Proceedings of the World Congress on Engineering 2010 Vol II
WCE 2010, June 30 - July 2, 2010, London, U.K.

Review of Various Losses Occurring in Single Glazed Flat Plate Collector – An Experimental Study

M. K. Bhatt and S. A. Channiwala

Abstract— **The efficiency of a flat plate collector is largely dependent on various losses such as, the top loss, the bottom loss, the side loss, the edge loss, the corner loss etc. The principal parameter governing its efficiency is top loss co-efficient. The experimental investigations are carried out on 1.21m x 0.71m x 0.16m, size single glazed, flat plate collector. The collector is equipped with 1 kW capacity heaters kept below the absorber. The temperatures at various points (48) are measured with chromel – alumel thermocouples. The natural wind is created by three pedestrial fans. The wind velocity is varied from 1 to 5 m/s and wind loss and top loss co-efficients are evaluated. The losses are measured and evaluated under steady state conditions. The various losses and loss co-efficients are presented in this paper.**

Index Terms— **Collector, Experimental Simulation, Tilt angle, Losses.**

I. Introduction

The measurement of collector efficiency is a ratio of useful energy gain to incident solar energy. The useful energy gain in turn depends on energy losses from the top. The losses from the edges of the collector and from the bottom are always to exist but their contribution is not as significant as the losses from the top. Thus accurate determination of top loss co-efficient (U_t) is desirable. The present experimental work is aimed to determine the various losses, under various wind velocities, at different plate temperatures and at different heat input flux carried out under steady state conditions for each set.

II. Nomenclature

Ap	Area of absorber plate , m^2
Qs	Loss of heat from sides, W
Qb	Loss of heat from bottom, W
Qt	Loss of heat from top, W
Ein	Energy input, W
β	Collector tilt angle, degrees
N	No. of covers
σ	Stefan Boltzman constant $5.67x10^{-8}$ w/m^2K^{-4}
ε_p	Emmisivity of plate
ε_c	Emmisivity of cover
Tb	Temperature of bottom cover of collector, K
Tc_1	Mean temperature of 1^{st} cover, K
Tc_2	Mean temperature of 2^{nd} cover
Tc	Thickness of cover, m
Ut	Top heat loss co.eff. w/m^2K
U_L	Over all heat loss co.eff. of collector, w/m^2K
Th	Temperature of heater plate, K
Tp	Temperature of absorber plate, K
hw	wind induced convective heat transfer coeff., w/m^2K
h_{C1-2}	Convective heat transfer co.eff. between 1^{st} & 2^{nd} cover, w/m^2K
Kc	Thermal conductivity of cover, w/m^2K
h_{p-c}	Convective heat transfer co.eff. between absorber plate to cover, w/m^2K
h_{c-a}	Convective heat transfer co.eff. between cover to atmosphere, w/m^2K
F_{p-c}	Radiation shape factor between plate to cover
ε_g	Emmisivity of glass cover
Qu	Useful energy gain, W
S	Flux absorbed by collector, $W\text{-}m^2$

Manuscript received January 20, 2010.

Dr. M.K. Bhatt is with the S. V. National Institute of Technology, Surat – 395007, Gujarat State, India (phone: 91-261-2223371; fax: 91-261-2227334; e-mail: mkbhatt51@ gmail.com).
Dr. S.A. Channiwala is with the S. V. National Institute of Technology, Surat – 395007, Gujarat State, India (phone: 91-261-2223371; fax: 91-261-2227334; e-mail: sac@ med.svnit.ac.in).

III. Experimental Set-up

The experimental research collector is developed during the course of this work. It essentially consists a cover plate of 5 mm thick. The powder coated absorber plate of copper having size 1210 mm x 710 mm x 1 mm, having two reflective electric heaters of 0.5 kW capacity are kept below the absorber. The wooden housing is filled with the cerwool insulation (k=0.03 w/mk) at back and the glass wool (k=0.04 w/mk) insulation is kept at sides. The experiments are conducted in a laboratory with black curtains on the windows so as to avoid any infiltration of external radiation.

The electricity is supplied by two heaters. The power is varied from 200 W to 700 W. There are 48 calibrated chromel – alumel thermocouples, mounted on bottom of glass cover, absorber plate, heater plate, bottom, sides and covers of housing. The wind is created by pedestrial fans.

IV. Evaluation of Various Losses and Loss Co-efficient

The collector is allowed to reach to steady state conditions. Once the steady state is achieved, the top loss and the overall loss co-efficients are evaluated from the energy balance equation as follows.

$$Q_{in} = Q_t + Q_b + Q_s + Q_e + Q_c + Q_{si} \tag{1}$$

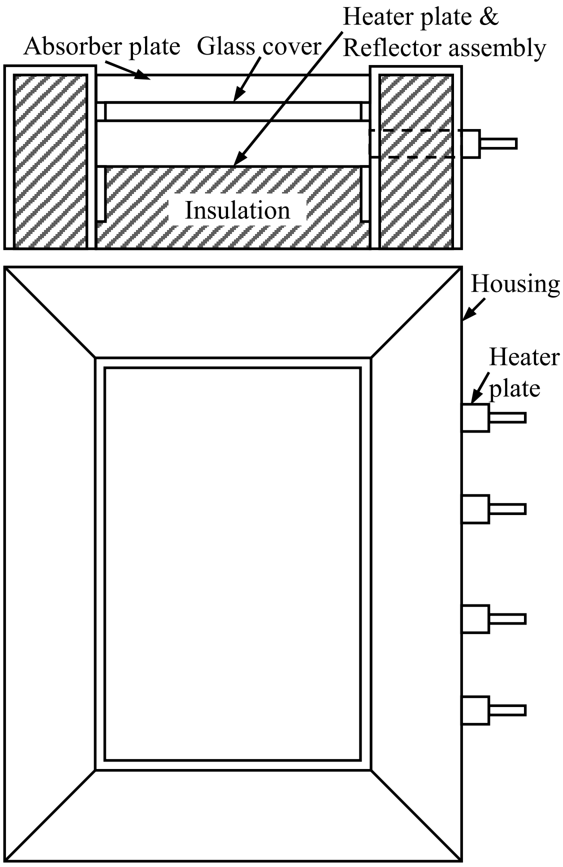

Fig. 1 Sketch of experimental research collector

The bottom loss Qb, the side loss Qs, the edge loss Qe, the corner loss Qc are calculated as per method suggested by Channiwala [10]. The sealing losses are assumed as 1% and hence the top loss Qt is obtained by subtracting all these losses from input energy Qin, Hence,

$$U_t = \frac{Q_t}{Ap\left(Tp - Ta\right)} \tag{2}$$

$$U_L = \frac{Q_{in}}{Ap\left(Tp - Ta\right)} \tag{3}$$

$$h_{p-c} = \frac{Q_t}{Ap\left(Tp - Ta\right)} - \frac{\sigma.F_{p-c}(T_p^4 - T_c^4)}{Ap\left(Tp - Ta\right)} \tag{4}$$

$$h_w = h_{c-a} = \frac{Q_t}{Ap.\left(Tc - Ta\right)} - \frac{\sigma.F_c(T_c^4 - T_a^4)}{Ap\left(Tc - Ta\right)} \tag{5}$$

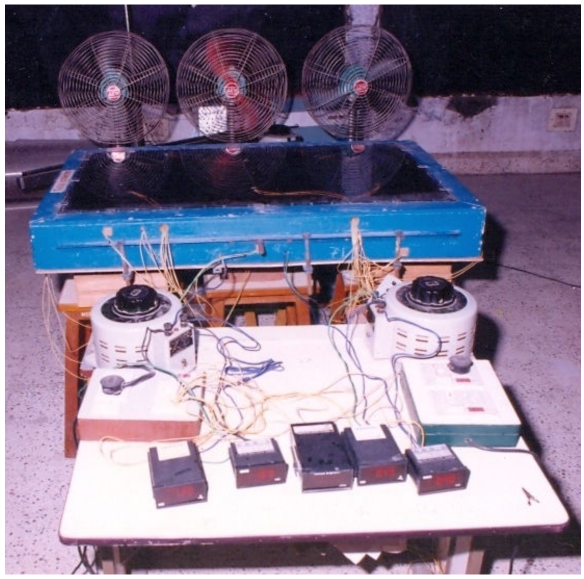

Fig. 2 Photograph of experimental set-up

The various correlations for Ut may be summarized,

As per Hottel & Woertz [22]

$$U_t = \left[\frac{N}{c\left(\frac{T_p - T_a}{N+f}\right)^{0.25}} + \frac{1}{h_w}\right]^{-1} + \frac{\sigma\left(T_p^2 + T_a^2\right)\left(T_p + T_a\right)}{\left(1/\hat{I}_p\right) + \left|\left(2N+f-1\right)/\hat{I}_g\right| - N} \tag{6}$$

As per Klein [17]

$$U_t = \left[\frac{N^*}{0.165\left(\frac{T_p - T_a}{N^*+f}\right)^{0.31}} - \frac{1}{h_w}\right]^{-1} + \frac{\sigma\left(T_p + T_a\right)\left(T_p^2 + T_a^2\right)}{\left|\hat{I}_p + 0.05N^*\left(1-\hat{I}_p\right)\right|^{-1} \left|\left(2N^*+f^*-1\right)/\hat{I}_g\right| - N^*} \tag{7}$$

$$f^* = 0.9556 - 0.211 h_w + \left[1 + \frac{N^*-1}{N^*+3}\right] h_w^2$$

As per Klein [18]

$$U_t=\left[\frac{N}{\left(\frac{C}{T_p}\right)\left(\frac{T_p-T_a}{N+f}\right)^{0.33}}+\frac{1}{h_w}\right]^{-1}+\frac{\sigma\left(T_p+T_a\right)\left(T_p^2+T_a^2\right)}{\left|\hat{I}_p+0.05N\left(1-\hat{I}_p\right)\right|^{-1}+\left|\left(2N+f-1\right)/\hat{I}_g\right|-N} \quad (8)$$

$$f=\left(1-0.04h_w+0.0005h_w^2\right)\left(1+0.091N\right) \quad (9)$$

$$C=365.9\left(1-0.00883\beta+0.0001298\beta^2\right) \quad (10)$$

$$h_w=5.7+3.8V \quad (11)$$

As per Klein [17, 18],

$$U_t=\left[\frac{N}{\left(\frac{C}{T_p}\right)\left(\frac{T_p-T_a}{N+f}\right)^{0.33}}+\frac{1}{h_w}\right]^{-1}+\frac{\sigma\left(T_p+T_a\right)\left(T_p^2+T_a^2\right)}{\left|\hat{I}_p+0.0591Nh_w\right|^{-1}+\left|\left(2N+f-1+0.133\hat{I}_p\right)/\hat{I}_g\right|-N} \quad (12)$$

$$f=\left(1+0.089h_w-0.1166h_w\hat{I}_p\right)\left(1+0.07866N\right) \quad (13)$$

$$C=520\left(1-0.000051\beta^2\right) \quad (14)$$

$$\text{for } 0^0<\beta<70^0 \text{ For } \beta>70^0,\text{use } \beta=70^0$$

$$e=0.43\left[1-\frac{100}{T_p}\right] \quad (15)$$

$$h_w=5.7+3.8V \quad (16)$$

As per Larson [9]

$$U_t=\left[\frac{N}{\left(\frac{C}{T_p}\right)\left(\frac{T_p-T_a}{N+f}\right)^{0.33}}+\frac{1}{h_w}\right]^{-1}+\frac{\sigma\left(T_p+T_a\right)\left(T_p^2+T_a^2\right)}{\left[\hat{I}_p+0.05N\left(1-\hat{I}_p\right)\right]^{-1}+\left[\left(2N+f-1\right)/\hat{I}_g\right]-N} \quad (17)$$

$$C=250\left[1-0.0044(\beta-90)\right] \quad (18)$$

$$f=\left(1-0.04h_w+0.0005h_w^2\right)\left(1+0.091N\right) \quad (19)$$

$$h_w=5.7+3.8V \quad (20)$$

As per Malhotra et. al [12]

$$U_t=\left[\frac{N}{\left(204.429/T_p\right).\left[L^3\cos\beta\left(T_p-T_a\right)/\left(N+f\right)\right]^{0.252}.L^{-1}}+\frac{1}{h_w}\right]^{-1}+\frac{\sigma\left(T_p^2+T_a^2\right)\left(T_p+T_a\right)}{\left[\hat{I}_p+0.0425N\left(1-\hat{I}_p\right)\right]^{-1}+\left[\left(2N+f-1\right)/\hat{I}_g\right]-N} \quad (21)$$

$$f=\left[\frac{9}{h_w}-\frac{30}{h_w^2}\right]\left[\frac{T_a}{316.9}\right]\left[1+0.091N\right] \quad (22)$$

The various correlations for 'hw' may be summarized as follows:

As per the Jurges [20],
$h_w = 5.7+3.8V$ (23)
V<5 m/s

As per the Wattmuff [16],
$h_w = 2.8+3V$ (24)
V<5 m/s

As per the Sparrow et al. [15],
$N_u=0.86\ Re_l^{0.5}.P_r^{1/3}\ L=4A/P$ (25)
$20 \times 10^3<Re_l<80 \times 10^{-3}$

As per the Test et. al. [13],
$h_w=8.55+2.56V$ (26)
$1.35 \times 10^5\leq Re\leq 3.15 \times 10^5$

As per the Shakerin [6],
$N_u=1.23\ Re^{0.5}.P_r^{1/3}\ ;\ \propto<40^0$ (27)
$N_u=0.9\ Re^{0.5}.P_r^{1/3}\ ;\ \propto<40^0$
$58000 \leq Re \leq 25000$

As per the Sharples [1],
$h_w=8.3+2.2V=9.31^{0.44}$ (28)
For I=0 & 0.8 <V<6.7 m/s
$h_w=7.9+2.6V=9.5.\ V^{0.46}$ (29)
For I=45 & 0.6<V<6.2 m/s
$h_w=6.5+3.3.V=9.5.V^{0.48}$ (30)
For I=0 & 0.8 <V<6.2

V. Results and Discussion

The salient features of the results obtained from the extensive experimental investigations, carried out on single glazed flat plate collector are given as under:

Fig. 3, 4, and 5 show the variations of top losses at 2, 3 and 4.5 m/s wind velocities. There is an increase in the loss is observed. This is obvious due to an increase in convective heat losses from the top with increasing wind velocities. From the graph of % losses, with increase in velocity, the absolute values of all the losses are found to be decreasing which is also an anticipated trend. Thus it is observed that the highest losses take place from the top are about 85-90%. The bottom losses are of the order of 5-10%.

Fig. 3, 5, and 7 give the effect of wind velocity on

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

distribution of losses that as input heat flux increases the top losses also increases this is due to an increase in the plate temperature. The bottom and the side losses are relatively decreasing. This is basically due to higher rate of heat loss by convection and radiation losses from the top as compared to the losses by conduction from the bottom.

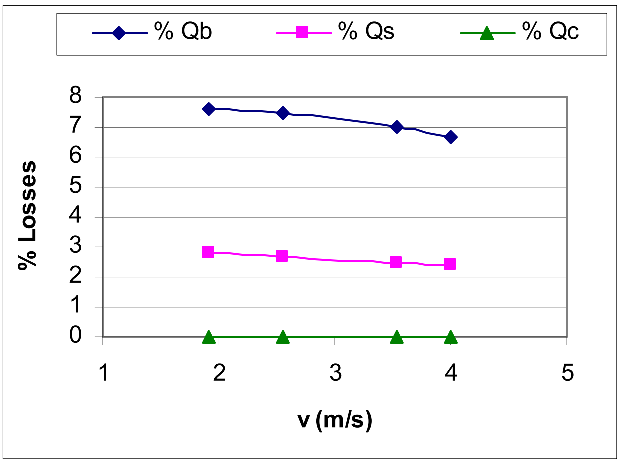

Fig. 3 Losses (%) Vs. Wind speed (m/s) when Q_{in}/A_p=207.42W/m^2

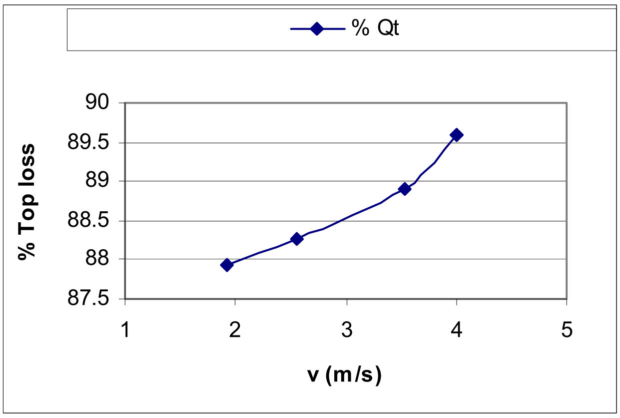

Fig. 4 Top loss (%) Vs. Wind speed (m/s) when Q_{in}/A_p=207.42W/m^2

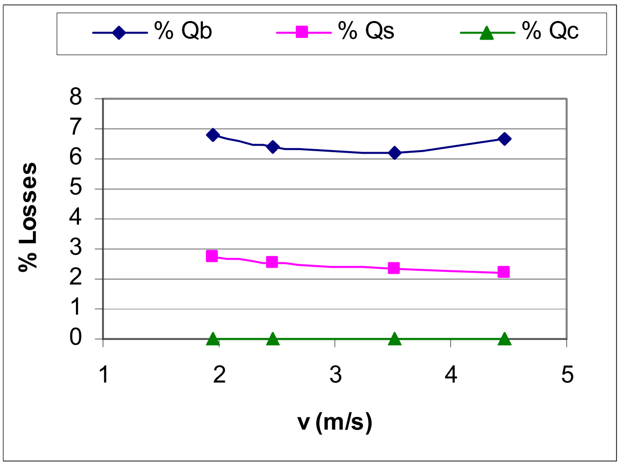

Fig. 5 Losses (%) Vs. Wind speed (m/s) when Q_{in}/A_p=425W/m^2

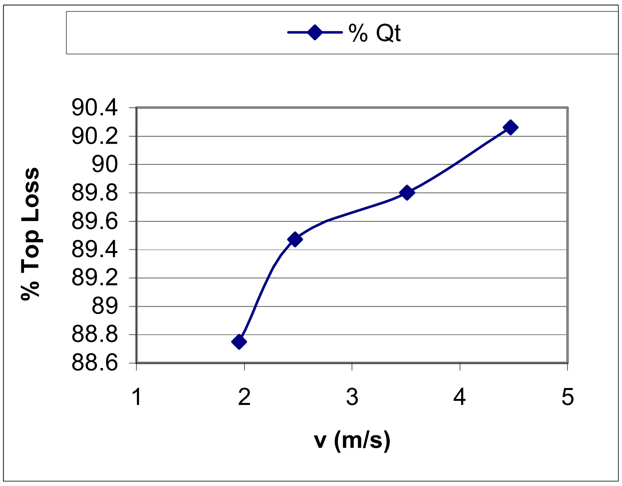

Fig. 6 Top Loss (%) Vs. Wind speed (m/s) when Q_{in}/A_p=425W/m^2

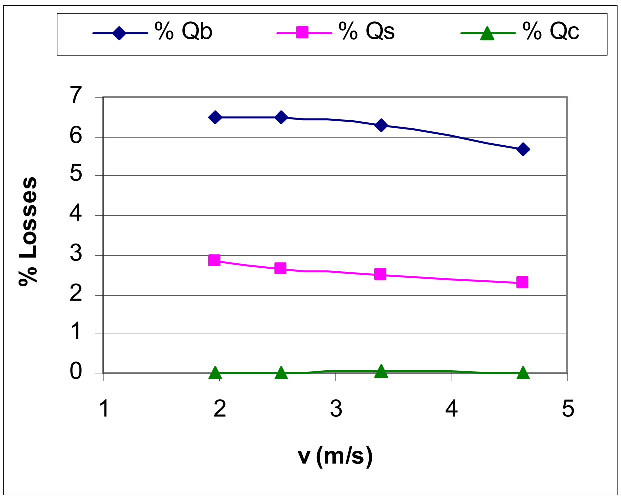

Fig. 7 Losses (%) Vs. Wind speed (m/s) when Q_{in}/A_p=780W/m^2

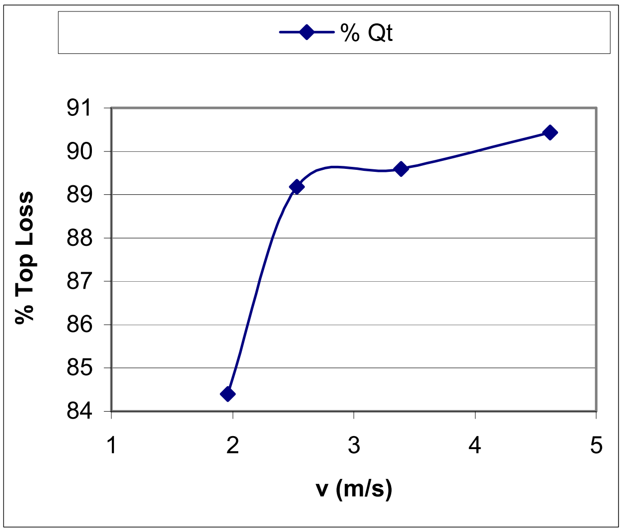

Fig. 8 Top Loss (%) Vs. Wind speed (m/s) when Q_{in}/A_p=780W/m^2

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

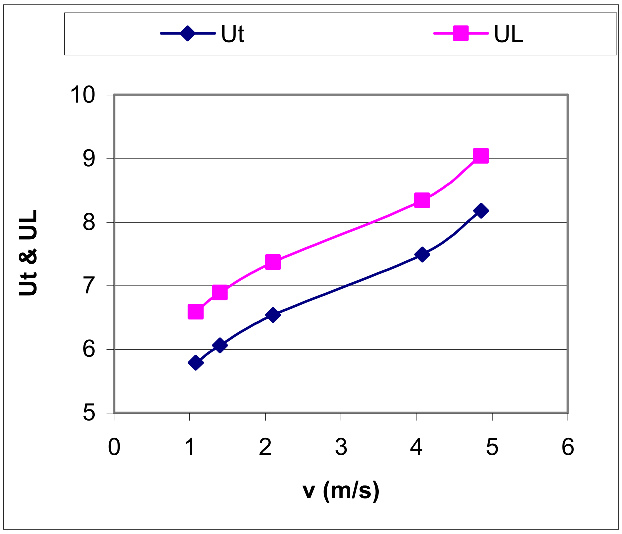

Fig. 9 U_t & U_L Vs. Wind speed (m/s) when Q_{in}/A_p=207W/m^2

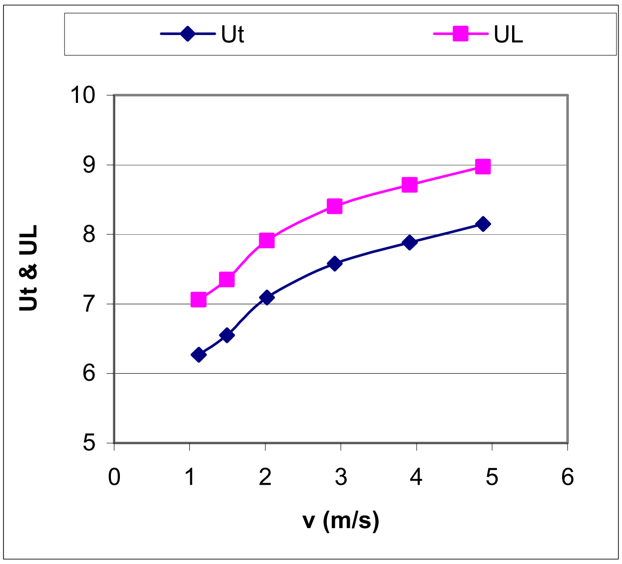

Fig. 10 U_t & U_L Vs. Wind speed (m/s) when Q_{in}/A_p=420W/m^2

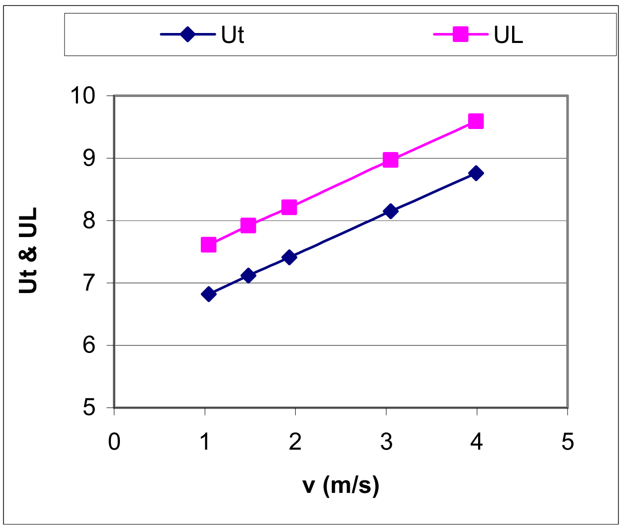

Fig. 11 U_t & U_L Vs. Wind speed (m/s) when Q_{in}/A_p=710W/m^2

With an increase in the wind velocity, there is an increase in the top loss coefficient of the collector as shown in Fig. 9, 10, and 11. This is quite obvious from the fact that at higher velocities, the convective losses are higher from the upper surface of the collector, which in turn results in higher top loss coefficients.

Fig. 9, 10, and 11 also indicate that the overall loss coefficient (U_L) increases with increase in velocity.

VI. Conclusion

Based on the present investigations, the effect of the wind velocities on different losses and the loss coefficients of a single glazed flat plate collector, following conclusions may be drawn.

The increase in the wind velocity, enhances the percentage top loss and the bottom loss coefficients, this is due to increased convective losses. The top loss co-efficient correlation in general over predicts the value of U_t by 5 to 15%, Klein [17], Samdarsai and Malluick [2, 5], Agrawal and Larson [9] correlation seems to correlate the present work with ± 10%.

References

[1] Sharples S, and Charlesworth P.S., "Full Scale Measurements of Wind Induced Convective Heat Transfer from a Roof Mounted Flat Plate Collector", *Journal of Solar Energy*, Vol. 62, No. 2, pp. 69-77, 1998.

[2] Samdarshi S.K. and Mullick S.C., "Generalised Analytical Equation for the Top Loss Factor of a Flat Plate Solar Collector with N Glass Covers", Personnel Communications, 1993.

[3] Duffie J. A. and Beckman W. A., *Solar Engineering of Thermal Processes*, 2nd Ed. John Willey and Sons, Inc., New York, 1991.

[4] Mullick S.C. and Samdarshi S.K., "Analytical Equation For The Top Heat Loss Factor Of A Flat Plate Collector With Double Glazing", *ASME Journal of Solar Energy Engineering*, Vol. 113, pp. 117-122, May 1991.

[5] Mullick S.C. and Samdarshi S.K., "An Improved Technique For Computing The Top Heat Loss Factor Of A Flat Plate Collector With A Single Glazing", *ASME Journal of Solar Energy Engineering*, Vol. 110, pp. 262.267, Nov.1988.

[6] Shakerin S., "Wind Related Heat Transfer Coefficient for Flat Plate Solar Collectors", *ASME Trans., Journal of Solar Energy Engineering*, Vol. 109, pp. 108-111 May 1987.

[7] Rabl A., *Active Solar Collectors and Their Applications*, Oxford University Press, 1985.

[8] Sukhatme S.P., *Solar Energy-Principle of Thermal Collection and Storage*, Tata McGraw Hill Publication Co., Delhi, 1984.

[9] Agarwal V.K. and Larson D.C., "Calculation of The Top Loss Coefficient of A Flat Plate Collector", *Solar Energy*, Vol. 27, pp. 69-71, 1981.

[10] Channiwala S.A. and Doshi N.I., "Heat Loss Coefficients For Box Type Solar Cooker", *Journal of Solar Energy*, Vol. 42, No.6, pp. 495·501, 1981.

[11] Hollands K.G.T., Unny T,E., Raithby G.D., and Konicek L., "Free Convective Heat Transfer Across Inclined Air Layers" *ASME Journal of Heat Transfer*, Vol. 98, No.2, pp. 189-193, May 1981.

[12] Malhotra A., Garg H.P. and Palit A., "Heat loss Calculation of Flat Plate Solar Collector", *Journal of Thermal Engineering*, Vol. 2, No.2, pp. 59-62, 1981.

[13] Test F.L., Lessmann R.C. and Johary A., "Heat Transfer During Wind Flow Over Rectangular Bodies in the Natural Environment", *ASME Trans. of Heat Transfer*, Vol. 103, pp. 262-267, May 1981.

[14] Sam R.G., Lessmann R.C., and Test F. L., "An Experimental Study of Flow Over a Rectangular Body", *ASME Journal of Fluid Mechanics*, Vol. 101. pp. 443·448, 1979.

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

[15] Sparrow EM., and Tien K.K., "Forced Convection Heat Transfer at an Inclined and Yawed Sequare Plate -Application to Solar Collectors", *ASME Journal of Heat Transfer*, pp. 507-512., Nov. 1977.

[16] Wattmuff J. H., Charters W. W. S., and Proctor D., "Solar and Wind Induced External Coefficients for Solar Collectors", *Int. Revue d' Hellio-technique* 2, 56, 1977.

[17] Klein S.A., "Calculation of Flat Plate Collector Loss Coefficients", *Solar Energy*, Vol. 17, pp. 79-80, 1975

[18] Klein S.A, *The Effect of Thermal Capacitance Upon The Performance of Flat Plate Solar Collector*, M.Sc. Thesis, University of Wisconsin, 1973.

[19] Swinbank W.C., "Long -wave Radiation from Clear Skies", *Quarterly Journal of Royal Meteorological Society*, Vol. 89, 1963.

[20] Jurges I.W., "Der warmeu bergang an Einer Ebenen Wand", *Biehefte Zum Gesundheits – Ingenieur*, Rehine – 1, Beihefte 19, 1924.

[21] Mc Admas W.H., *Heat Transmission*, 3rd Ed. McGraw Hill. New York, 1954.

[22] Hottel H.C. and Woertz B.B., "Performance of Flat Plate Heat Solar Collector". *Trans. ASME*, Vol. 64, pp. 94 -102, Feb. 1942.

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)