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Effect of overall Heat loss coefficient on performance of Circular Solar collector for close water open air (CWOA) humidification dehumidification process

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Abstract: Solar energy is an abandoned energy source which are alternate in comparison of other resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat. The flat-plate collector is commonly used which having high heat loss result in low convective heat transfer. Also it can be used in water heating systems serious corrosion problem arrived. The solar air heater is newly developed air tight circular collector whose absorber is usually made of a metal tube of high thermal conductivity, such as copper or aluminum. Its surface is coated with dull black painted over the entire outer surfaces to maximize radiant energy absorption while minimizing radiant energy emission. Q_a is the amount of solar radiation received by the circular collector. As the collector absorbs heat energy ,effect in its temperature rising , comparison with than that of the surrounding and heat is lost in to the atmosphere by convection and re radiation, this heat loss rate can be presented by Q_l.The overall heat loss coefficient is a key factor for the performance of air tight circular solar collector. The overall heat loss coefficient of airtight circular collector is increase with increasing in absorber temperature, which wills effects on efficiency of airtight circular solar collector.

Keyword: Heat Loss coefficient, circular solar collector, humidification, dehumidification

I. INTRODUCTION

. Q_a is the amount of solar radiation received by the circular collector. As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost in to the atmosphere by convection and radiation, this heat loss rate presented by Q_l[4]
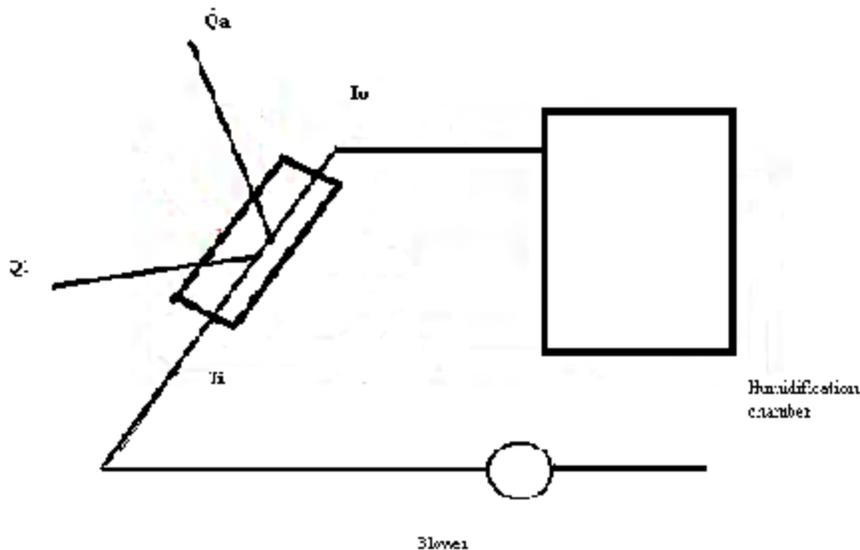
Figure 1   Schematic Diagram of Circular solar air heater and position of different parts

The solar air heater is air tight circular collector in which absorber tube is place concentrically in glass tube, between glass tube and absorber tube only air is present and at the both end, neoprene rubber air seals are kept between glass tube and absorber tube[5]
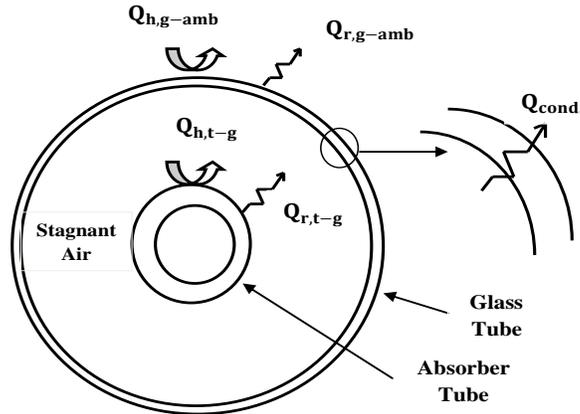
Figure 2   Heat losses through circular solar air heater

Energy balance for radiation absorb by absorber Q_a , heat loss Q_L and useful energy gain Q_u is given by
$$Q_a = Q_L + Q_u$$

Under steady state, conditions heat transfer, are same as the heat loss through collector having area A_o

1. From absorber tube to inner glass cover (Q_{t-g})
2. By conduction through glass ($Q_{cond.}$) and
3. From glass upper surface to ambient (Q_{g-amb})]

1. Heat transfer Q_{t-g} from absorber tube to inner glass surface is due to combine natural convection heat transfer $Q_{h,t-g}$ and radiation heat transfer $Q_{r,t-g}$, which is given by $Q_{t-g} = Q_{h,t-g} + Q_{r,t-g}$

a. Natural convection heat transfer ($Q_{h,t-g}$): For concentric cylindrical enclosure maintains at uniform but different temperature, is given by

$$Q_{h,t-g} = \frac{2\pi k_{eff} L}{Ln\left(\frac{D_{ci}}{D_o}\right)} \left(T_{t_o} - T_{g_1}\right)$$

[3]

The recommended relation for effective thermal conductivity k_{eff}
$\frac{k_{eff}}{k} = 0.317(Ra^*)^{\frac{1}{4}}$ **(Correlation due to Raithby and Hollands)**
Rayleigh number

$$R_a = \frac{g \; X \; \Delta t \; X \; (D_{ci} - D_o)^3 X \; Pr}{T_{mean} \; X \; v^2}$$

[3]

Modified Rayleigh number:

$$(R_a^*)^{1/4} = \frac{\ln (D_{ci}/D_o)}{b^{3/4}\left(\frac{1}{D_o^{3/5}} + \frac{1}{D_{ci}^{3/5}}\right)^{5/4}} \ X \ R_a^{1/4}$$ [3]

$$Where, b = \left(\frac{D_{ci} - D_o}{2}\right)$$ [3]

b. Radiation heat transfer $Q_{r,t-g}$: The radiation heat transfer from the absorber tube to the bottom portion of glass cover is in good approximation according to Duffie and Beckman (2006)

$$Q_{r,t-g} = \frac{A_{abs}\sigma\left(T_{mean}^4 - T_{g_i}^4\right)}{\frac{1}{\varepsilon_p} + \frac{A_{abs}}{A_{gi}}\left(\frac{1}{\varepsilon_c} - 1\right)}$$ [3]

$$\therefore Q_{t-g} = h_{t-g}A_{abs}\left(T_{mean} - T_{g_i}\right)$$ **Hence,**

$$h_{t-g} = \left|\frac{2\pi k_{eff}L}{Ln\left(\frac{D_{ci}}{D_o}\right)} \times \frac{1}{A_{abs}} + \frac{\sigma\left(T_{mean}^2 + T_{g_i}^2\right)\left(T_{mean} + T_{g_i}\right)}{\frac{1}{\varepsilon_p} + \frac{A_{abs}}{A_{gi}}\left(\frac{1}{\varepsilon_c} - 1\right)}\right|$$

$$R_{t-g} = \frac{1}{h_{t-g}} = \frac{1}{\left[\frac{2\pi k_{eff}L}{Ln\left(\frac{D_{ci}}{D_o}\right)} \times \frac{1}{A_{abs}} + \frac{\sigma\left(T_{mean}^2 + T_{g_i}^2\right)\left(T_{mean} + T_{g_i}\right)}{\frac{1}{\varepsilon_p} + \frac{A_{abs}}{A_{gi}}\left(\frac{1}{\varepsilon_c} - 1\right)}\right]}$$

2. Heat transfer Q_{cond} by conduction through glass tube.

As the glass having significant thickness, heat transfer by conduction through glass is consider, which is given by

$$Q_{cond} = \frac{2\pi k_g L\left(T_{g_i} - T_{g_o}\right)}{\ln\left(\frac{D_{co}}{D_{ci}}\right)}$$ [3]

3. Heat transfer Q_{g-amb} from outer glass surface to ambient.

Heat transfer from outer glass surface to ambient are due to the combined natural convection and radiation heat transfer, which is given by

$$Q_{g-amb} = Q_{r,g-amb} + Q_{h,g-amb}$$

$$= \epsilon_g A_{g_0} \sigma \left(T_{g_0}{}^4 + T_a{}^4 \right) + h_{h,g-amb} A_{g_0} \left(T_{g_0} - T_a \right)$$

$$= \left[\epsilon_g \sigma \left(T_{g_0}{}^2 + T_a{}^2 \right)\left(T_{g_0} + T_a \right) + h_{h,g-amb} \right]\left[A_{g_0}\left(T_{g_0} - T_a \right) \right]$$

$$= h_{g-amb}\left[A_{g_0}\left(T_{g_0} - T_a \right) \right]$$

Where $h_{g-amb} = \left[\epsilon_g \sigma \left(T_{g_0}{}^2 + T_a{}^2 \right)\left(T_{g_0} + T_a \right) + h_{h,g-amb} \right]$ is combined convection radiation heat transfer coefficient from glass to ambient.[10]

Correlation for natural convection heat transfer coefficient $h_{h,g-amb}$ for cylinder given as follows

Co relation based on the data of R. Hilpert

$Nu = C_1 R_e{}^n$

$Nu = Nusselt\ number$

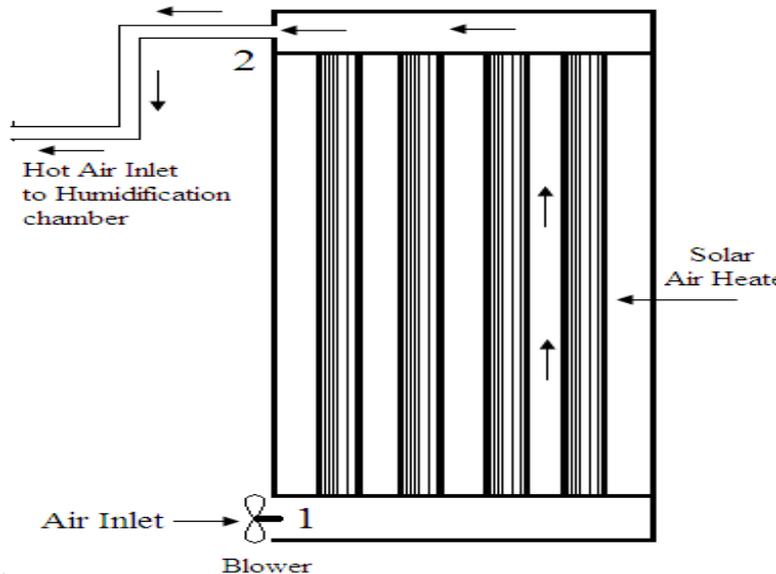$Where, C_1 \& n\ are\ constants\ having\ the\ following\ values$

$For\ 40 < Re\ < 4000, \quad C_1 = 0.615, \quad n = 0.466$

$For\ 4000 < Re\ < 40000, \quad C_1 = 0.174, \quad n = 0.618$

$For\ 40000 < Re\ < 400000, \quad C_1 = 0.0239, \quad n = 0.0805$

Overall heat loss coefficient of collector i.e. overall heat loss coefficient based on outer glass surface area ($A = \pi D_{co} L$) is given by,

$$U = \frac{1}{\left(R_{t-g} + R_{cond.} + R_{g-amb} \right)A} \quad [1]$$

Figure 3   Schematic diagram of actual model for air inlet and outlet

II   DESCRIPTION OF EXPERIMENTAL SYSTEM

Air heater is developed with the help of different parts like absorber tubes, glass tube covers, neoprene rubbers, air inlet unit, air outlet unit, support cover, a blower, and speed regulator for blower and steel stand. It is connected by RTD (PT 100) at various locations in different position which are co-associated with temperature indicator for getting temperature during regular time interval.[6] Air speed (wind) can be read by anemometer, solar radiation can be obtained with the help of pyranometer. Four aluminum tubes that having length 1600 mm, outside diameter and inside diameter are 38mm, 36mm respectively used as absorber tubes. Spacing between two absorber tubes are 120 mm. Black dull paint is used on over the entire outer surfaces of the tube to absorb maximum amount of radiation from the Sun during a day. Spray painting machine utilized for preparation of uniform surface thickness of absorber tube. All four absorber tubes are covered by borosilicate glass tubes whose dimensions are 1500 mm length, 60 mm outside diameter and54 mm inside diameter respectively.[7] Spacing between two glass cover are 60mm. Fire work is done on both end of glass tube to prevent fracture at the time of assembly. Borosilicate glass tube used as a collector cover for reducing convectional and radiation heat losses. The absorber tube is placed concentrically in borosilicate glass tube, and at the both ends is sealed with neoprene rubber, which will act as sealant to the air present between absorber and glass tubes .Neoprene rubber also maintain gap between absorber and glass tube. Air inlet unit is manufactured from mild steel cylinder, having 760 mm length, 120 mm inside diameter and 123.2 mm outside diameter. It supports four absorber tubes as well air blower.[8] Air outlet unit also made from Aluminum rectangular section 85mm×45mm .There are four circular holes drilled for joining absorber tubes. It is closed at one end with cover and other end of duct is connected with Humidification chamber. Air outlet unit having 830 mm length. Two support cover are made from MS sheet which are bended on hydraulic press and punched six circular holes. They are supports to solar circular collectors, air inlet unit and air out let unit. They are clamped on frame having slope of 350 with horizontal surface.[9]

III   EXPERIMENTAL PROCEDURE

The experimental apparatus is located Vadodara latitude 22.000 N 73.10° E. The air heater is inclined at 350 south facing and connected to humidification chamber. The whole assembly is mounted on the fixed stand. The experimental setup was run from 07:00 am to 06:00 pm. Every one hour interval   temperature on four absorber outer surface has been taken. Simultaneously four outer surface temperatures on glass tube are noted. Also air inlet temperature and out let temperature are readied by Digital temperature indicator. The experiments are conducts by varying flow rate of air are 5.7×10^{-3} m^3/s, 7.92×10^{-3} m^3/s, 9.72×10^{-3} m^3/s, 11.52×10^{-3} m^3/s, 13.32×10^{-3} m^3/s, 14.4×10^{-3} m^3/s and the measurements of solar radiation using pyranometer.[11] Instrument adaption for data collection for different sensors. This is the main core area of the research work the components were selected. Then the system was fabricated and installed. Nearly three months readings were taken with the help of accurate and sophisticated instruments then the most prominent are presented, discussed and analyzed to draw the conclusions.[14] The assumptions are made as the performance of the unit is time-dependent. The climatic conditions are averaged through an hour. There is no air leakage from the system, when air passes through the air heat. [2]

Figure 4 Setup of circular solar air heater

IV   RESULT AND DISCUSSION

Table 1 (12/04/2014) Overall heat loss coefficient and efficiency at different absorber surface temperature

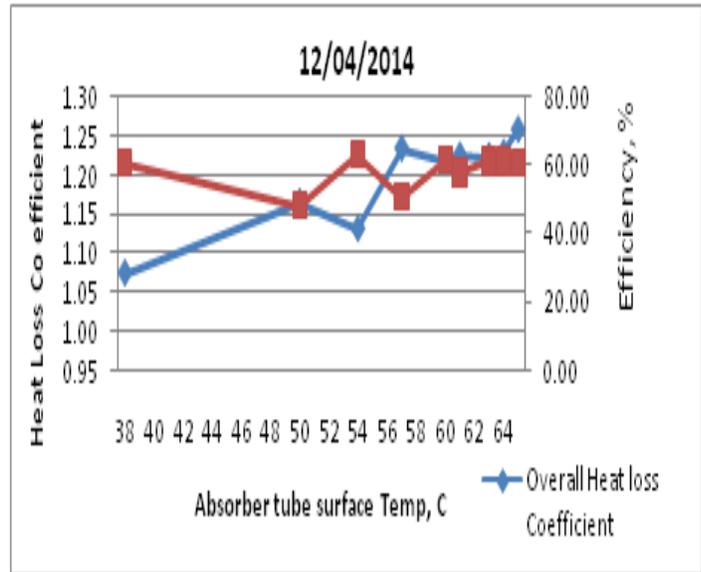| Absorber tube Temp, C	Overall Heat loss Coefficient	Collector Efficiency
38.75	1.07	60.88
50.25	1.17	48.28
54.25	1.13	63.04
57.75	1.24	50.69
60	1.22	61.67
61.25	1.23	57.82
63.5	1.22	61.44
63.5	1.22	60.76
64	1.23	61.11
65.25	1.26	60.89

Figure 5 Overall heat loss coefficient and efficiency at different absorber surface temperature

Table 2 (21/04/2014) Overall heat loss coefficient and efficiency at different absorber surface temperature

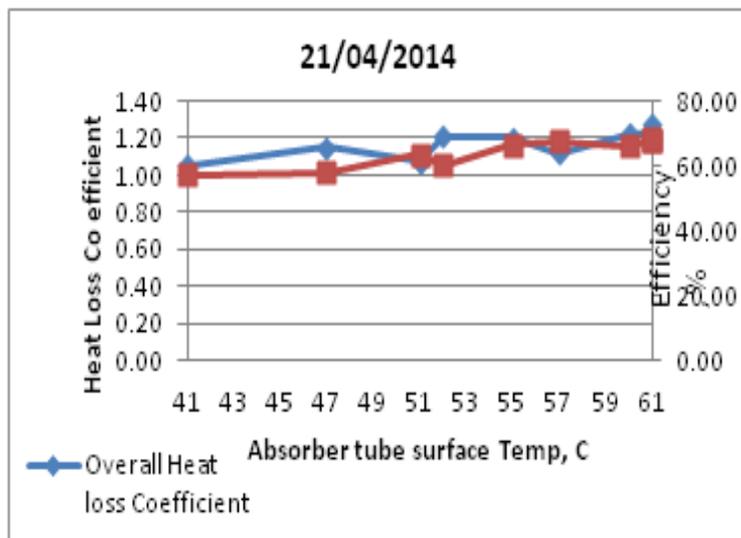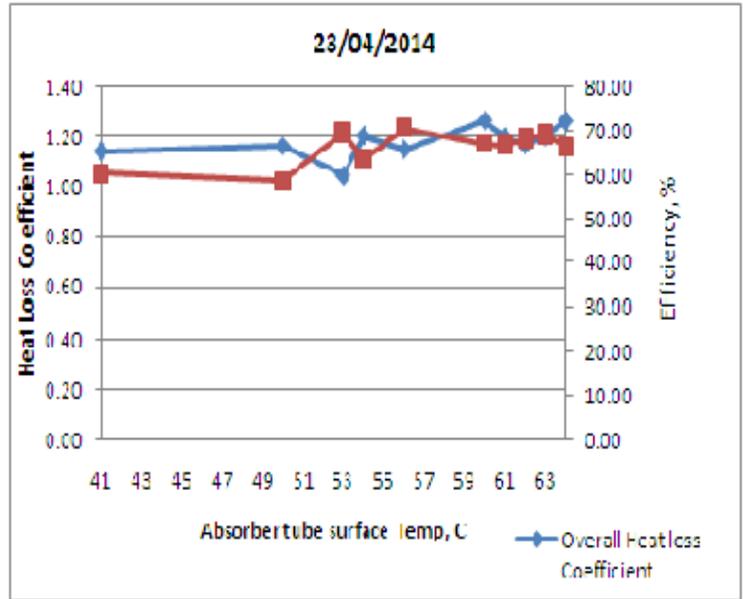| Absorber tube Temp, C	Overall Heat loss Coefficient	Collector Efficiency
41.25	1.05	57.29
47.25	1.15	58.02
51.5	1.07	63.45
52.75	1.21	60.11
55.25	1.20	66.36
57.75	1.12	67.67
60.25	1.22	66.25
61	1.23	68.02
61.25	1.20	68.07
61.5	1.27	68.22

Figure 6 Overall heat loss coefficient and efficiency at different absorber surface temperature

Table 3 (23/04/2014) Overall heat loss coefficient and efficiency at different absorber surface temperature

Absorber tube Temp, C	Overall Heat loss Coefficient	Collector Efficiency
41.5	1.15	60.26
50	1.17	58.61
53.5	1.05	69.45
54.5	1.21	63.49
56.5	1.15	70.52
60.25	1.27	67.04
61	1.20	66.70
62.25	1.17	68.25
63.25	1.20	69.13
64.75	1.26	66.39

Figure 7 Overall heat loss coefficient and efficiency at different absorber surface temperature

Table 4 (25/04/2014) Overall heat loss coefficient and efficiency at different absorber surface temperature
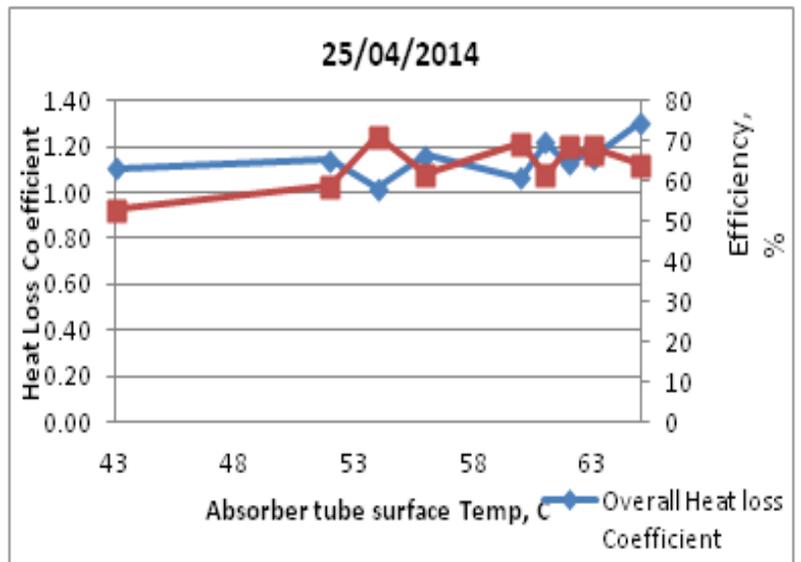
Absorber tube Temp, C	Overall Heat loss Coefficient	Collector Efficiency
43.5	1.10	52.81
52	1.14	58.65
54	1.02	71.02
56	1.16	61.72
60	1.07	69.47
61.75	1.22	61.25
62.5	1.13	68.47
63.25	1.18	66.55
63.75	1.15	68.40
65	1.30	64.09

Figure 8 Overall heat loss coefficient and efficiency at different absorber surface temperature

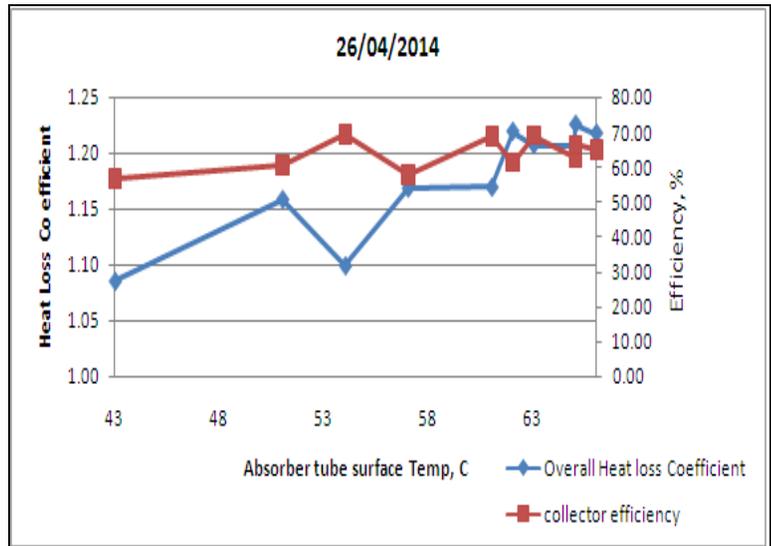*Table 5(26/04/2014)* Overall heat loss coefficient and efficiency at different absorber surface temperature

Absorber tube Temp, C	Overall Heat loss Coefficient	Collector Efficiency
43.5	1.09	56.77
51	1.16	60.50
54.75	1.10	69.38
57.25	1.17	58.06
61	1.17	68.83
62	1.22	61.37
63.25	1.21	68.97
65.5	1.21	62.81
65.75	1.23	66.42
66	1.22	65.08

Figure 9 Overall heat loss coefficient and efficiency at different absorber surface temperature

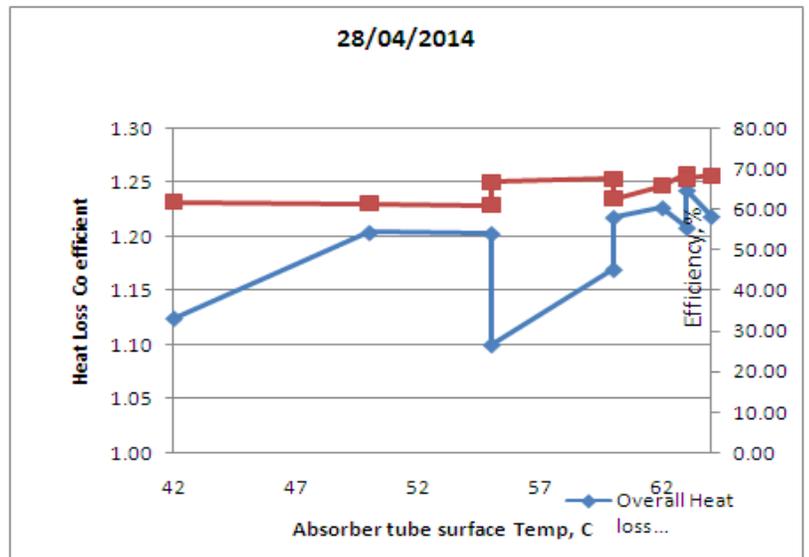*Table 6 (28/04/2014)* Overall heat loss coefficient and efficiency at different absorber surface temperature

Absorber tube Temp, C	Overall Heat loss Coefficient	Collector Efficiency
42.25	1.12	61.68
50.25	1.20	61.39
55.25	1.20	61.03
55.25	1.10	66.68
60.5	1.17	67.49
60.75	1.22	62.69
62.75	1.23	65.87
63	1.21	68.79
63.75	1.24	67.74
64.5	1.22	68.44

Figure 10 Overall heat loss coefficient and efficiency at different absorber surface temperature

V   CONCLUSION

Following variation of different parameters can be seen at different air flow rate

- The overall heat loss coefficient of airtight circular collector is increase from 1.06 to 1.26 with increasing in absorber temperature from38.75 to 62.25, which wills effects on efficiency of airtight circular collector at 5.7×10^{-3} m^3/s,air fiow rate

- The overall heat loss coefficient of airtight circular collector is increase from 1.05 to 1.27 with increasing in absorber temperature from41.25 to 61.5, which wills effects on efficiency of airtight circular collector at 7.92×10^{-3} m^3/s, ,air fiow rate

- The overall heat loss coefficient of airtight circular collector is increase from 1.15 to 1.26 with increasing in absorber temperature from41.5 to 64.75, which wills effects on efficiency of airtight circular collector at 9.72×10^{-3} m^3/s,air fiow rate

- The overall heat loss coefficient of airtight circular collector is increase from 1.10 to 1.30 with increasing in absorber temperature from43.5 to 65, which wills effects on efficiency of airtight circular collector at 11.52×10^{-3} m^3/s,air fiow rate

- The overall heat loss coefficient of airtight circular collector is increase from 1.09 to 1.22 with increasing in absorber temperature from43.5 to 66, which wills effects on efficiency of airtight circular collector at13.32×10^{-3} m^3/s air fiow rate

- The overall heat loss coefficient of airtight circular collector is increase from 1.2 to 1.22 with increasing in absorber temperature from42.25 to 64.5, which wills effects on efficiency of airtight circular collector at 14.4×10^{-3} m^3/s,air fiow rate

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