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A Review of Solar Air Heater with Close Water Open Air (CWOA) For Humidification-Dehumidification Process

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Abstract — *The process of humidification-dehumidification has many advantages, such as the simple equipments, working under normal condition like atmosphere pressure, the cost of investment and operation is moderate too low, the flexible scale and the low-grade energy available,. Hence, it has a good developing prospect. Humidification dehumidification process is viewed as a promising technique for house hold capacity production plants. The process has many attractive features, which includes operation at low temperature sources, and requirements of low level of technical features. On the other hand, most of the ongoing researches concentrate on large-scale plants which are suitable for mass production of fresh water they also cause environment pollution because they are fossil-fuel driven solar air heating, in contrast, has not been studied extensively. The heaters will be compared on the basis of their collection efficiencies These heaters can utilize about 40% or over of the total cost of a humidification-dehumidification system and so the development of a cost effective and efficient solar collector is essential to the system's overall feasibility [1]. Considering the importance of solar air heaters to the overall performance and cost of HDH air-heating systems, they are reviewed in the current paper , which is defined as the useful heat gain of the air stream (in watts) divided by the solar irradiation incident on the collector (also in watts), Heat gained by air*

$$\eta = \frac{Heat\ gained\ by\ air}{Solar\ incident\ radiation} \qquad (1)$$

The collectors which are flat plate with large airflow channels. Air flows over or under the absorber plate, and double-pass strategies are sometimes employed. In flat plate air heaters cost incurred due to insulation cladding are more so the air heaters with less amount of insulation are required to develop. Air heater with Circular solar Collector having, minimum incident angle effect, high efficiency, variable mass flow and with insulation on outlet air unit to reduce heat loss.

Keywords- *Humidification; Solar Radiation; Circular Solar Collector; Dehumidification; Air Heater*

1. Introduction

Air heating collectors have been occasionally used since World War II, mostly for low temperature space heating applications. Gupta and Garg [6] tested several designs that used both corrugated absorber surfaces as well as wire mesh packing over the absorber. They also provided an overall efficiency that took into account the power to force air through the heater. They showed that corrugated surfaces performed better than those enhanced with wire mesh, achieving a maximum of 65% overall energy conversion efficiency. A design by Close was able to achieve temperatures of around 65 ^{0}C with a collector efficiency of 50%. This study also investigated the use of corrugated absorber surfaces to maximize heat transfer by increasing surface area, and used a trapped layer of air between the single glazing surface and absorber. Interest in solar air heating, and alternative energy in general, picked up with the 1973 oil crisis Many air heaters included novel designs using multiple glazing's, forcing air through jets to create more turbulence to enhance heat transfer near the absorber plate, and circulating air between the glazing's. Satcunanathan and Deonarine also explored passing air between multiple glazing before heating it, and they found collector efficiency gains of 10-15%. Use of pickings to enhance heat transfer were investigated by Choudhury and Garg [9] who achieved a collector efficiency of 70% by using a packing material placed above the absorber plate and allowing air to pass through it. Sharma et al. used a wire matrix packing above the absorber plate to enhance heat transfer. Solar air heater is device, which is used to increase the temperature of flowing air through the heater. Solar air heaters are used for moderate temperature applications like: Space heating. Crop drying. Timber seasoning Industrial applications. Also the solar air heater is a vital component of a HD desalination system. The standard metric of a solar air heater's performance is the collector thermal efficiency. It is defined by $\eta = \frac{mc_p(T_{out} - T_{in})}{I_T A_P}$

Where, terms are defined in nomenclature. It is the energy gain of the airstream divided by the total solar energy incident on the collector. This definition of performance is that used by the ASHRAE 93-2003 Standard for solar collector testing [4] and it defines both the instantaneous and time averaged efficiencies when evaluating dynamically changing solar radiation inputs and temperature profiles.

2. Modern Air Heater Designs

Improving Convective Heat Transfer and Air Residence Time, Modern air heater designs have focused mainly on improving convective heat transfer at the absorber. Mittal and Varshney [10] investigated using wire mesh as a packing material, with air flowing between the absorber the second glazing through the mesh, achieving a collector efficiency of 70%. Figure 1 shows the flow path of this heater.

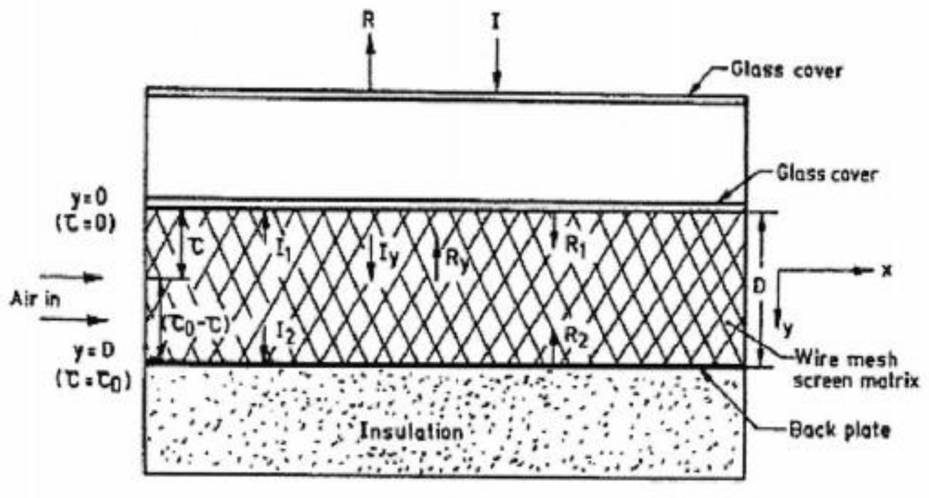

Figure 1: Flow path from Mittal and Varshney

Mohammad [11] found that a packed bed of porous media improved heat transfer as well as pre-warming the air by first running it between two glazing plates. This also improved collector efficiency by reducing heat loss to the environment, and helped achieve an overall efficiency, which accounts for pumping losses for moving air through the collector, of 75%. Esen [12] compared several obstacles mounted on a flat plate to a plain flat plate and found that short triangular shaped barriers improved heat transfer efficiency the most by breaking up the boundary layer and reducing dead zones in the collector. Sahu and Bhagoria [13] used short (1.5 mm) ribs perpendicular to the absorber plate to break up airflow as it went over the absorber plate and ribs, as shown in figure 2.

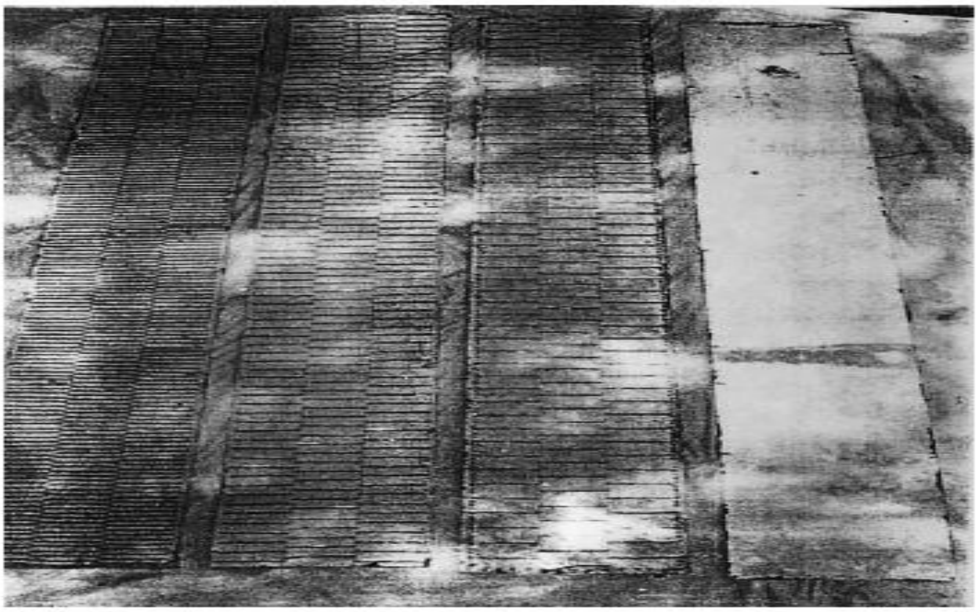

Figure 2: Roughened Absorber Plates

Romdhane [14] used small extensions from a metal plate to improve mixing of air on the plate. These extensions had the advantage of not increasing pressure drop like packed bed solar air heaters. Ho et al. [15] increased the collector efficiency of a flat metal absorber plate to 68% by running the air above and below the absorber plate, as shown in Figure3.The flow turns 180 degree to move back above the plate.

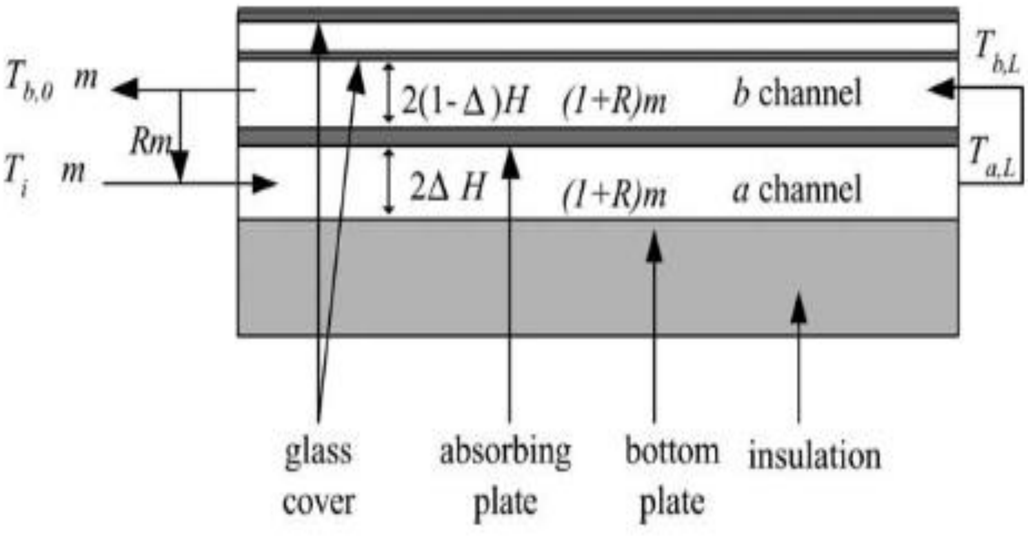

Figure 3: Flow path for heater

Ramadan [16]et al (2007) also reported an efficiency increase using double pass heating in addition to using a limestone packing above the absorber plate and passing air through it, as shown in figure 4.

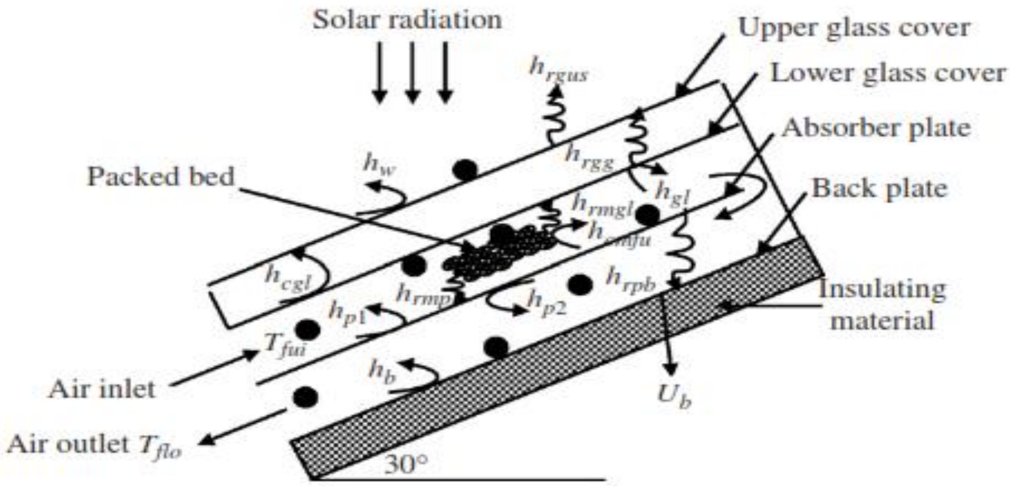

Figure 4: Flow path for a packed bed air heater

3. Roll of Selective Absorber Material

A selective absorber coating is a coating that has a high solar absorptivity, and low infrared emissivity. These coatings can help improve efficiency by increasing the absorptivity of the absorber plate and decreasing radiative loss. However at low temperature differences between the absorber and the environment, there is little improvement. Hachemi[17] studied the effect of selective surfaces on a solar air heater. The heater he tested compared a selectively coated absorber plate and a black painted absorber plate. The black plate was made from aluminum and the selective plate was sun-copper. Both collectors used a polycarbonate glazing with a stagnant air layer between the glazing and the absorber with air flowing under the absorber. For the case where fins were used, 5 cm long fins were attached to the bottom of the absorber plate perpendicular to the airflow in a staggered pattern. The fins impinged on the airflow to increase the rate of heat transfer. Their configuration is shown in Figure 5.The study found that, with a well-designed solar collector, which minimizes thermal radiation from the absorber, efficiency gains from using selective surfaces alone vanish at high temperature difference. It also shows that using other improvements such as fins; make the marginal gain in efficiency even less.

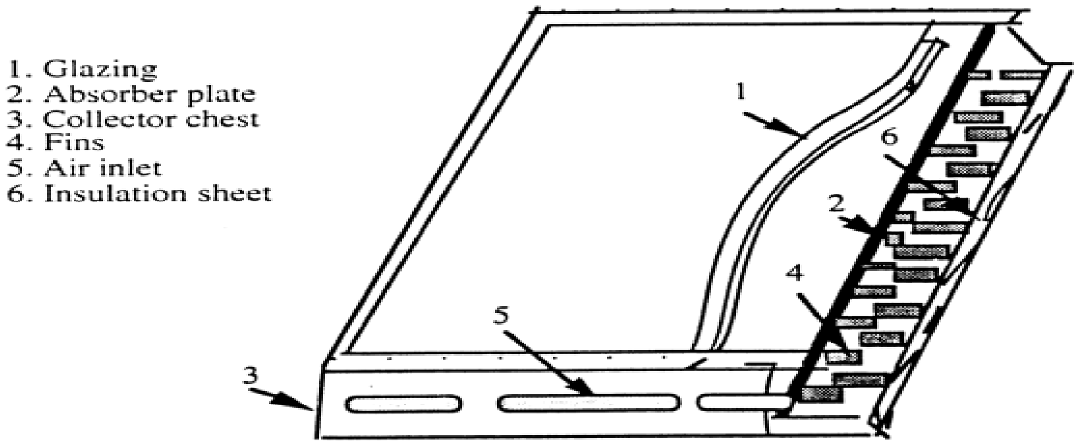

Figure 5 Configuration of impinging fins used by Hachemi [17]

Texieria et al. [18] found a doubling of efficiency for an unglazed flat plate operating at a temperature difference of 70 ^{0}C and solar irradiation of 1000 W/m^2 using selective surfaces as opposed to non-selective surfaces. This design's greatest enhancement was the addition of a selective surface as opposed to changing the absorber shape or adding glazing or additional insulation. Liu et al. [19] found only a 5% efficiency increase when using selective coatings on a corrugated absorber in a single-glazed solar air heater using a heavily insulated back plate with air flowing under the absorber. This compares with a reported 20% increase in efficiency by adding corrugation and not using selective surfaces.

4. Development in More Basic Designs

Other attempts have been made to improve existing flat plate absorber with limited success. These designs sacrifice efficiency for simplicity. Koyuncu [20] compared several flat plate designs, with one ribbed plate design, and several glazing configurations. The most efficient, at 45.8%, was flat black metal plate with a single polymer glazing, and air passing over the absorber. Matrawy [21] used fins below the absorber plate to enhance heat transfer to the air as it flowed under the absorber, but only achieved 50% collector efficiency.

5. Comparison of solar air heater Designs

When evaluating the performance of different solar air heaters it is necessary to take into account a variety of parameters. Performance data varies widely among academic literature. The following table summarizes some air heaters for which the necessary performance parameters if given with other important operation and performance parameters listed if known. Some values in the table were calculated from other parameters.

Table1 Comparison of solar air heater Designs

Author	dh [m]	$\dot{m}$ [kg/s]	Re_{d_h}	I [W/m2]	T_{out} [°C]	$T_{out} - T_{in}$ [°C]	η
Romdhane [14]						60	80%
Sahu and Bhagoria [13]	0.044	0.0164	8000	815	53	12	79.5%
Mohamad [11]							75%
Ramadan et al.[16]	0.214	0.0105	1026	662	68.5	38.5	45.3%
Mittal and Varshney[10]	0.047	0.025	6291	600	48	18	70%
Ho, Yeh, and Wang [15]	0.086	0.0214	6693	1100			68%
Satucunanathan and Deonarine[25]	0.073	0.0418	5378	850		23.8	68%
Esen [12]		0.02		900	28.9	23.3	53%

Close [23]	0.157	0.2842	31091	504	54.4	30.8	40%
Sharma et al. [24]	0.328	0.0165	1627	900	50	14	50%
Matrawy [21]	0.095	0.0140	1459	800	63	33	50%
Koyuncu [20]				1000	45	15	46%
Chafik[22]	0.011	0.0006	2411	800	48	22	40%

6. Air heater with Circular solar Collector

The solar air heater is air tight circular collector in which absorber tube is place concentrically of 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 which is shown in fig.6 [43]

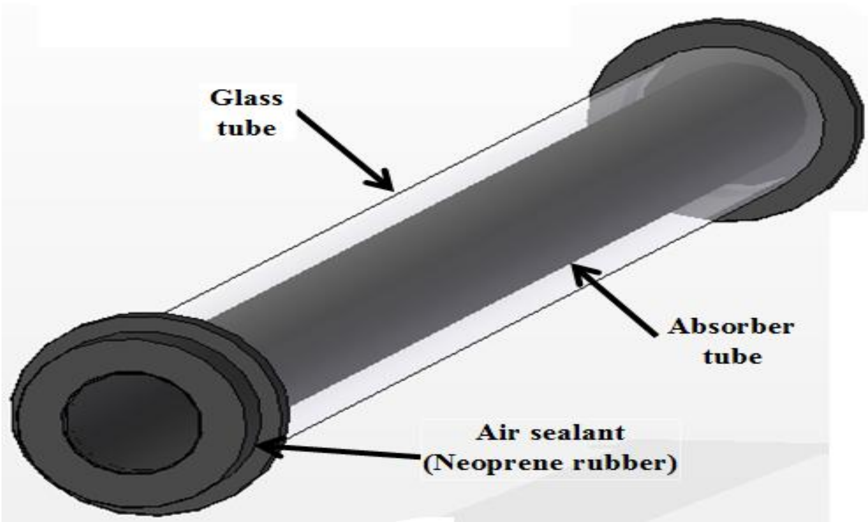

Figure 6 solar collector tube

If the θ is the angle between an incident beam radiation I and normal to the plane surface, then the equivalent flux or radiation intensity falling normal to the surface is given by $I \cos\theta$. θ is the incident angle and $\cos\theta$ is the incident angle effect which reduces the radiation intensity. We cannot get constant radiation intensity in case of flat plate air heater.

Hence, circular geometry collector is consider to minimize the angle of incidence of beam radiation on the collector surface and thus maximize the incident beam radiation. For the circular geometry collector in which plane rotated about a horizontal north-south axis with continuous adjustment following correlations are consider

$$\cos\theta = [\cos^2\theta_z + \cos^2\delta \sin^2\omega]^{1/2}$$

Where, θ_z is zenith angle, which is given by,

$$\cos\theta_z = \cos(\varphi - \beta)\cos\delta\cos\omega + \sin(\varphi - \beta)\sin\delta$$

Declination angle δ is the angular distance of sun's rays north (or south) of the equator. It is the angle between line extending from center of sun to the center of the earth and projection of this line upon the earth equatorial plane. This is the direct consequence of tilt and it's vary between 23.5o on June 22 to 23.5 o on December 22, which is given by

$$\delta(\text{in degrees}) = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$

Where, n is the day of the year,

$$\text{Hour angle } \omega = 15(t - 12)$$

Where, t is the local solar time, given by

$$\text{Local solar time } t = \text{standard time} \pm 4(L_{st} - L_{loc}) + E$$

negative sign is applicable for the eastern hemisphere.
where Lst is the standard meridian for the local time zone. Lloc is the longitude of location. And E is the equation of time in minutes.
Considering the Vadodara latitude φ = 22.55o N, slope β = 35o, longitude of Vadodara = 72o 95' N and Lst the standard meridian for the local time zone = 82o 30'. Incident angle effect $\cos\theta$ is calculated and tabulates as follows.

Table 2 Incident angle effect $\cos\theta$ for solar air heater on 1st day of every month

Local time	Incident angle effect $\cos\theta$											
	1st Jan	1st Feb	1st Mar	1st Apr	1st May	1st Jun	1st Jul	1st Aug	1st Sep	1st Oct	1st Nov	1st Dec
9:00	0.969	0.973	0.98	0.96	0.913	0.877	0.868	0.902	0.946	0.978	0.977	0.946
10:00	0.943	0.972	0.964	0.931	0.885	0.853	0.846	0.874	0.916	0.956	0.971	0.916
11:00	0.919	0.968	0.946	0.905	0.861	0.833	0.827	0.851	0.89	0.934	0.964	0.89
12:00	0.903	0.965	0.934	0.888	0.846	0.821	0.816	0.836	0.873	0.919	0.958	0.873
13:00	0.899	0.964	0.93	0.884	0.845	0.818	0.815	0.833	0.871	0.915	0.956	0.871
14:00	0.909	0.966	0.937	0.896	0.857	0.826	0.822	0.842	0.884	0.923	0.959	0.884
15:00	0.930	0.969	0.951	0.919	0.88	0.842	0.838	0.862	0.908	0.942	0.965	0.908
16:00	0.955	0.973	0.969	0.947	0.908	0.864	0.859	0.888	0.938	0.964	0.973	0.938
17:00	0.979	0.973	0.985	0.974	0.936	0.889	0.884	0.916	0.965	0.984	0.977	0.965

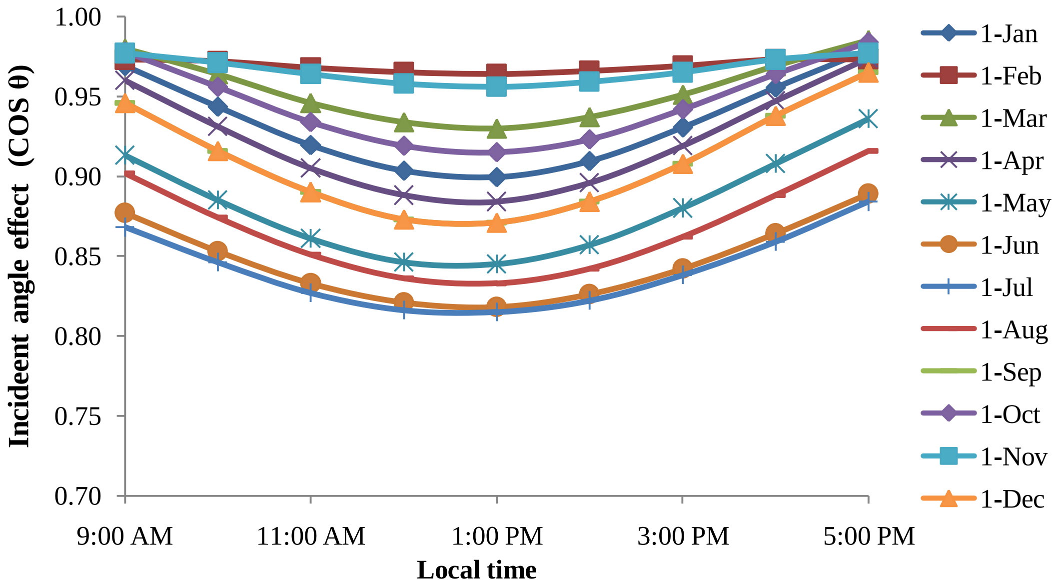

Figure 7 Incident angle effect $\cos\theta$ for solar air heater (Airtight circular collector)

From fig.7 it is observe that incident angle effect $\cos\theta$ for airtight circular collector is varying from 0.818 to 0.984 for different months at different hours. Due less incident effect maximum solar radiation can be receive by collector surface.

The solar air heater is used to estimate the U-value of air tight circular collector. For calculating the overall heat loss coefficient from the absorber to ambient, assumes in a steady state condition. Energy balance for radiation absorb by absorber Q_a , heat loss Q_L and useful energy gain Qu is given by

$$Q_a = Q_L + Q_u$$

$$I \times \tau_g \alpha_a \times A_c = U\,A\left(t_{t_o} - t_a\right) + Q_u$$

$$\text{Also } Q_u = m\,c_p \Delta t$$

$$Q_u = m\,c_p(t_1 - t_2) \qquad Q_u = m\,c_p(t_1 - t_2)$$

Also, a measure of collector performance is the collector efficiency, defined as ratio of useful gain over some specific time period to the incident solar energy over same time period.

$$\eta = \frac{Q_u}{I \times A_c}$$

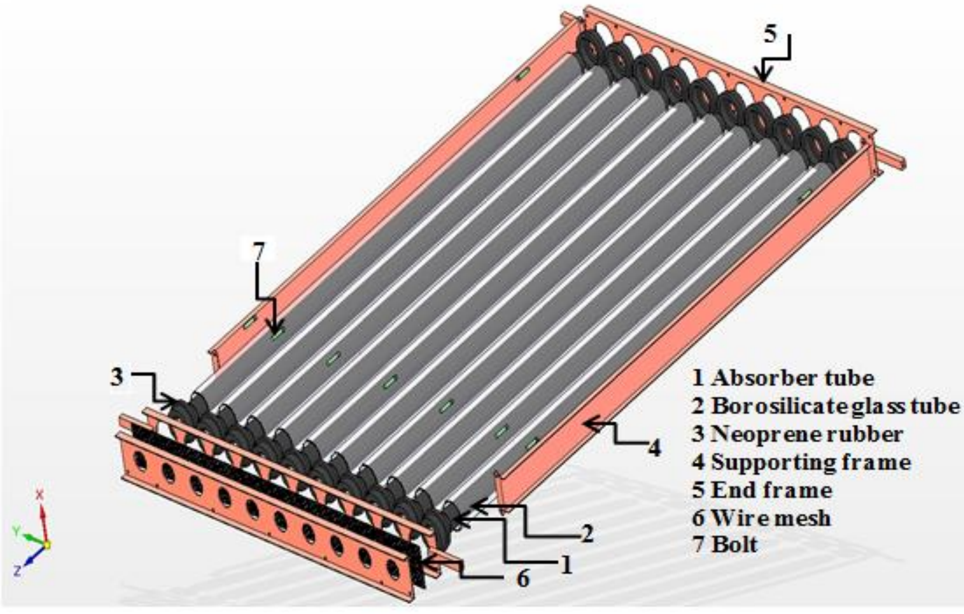

Figure 8 Air heater with Circular solar Collector

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