained are compared with those obtained using [2] and other equation. [4] Have proposed next equation. He has modifies equation of [2] taking into account the variation of convective heat transfer coefficient with air gap spacing L between two parallel plates and proposes and empirical relation for factor f expressing it as a function of the number of glass covers wind heat transfer coefficient and ambient temperature. All above equation refer to flat plate collectors with N glass cover in general. There is several application of flat plate collector wherein a single glass cover will suffice.

[5] Have proposed an improved technique for calculating the top heat loss factor of a flat plate collector with single glazing. The method enables calculation of the heat loss factor by an analytical equation in place of the semi-empirical equation. The proposed method of calculating the top heat loss factor by an analytical equation leads to a reduction in the computing errors by a factor about ten compared to the semi empirical equations and the simplicity of the approximately method is not loss. [5] Has extended the research and proposed an equation for a flat plate collector with double glazing also [6]. [7] Has improved equation form for computing the glass cover temperature of flat-plate solar collectors with single glazing. A semi-analytical correlation for the factor *f* —the ratio of inner to outer heat-transfer coefficients—as a function of collector parameters and atmospheric variables is obtained by regression analysis. [8] has developed a set of correlations for computing the glass-cover temperatures of flat-plate solar collectors with double glazing. A semi analytical correlation for the factor f2—the ratio of outer to inner thermal resistance of a double-glazed collector—as a function of collector parameters and atmospheric variables is obtained by regression analysis [9] Absorption of solar radiation in the glass cover(s) of a flat plate solar collector increases the temperature of cover(s) and hence changes the values of convective and radiative heat transfer coefficients. The governing equations for the case of single as well as double glazed collector have been solved for inner and outer surface temperatures of glass cover(s) with/without including the effect of absorption of solar radiation in the glass cover(s), with appropriate boundary conditions.
The above study indicates that there exist a variety of equations for determination of top loss coefficient for solar flat plate collector based on tilt angle, No. of glass cover, glass cover temperature and other parameters but in depth study for effect of wind velocity on top loss coefficient is still required. The present work gives correct and accurate results for effect of wind velocity on top loss coefficient by generating some experimental data for better performance of collector.

Experimental Work

Our experimental model of solar flat plate collector (The experimental research collector) fabricated during the course of this work consists of several basic elements as given below:

1. A flat absorbing plate
2. Reflector & electric heater
3. Thermal insulation
4. Transparent cover
5. Thermocouples
6. Weather tight housing

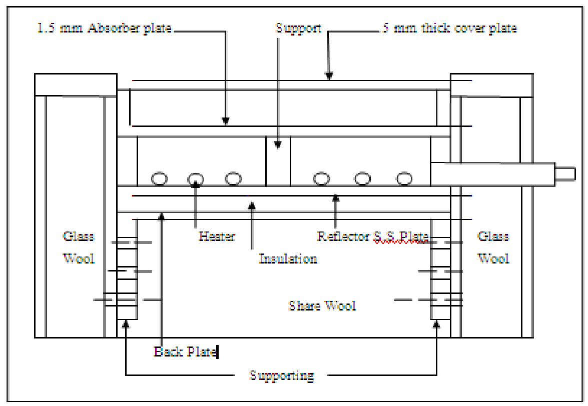


Fig – 1 Sectional Elevation of Solar Flat Plate Collector

The full fledge solar flat plate collector has been developed in laboratory. The experimental investigations have been carried out on this specially designed solar research collector. The block diagram of experimental set up has been shown in figure contains instruments used during the course of project work.

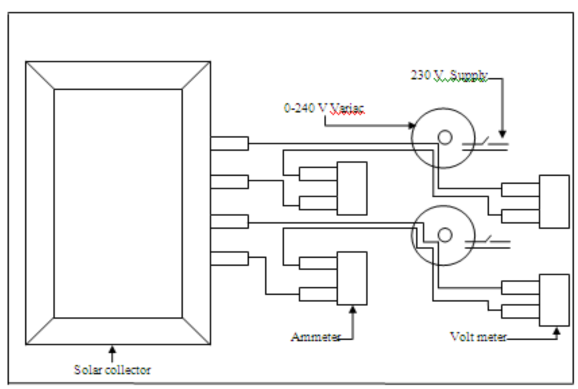


Fig-2 External Circuit of Solar Flat Plate Collector

Investigation Stages:

The experimental investigation has been carried out as described below.

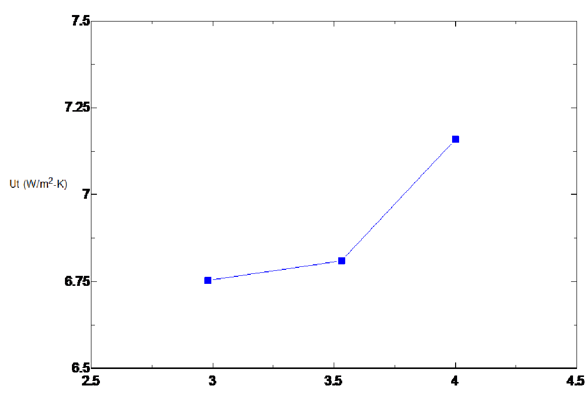
In this experiment, effect of wind velocity on top loss coefficient was undertaken as well as the effect of wind velocity was studied by varying the velocity from 0 to 5 m/s. Three pedestal fans were used to get desired velocities and a variac was connected to vary the velocity. 4 to 5 different velocities were varied for heat input. Observations were taken for various heat inputs after attaining the steady state conditions, all temperature and power inputs were recorded. This is done for 0^o, 45^o and 90^o yaw angles as stated below in sequence. The yaw angle is the angle between principal axis of collector and wind direction.

1. During first turn, the collector was kept horizontal, the yaw angle was kept 0^o & power inputs were varied.
2. During second turn, keeping the collector horizontal, yaw angle was kept 45^0 & power inputs were varied.
3. During third turn, the collector was kept horizontal, yaw angle was kept 90^o & power inputs were varied.

Result & Discussion

At I (yaw angle) =0

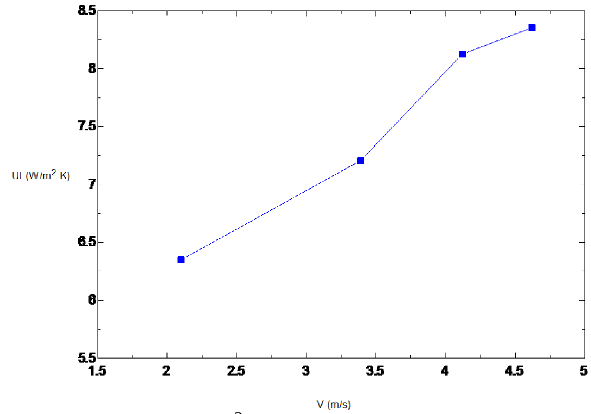
Tp-Ta (^{0}C)	27		
Wind Velocity (V in m/s)	2.98	3.53	4
U_t (W/m^2 – K)	6.753	6.809	7.159



Graph-1. U_t (W/m^2-K) V/S V (m/s)

At I (yaw angle) =0

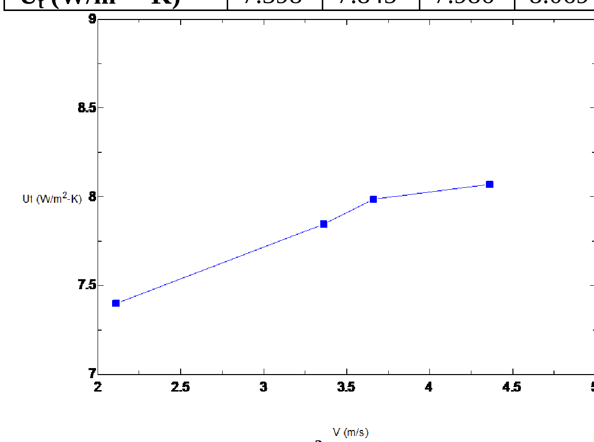
Tp-Ta (^{0}C)	46			
Wind Velocity (V in m/s)	2.1	3.39	4.12	4.62
U_t (W/m^2 – K)	6.349	7.205	8.126	8.352



Graph-2 U_t (W/m^2-K) V/S V (m/s)

At I (yaw angle) =0

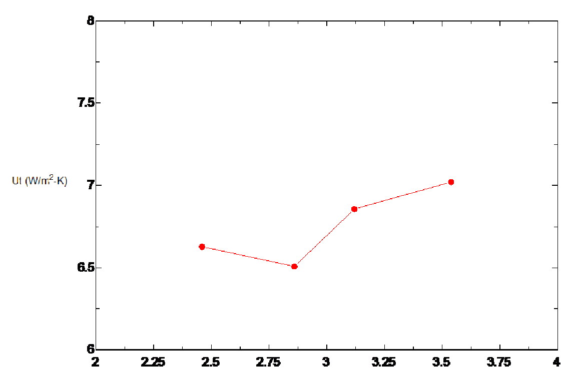
Tp-Ta (^{0}C)	77			
Wind Velocity (V in m/s)	2.11	3.36	3.66	4.36
U_t (W/m^2 – K)	7.398	7.845	7.986	8.069



Graph-3 U_t (W/m^2-K) V/S V (m/s)

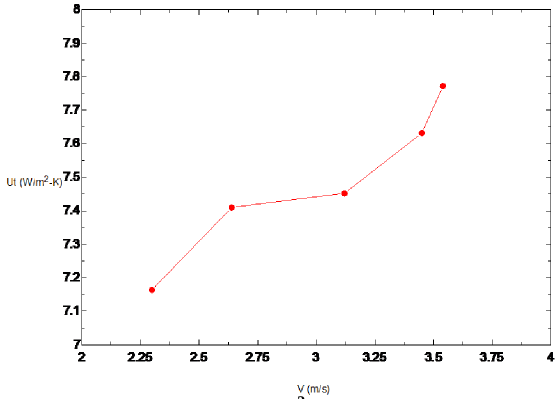
At I (yaw angle) =45

Tp-Ta (^{0}C)	31			
Wind Velocity (V in m/s)	2.46	2.86	3.12	3.54
U_t (W/m^2 – K)	6.626	6.507	6.856	7.020



Graph-4 U_t (W/m^2-K) V/S V (m/s)
At I (yaw angle) =45

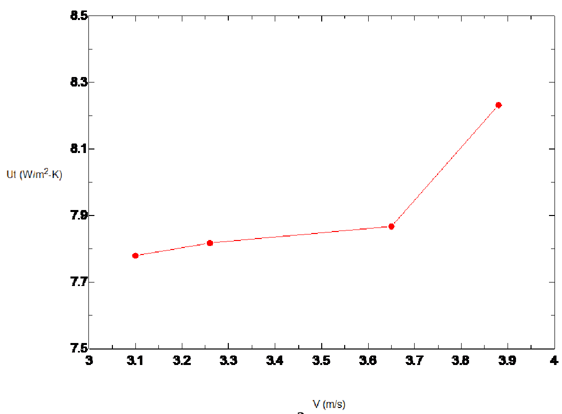
Tp-Ta (^{0}C)	56				
Wind Velocity (V in m/s)	2.3	2.64	3.12	3.45	3.54
U_t (W/m^2 – K)	7.16	7.41	7.45	7.63	7.77



Graph-5 U_t (W/m^2-K) V/S V (m/s)

At I (yaw angle) =45

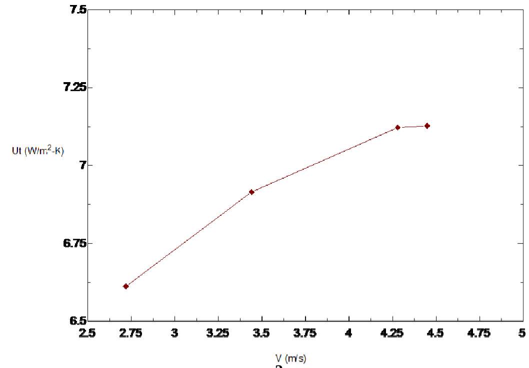
Tp-Ta (^{0}C)	71			
Wind Velocity (V in m/s)	3.1	3.26	3.65	3.88
U_t (W/m^2 – K)	7.779	7.817	7.867	8.232



Graph-6 U_t (W/m^2-K) V/S V (m/s)

At I (yaw angle) =90

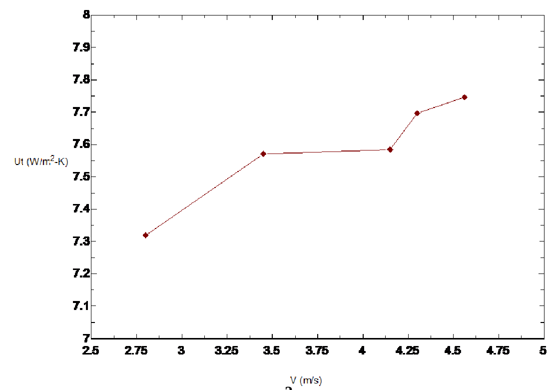
Tp-Ta (^{0}C)	29			
Wind Velocity (V in m/s)	2.72	3.44	4.28	4.45
U_t (W/m^2 – K)	6.612	6.915	7.122	7.127



Graph-7 U_t (W/m^2-K) V/S V (m/s)

At I (yaw angle) =90

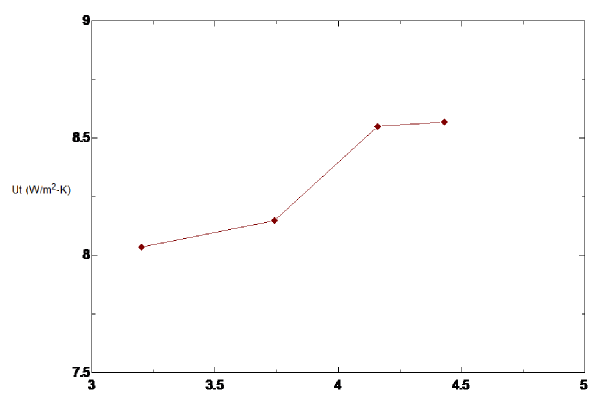
Tp-Ta (^{0}C)	50				
Wind Velocity (V in m/s)	2.8	3.45	4.15	4.3	4.56
U_t (W/m^2 – K)	7.32	7.57	7.58	7.69	7.75



Graph-8 U_t (W/m^2-K) V/S V (m/s)

At I (yaw angle) =90

Tp-Ta	78			
Wind Velocity (V in m/s)	3.2	3.74	4.16	4.43
U_t (W/m^2 – K)	8.035	8.149	8.550	8.568



Graph-9 U_t (W/m^2-K) V/S V (m/s)

The result of experiment has been presented in terms of graphs as shown above along with the tables of actual data obtained during this work.
Graph. 1-9 shows U_t Vs Velocity, in which as velocity increase, U_t increases due to increase in convection losses.
Graph. 1-3 shows variation of U_t as a function of wind velocity respectively on different $(T_p - T_a)$ isotherms with yaw angle as 0^o while Graph 4-6 & Graph. 7-9 shows the variation of U_t as a function of wind velocity at different $(T_p - T_a)$ isotherms at yaw angle of 45^o and 90^o respectively.

Conclusion

Based on extensive experimental investigations on effect of wind velocities on top loss coefficient for flat plate collector, following conclusions may be drawn.

i) The effect of yaw angle is found to be negligible, which may be due to the turbulent flow observed on collector.

ii) U_t value clearly increases with increase in wind velocity and $(T_p - T_a)$ values. Increase in U_t due to wind velocity is due to increased convective losses while that due to $(T_p - T_a)$ are a result of increased radiation losses.

Sample Calculation

Size of absorber plate : 0.71 x 1.21 m^2
Spacing between plate and glass : 0.0225m
Glass cover Emissivity : 0.88
Absorber plate Emissivity : 0.9
Thickness of glass cover : $\delta_g = 0.005$ m
Thermal conductivity of glass : 0.75 W/m-K
Wind speed : V = 4 m/s
Input Watt : Q_{in} = 178.22 W
Tilt angle : $\beta = 0^o$
(Keq.) side : 0.060606 W/m-K
(Keq.) bottom : 0.034662 W/m-K

Average 1	:	2.91
Average 2	:	2.335
Average 3	:	1.56
Average 4	:	2.14
Average 5	:	1.305
Average 6	:	1.32
Average 7	:	1.6075
Average 8	:	1.29
Average 9	:	1.27

$T_h = a \times avg.\ 1 + b \times (avg.\ 1)^2 + c \times (avg.\ 1)^3$ where
T_h = Heater plate temperature
$= (23.7158 \times 2.91) + [0.189090178 \times (2.91)^2] + [-0.009326 \times (2.91)^3]$
$= 70.38\ ^oC$
Similarly,
Tp = 56.29 ^oC
Tcb = 37.42 ^oC
Twi = 51.52 ^oC
Two = 31.22 ^oC
T_b = 31.61 ^oC
Twie = 38.57 ^oC
Twoe = 30.88 ^oC
Ta = 30.41 ^oC

Calculation of Losses

(1) Bottom Loss :-

$Q_b = [(Keq.)_{bottom} \times Ap \times (T_h - T_b)] / (X_b)$
$= [(0.0346619 \times 0.70 \times 1.21 \times (70.384 - 31.613)] / (96.76 \times 10^{-3})$
$= 11.93$ W

(2) Side Loss :-

$Qs = [(Keq.)_{side} \times 2 \times l_3 \times (l_1 + l_2) \times (Twi - Two)] / (Xs)$
$= [0.060606 \times 2 \times 67.24 \times 10^{-3} \times (0.71 + 1.21) \times (51.526 - 31.226)]/(75 \times 10^{-3})$
$= 4.236$ W

(3) Edge Loss :-

$Qe = Ke \times Se \times (Twie - Twoe)$
$= Ke \times 0.54\ le \times (Twie - Twoe)$
$= Ke \times 0.54\ [2 \times (l_1 + l_2) + 4 \times l_3] \times (Twie - Twoe)$
$= 0.0606060 \times 0.54\ [2 \times (1.92) + 4 \times 67.24 \times 10^{-3}] \times (38.553 - 30.88)$
$= 1.0333$ W

(4) Corner Loss :-

$Qc = Kc \times Sc \times [Twie - (2Twoe + T_b)/3]$
$= Kc \times 0.15 \times [4 \times (Xs^2 + Xs^2 + X_b^2)^{0.5}] \times [Twie - (2Twoe + T_b)/3]$
$= 0.0606060 \times 0.15 \times \{4 \times [2 \times (75 \times 10^{-3})^2 + (96.76 \times 10^{-3})^2]^{0.5}\}$
$\times [38.573 - (2 \times 30.88 + 31.613)/3]$
$= 0.039$ W

(5) Sealing Loss :-

Assume to be 1% of Input watt
Qsl = 1.7822 W

(6) Top Loss :- $Qtop = Qin - Q_b - Qs - Qe - Qc - Qsl$ = 159.199 W

■ $Qtop/Ap]_{exp}$ = 159.199 / (0.71 x 1.21)
= 185.310 W/m^2

■ U_t

$Qtop/Ap]_{exp} = U_t\ [Tpm - Ta]$
So, U_t = 185.310 / (56.29 – 30.41)
= 7.159 W/m^2 - K

Nomenclature

Tp or Tpm - Mean plate temperature in ^oC

Ta - Ambient temperature in ^oC
Tcb = Glass bottom temperature ^oC
Twi = Inside wall temperature

Two = Outside wall temperatur
T_b = Absorber plate temperature
Twie = Inside edge temperature
Twoe = Outside edge temperature
U_t - Top loss coefficient in W/m^2-K
V - Wind velocity in m/s
I - Yaw angle in degree

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