Fabrication and Performance evaluation of a v-groove solar air heater

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Abstract
In the present study, a v-groove solar air collector is used for research purposes. The absorber of solar collector made by copper with an area of 1.9m length and .97m.The surface of absorbent plate was covered by black paint. To insulate the collector, the glass wool with the thickness of 100 mm was used. The experiments were conducted and data was collected from the collector. The results of the collector efficiency in the forced convection were evaluated and their graphs were plotted. The results showed that the collector efficiency is about 35%. The low temperature difference between inlet and outlet of the collector decreased its heat loss.
Key Words : v-groove, solar collector, efficiency, temperature

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Introduction

Energy in various forms has played an increasingly important role in worldwide economic progress and industrialization.(1) Increased energy prices and the continuous reduction of the Earth's conventional fuels resources as well as the increased world-wide global warming have been the motivation for the recent growing interest in alternative sources of energy, such as solar energy. The development of new and renewable energy technologies is important for the future of a balanced global energy economy(2).Sunlight available freely as a direct and perennial source of energy provides a non-polluting reservoir of fuel. The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications by using solar collectors(1).Flat-plate collectors have an important place among applications of solar energy system. The main part of flat-plate collectors is black absorber surface.(3) . Flat plate solar air heaters are non-adiabatic radiative heat exchangers; they are essentially used at low temperature levels (T < 375K) in air heating and drying systems (4).Solar air heaters are simple devices to heat air by utilizing solar energy. Such heaters are implemented in many applications which require low to moderate temperature below 60 °C.(5). Solar air heaters, because of their inherent simplicity are cheap and most widely used collection devices. The main applications of solar air heaters are space heating; seasoning of timber, curing of industrial products, and these can also be effectively used for curing/drying of concrete/clay building components. The solar air heater occupies an important place among solar heating system because of minimal use of materials and cost. The thermal efficiency of solar air heaters in comparison of solar water heaters has been found to be generally poor because of their inherently low heat transfer capability between the absorber plate and air flowing in the duct. In order to make the solar air heaters economically viable, their thermal efficiency needs to be improved by enhancing the heat transfer coefficient.(3).On the other hand, the most important advantages for air-type collectors include: no freezing, boiling or pressure problems; generally lower weight and low construction cost(5).Several improvements have been suggested in literature to enhance the performance of the system. The objective of the present study is to design , fabricate a v-groove solar air heater and study the thermal performance of fabricated collector.

Design

To model the heaters considered, a number of simplifying assumptions can be made to lay the foundations without obscuring the basic physical situation. These assumptions are as follows:

- Thermal performance of heaters is steady-state.
- There are a negligible temperature drop through the glass cover, the absorber plate and the bottom plate.
- There is one-dimensional heat-flow through the back insulation, which is in the direction perpendicular to the air flow.
- The sky can be considered as a blackbody for long-wavelength radiation at an equivalent sky-temperature.
- Loss through the front and back are to air at the same ambient temperature.
- Dust and dirt on the heater and the shading of the heater absorbing-plate are negligible.
- Thermal inertia of heater components is negligible.
- Operating temperatures of heater components and mean air-temperatures in the air channels are all assumed to be uniform.
- Temperature of the air varies only in the flow direction.
- All air channels are assumed to be free of leakage.
- Thermal losses through the heater backs are mainly due to the conduction across the insulation: those caused by the wind and the thermal radiation of the insulation are assumed negligible.

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A v-groove solar air heater is designed and fabricated for the study. The use of v- groove absorber in the place of flat absorber obviously provides a large surface area for heat transfer to the air stream. The convective heat transfer from plate to cover increases in this case but the loss is largely compensated by the increased heat transfer to the flowing air.

Materials

A solar air collector of length 2m and breadth 1 m was fabricated with v-groove type absorber of area 1.9m length and .97m breadth . Height of the V was 2.5cm. The body of the air collector is made of stainless steel frame. Solar collector generally consists of three main parts. These parts are glass cover which minimizes upward heat losses, insulation material which reduces conduction losses and an heat absorbing media (Absorber) which increases heat transfer surface area.

Normal window glass of 2 mm thickness is used as single glazing for receiving the solar radiation. The glass is fixed using frames of 5cm thickness. The collector is insulated with glass wool on sides and bottom for 100 mm thickness and Black chrome copper sheet of 2mm thickness acts as an absorber of incident solar radiation. The space between the absorber plate and the glass cover is 3 cm. The electric motor with centrifugal fan of diameter 11 cm was used to circulate air inside collector. Air is sent into air duct by a radial fan. Air speed can be varied by moving the air lid on the front side of the fan. This fan obtains 1650 revolutions per minute and power of 180 watts and Amps 0.81. A divergent rectangular duct of length 0.74 m and width varying from 0.25 to 0.84 m made from galvanized iron sheet of 0.812 mm connecting the motor–fan assembly was provided at the entry of air heater to provide uniform air circulation over absorber surface.

2)

Fig1(a) and (b) shows the outline design of the v-groove collector and thermal network for single cover solar air heater.

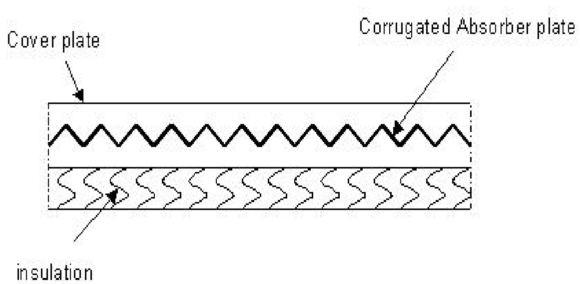
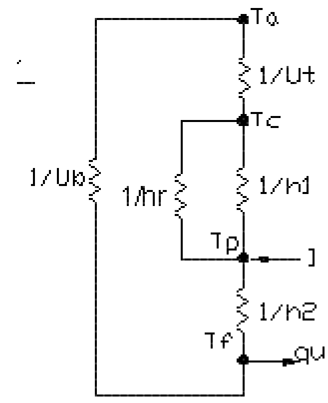


Fig 1(a)



1(b)

Fig 1(a) and 1(b) shows the outline design and thermal network of the V-Groove Solar air heater

Experimental Methods

The experiment was performed from September 2012-November2012 at Coimbatore.(11.0183° N, 76.9725° E). The readings are noted and tabulated for every half an hour. The air blower was switched on and the test was performed at various mass flow rates. The mass flow rate was set to 0.02kg/sec, 0.025kg/sec 0.03kg/sec 0.035kg/sec 0.04kg/sec 0.045kg/sec 0.05kg/sec. The velocity of air is measured at the blower inlet and outlet point. Temperature readings, solar radiation, wind speed were noted and tabulated for every half an hour. Temperature at blower inlet, collector inlet, glass cover, absorber plate, hot air inside the collector and collector outlet were recorded.

The Instrumentation used in the testing is as follows:

1) Pyranometer : Used to measure the intensity of solar radiation incident on the collector.

2) Multimeter :Used to measure the voltage output of the pyranometer, used to determine the intensity of solar radiation in W/m².

3) K-Type Thermocouples **:** Used to measure the temperature at various positions in solar air heater. Positions are Blower inlet, collector inlet , glass cover , absorber plate , two positions one above and below the absorber plate, one below the glass cover and outlet temperature.

4) Rotating Vane Anemometer Used to measure air speed in m/s through the collector.

Thermal analysis

The thermal performance of a solar collector depends on many parameters such as :

- Ambient conditions : Ambient temperature, wind speed, solar radiation
- Geometry of collector (L, a, b)
- Characteristics of working fluid (cp, k, ρ, μ)
- Inlet temperature of fluid (Tin)
- Flow rate (ṁ)
- Choice of the absorber material
- Location of the construction : Inclination angle, direction

The energy balance on the absorber is obtained by equating the total heat gained to the total heat lost by the heat absorber of the solar collector. Therefore,

$$IA_c = Q_U+Q_{cond}+Q_{conv}+Q_R+Q_P$$

The three heat loss terms Q_{cond}, Q_{conv} and Q_R are usually combined into one-term (Q_L), that is,

$$Q_L=Qcond+Q_{conv}+Q_R+Q_P$$

Energy Balance Equation

In steady state, the performance of a flat-plate solar collector can be described by the useful gain from the collector, *Qu*, which is defined as the difference between the absorbed solar radiation and the thermal loss or the useful energy output of a collector:

$$Q_U =A_PS-A_c U_L (T_{pm}-T_a)$$

where *Ac* and *Ap* are the gross and aperture area of the collector, respectively. The first term is the absorbed solar energy and the second term represents the heat loss from the collector. The solar radiation absorbed by a collector per unit area of absorber *S* can be calculated using the optical properties of covers and a plate. The thermal energy loss from the collector to the surroundings can be represented as the product of a heat transfer coefficient *UL* times the difference between the mean absorber plate temperature *Tpm* and the ambient temperature *Ta*. The + superscript indicates that only positive values of the terms in the square brackets are to be used. Thus, to produce useful gain greater than zero the absorbed radiation must be greater than the thermal losses. Gross collector area *Ac* is defined as the total area occupied by a collector and the aperture collector area *Ap* is the transparent frontal area.

ASHRAE Standard employs the gross area as a reference collector area in the definition of thermal efficiency of the collector. The useful gain from the collector based on the gross collector area becomes

$$Q_u = A_C F_R(S_c -U_L (T_i-T_a))$$

where *Sc* is the absorbed solar radiation per unit area based on the gross collector area, defined as

$$S_c = S (Ap/Ac)$$

Since the radiation absorption and heat loss at the absorber plate is considered
based on the aperture area in this study, it is convenient to make the aperture collector area the reference collector area of the useful gain.

Collector Heat Removal Factor:

The collector heat removal factor, *FR*, is the ratio of the actual useful energy gain of a collector to the maximum possible useful gain if the whole collector surface were at the fluid inlet temperature. It is defined as

$$F_R = \frac{mC_P (T_o - T_i)}{A_P (S-U_L' (T_i - T_a))}$$

where the aperture area *Ap* is used as a reference area for the useful gain from the collector.

$$F_R = \frac{mC_p}{A_cU_L}\left(1- \frac{S/U_L(T_o - T_a)}{S/U_L(T_i - T_a)}\right)$$

Physically the collector heat removal factor is equivalent to the effectiveness of a conventional heat exchanger. By introducing the collector heat removal factor and the modified overall heat transfer coefficient into Equation 2.2.4, the actual useful energy gain *Qu* can be represented as

$$Q_u = A_pF_R [S – U_L' (T_i – T_a)]$$

$$Q_u = A_cF_R [S – U_L (T_i – T_a)]$$

Using Equations, the useful energy gain can be calculated as a function of the inlet fluid temperature not the mean plate temperature.

Collector Thermal Efficiency

The efficiency of solar collector is defined as the ratio of the useful energy gain to the incident solar energy. Efficiency of the solar collector is given by

$$\eta = \frac{Q_u}{I_tA_c} = \frac{mC_p(T_o-T_i)}{I_tA_c}$$

The efficiency of a solar collector is defined as the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any period of time.

$$\eta = \frac{\text{Solar Energy Collected}}{\text{Total Solar Striking Collector Surface}}$$

$$= \frac{Q_{Useful}}{I_t\, A_c}$$

Useful heat collected for an air-type solar collector can be expressed as:

$$Q_u = \dot{m} C_p (T_o - T_i)$$

So, collector thermal efficiency becomes,

$$\eta = \frac{Q_u}{I_t A_c} = \frac{\dot{m} C_p (T_o - T_i)}{I_t A_c}$$

Energy analysis

The useful heat gain (Qu) by the working fluid is

$$Qu = \dot{m}\, C_p\, (T_{out} - T_{in}) \quad (1)$$

The Hottel–Whillier equation for the useful heat gain (Qu) of a flat plate solar collector system, considering the heat losses from the solar collector to the atmosphere, is

$$Qu = A_p F_R (S - U_l (Tin - Ta)) \quad (2)$$

(F_R) is defined as

$$F_R = \frac{\dot{m}\, Cp}{U_l A_p} \left\{ 1 - \exp\left[- \frac{F' U_l A_p}{\dot{m}\, Cp} \right] \right\} \quad (3)$$

An energy balance on the absorber plate yields the following equation for a steady state

$$Qu = A_p S - U_l A_p (Tp - Ta)$$

(4)

The calculation of the overall loss coefficient (U_l) is based on simulation convection and re-radiation losses from the absorber plate to the atmosphere.

Optical analysis

In Eq. (2) the radiation absorbed flux by unit area of the absorber plate (S) is defined as

$$S = (\tau\alpha) I_T \quad (6)$$

Collector overall loss coefficient :

The solar thermal efficiency depends essentially on thermal losses from outer surfaces of the collector.

The top heat loss coefficient:

The top loss coefficient (*UL*) is required in performance models of solar collectors. This coefficient determines the sum total of energy lost from the absorber to the ambient by the combined processes of convection and radiation. This equation gives approximately the actual iterative results.

$$U_t = \left[\frac{N}{\frac{C}{T_p}\left(\frac{T_p - T_a}{N + f}\right)^{e}} + \frac{1}{h_w} \right]^{-1} + \frac{\delta (T_p^2 - T_a^2)(T_p - T_a)}{\frac{1}{d} + \frac{2N+f-1}{\varepsilon_g} - N}$$

$$C = \frac{204.429 (\cos\ \beta)^{0.252}}{L^{0.24}}$$

$$d = \varepsilon_p + 0.0425 N (1 - \varepsilon_g)$$

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

$$h_w = 5.7 + 3.8\ V$$

$$e = 0.252$$

The bottom heat loss coefficient:

Energy dissipation from the bottom of the collector is the collective effect of conduction from the absorbing surface to the insulator at the bottom and convection and radiation from the outside wall to the ambient surroundings. Thermal loss coefficient from the bottom could be calculated as follows :

$$U_b = \frac{ki}{xi}$$

The edge heat loss coefficient

The edge loss coefficient depends on the area of the solar collector and this loss is very small when compared with the losses from top and bottom of the solar collector. The edge loss coefficient is given by the following equation:

$$Ue = \frac{(L_1 + L_2)\, L_3\, K}{L_1 L_2 \delta_e}$$

The total heat loss coefficient is given by the following:

$$U = U_t + U_b + U_e$$

Computation of heat transfer coefficients

The radiative heat transfer coefficient between absorber plate and glass cover, hrpg is computed using the following standard relation (Duffie and Beckman, 1991).

$$h_{rpg} = \frac{\sigma\left[(T_p + 273)^2 + (T_g + 273)^2\right]\left[(T_p + 273) + (T_g + 273)\right]}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_g} - 1}$$

hrga, the radiative heat transfer coefficient between glass cover and ambient air is computed from the following relation (Duffie and Beckman, 1991).

$$hrga = \frac{\sigma\varepsilon_g\left[(T_g + 273)^4 - (T_s + 273)^4\right]}{T_g - T_a}$$

hcga, the convective heat transfer coefficient between glass cover and ambient air for natural convection is obtained from standard relation (Holman, 2003):

$$h_{p\text{-}c} = Nu\frac{k}{L}$$

k = 0.0293 W/m C.
L = 25mm=0.025m.

$\beta = 45^o$

$$Ra = \frac{g\,\beta'\Delta T L^3}{v\alpha}$$

g = 9.81
v = 1.88×10^{-5} m²/sec
α = 2.69×10^{-5} m²/sec

Results and Discussions:

First of all, raw data collected from measuring instruments were processed to be used in results. Mass flow rate (m), Overall heat loss coefficient(U_L) W/m^{2o}C, useful energy gain (Q_u) , total heat (Q) and efficiency (η) were calculated by using the data which are air speed (V), inlet temperature of air (Tin), outlet temperature of air (Tout), environment temperature (Tamb) and total solar radiation on horizontal surface (Io)

Collector parameters	Value
Apparent sun temperature(T_s)	4350 K
Emissivity of the absorber plate(ε_p)	0.92
Emissivity of the covers(ε_c)	0.88
Thermal conductivity of the absorber plate(K_p)	384 W/mK
Thermal conductivity of the insulation, (K_i)	0.05 W/mK
specific heat of the air (cp)	1.005 kJ/kg k
Density of air (ϱ)	1.127 kg/m³
Kinematic Viscosity	16.97×10^{-6}m²/sec
Avg. solar radiation during experiment period	765 W/m²
Average ambient temperature during experiment period	35.8(°C)

Calculated parameters are

Efficiency	35%
U_L	6.4(W/m²)
h_{p-c}	3.73(W/m²)
hr_{p-c}	7.4(W/m²)
hr_{c-a}	5.51(W/m²)
Q_u	1264 (J)
T_c	35.8(°C)
T_p	85(°C)
T_o	61.4(°C)

Fig. 3 shows the variation of efficiency with flow rate for v-corrugated collectors From the figure, it can be seen that the efficiency of the air collector is strongly dependent on the air flow rate. Variation of Solar radiation and Efficiency with month was shown in **Fig 4.**

Fig 5 gives the variation of efficiency with different mass flow rate. Increasing the mass flow rates resulted in 1.5- to 3.5-fold increase in collector efficiency. As seen from the results, the collector efficiency increased with increasing mass flow rate of fluid. The typical variation of different temperatures of solar air heater is given in **Fig. 6**. All the temperatures were varying with radiation intensity. Results are in close agreement with the study conducted by S.S. Krishnananth et., al, where the absorber plate is the hottest part in the air heater and it reached 52°C.around noon. The glass also reached the maximum temperature with absorber plate during noon. The exit air temperature closely varied with surface temperature. The exit air temperatures reached a maximum value of 46°C around noon. Only after

8 AM, there was an appreciable rise in all temperatures and after 5 PM all temperatures reached the low value.

The incident solar radiation is one of the most important parameters in the collector efficiency. **Fig 7** shows that when the radiation is maximum, collector efficiency is also maximum. The radiation values change in the range of 880 W/m² and480 W/m² and it reaches the maximum in the midday.

Variation of temperatures with Time on 30th August 2012 with flow rate 0.035 kg/sec is shown in

Fig 8. The temperatures attain the maximum value at 1:00 noon and the absorber plate reaches the maximum of 47°C.

Collector outlet temperature is an important parameter for determining collector performance. Outlet air temperature was investigated for wide range of flow rates. The variation of outlet temperature with flow rate is shown in **Fig. 9**. The results show that outlet temperature decreases continuously with flow rate and remains in the useful temperature range for drying purposes up to the flow rate of 0.05 kg/sec. the outlet temperature of the flowing air through the collector decreased with increased flow rate but, after a flow rate of about 0.045 kg/s, the rate of temperature drop was lower and at a flow rate of 0.050 kg/ s, the curve became rather insensiti.he results indicate that for drying purposes, the designed air flow rate would be in the range of about 0.020– 0.045 kg/m2 s. This range of flow rate gives an outlet temperature suitable for most agricultural drying applications, and the corresponding efficiency is considered reasonable As temperature of fluid decreases with flow rate, efficiency gets correspondingly increased due to decreased thermal losses to the environment. Fig. also shows the relationship between efficiency and outlet temperature with flow rate. The results was found to be in close agreement to study conducted by Md Azharul Karim .,et,al,2006 and M.A. Karim et.,al ,2004.**Fig 10** gives the variation of solar radiation and temperature difference with mass flow rate.

Result obtained matches with that of Deniz Alta,. etal and A. Sreekumar for the parameters monitored (such as ambient temperature, inlet air temperature, outlet temperature, and intensity of solar radiation) variation with time as shown in **Fig. 11** on 17 November, 2012 . It seems that inlet and outlet air temperatures are increase with solar radiation and the maximum values are at midday. The maximum temperature of air monitored at the outlet of the solar air heater was 63.2°C,which was at 2.00 p.m. During the study, the air flow rate was maintained as 0.045kg/sec. The high temperature output from the air heater, despite the high air mass flow rate, was due to the usage of copper sheet as absorber material. The intensity of solar radiation was 848 W/m² , when the collector achieved its maximum temperature. Ambient temperature varied from 29.8°C to 30.1 °C.

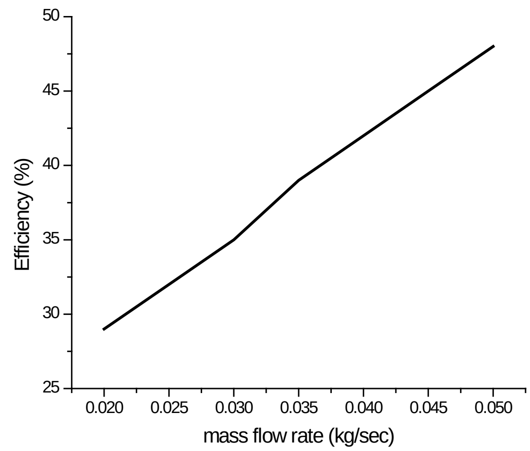


Fig 3: Variation of Efficiency for different mass flow rates

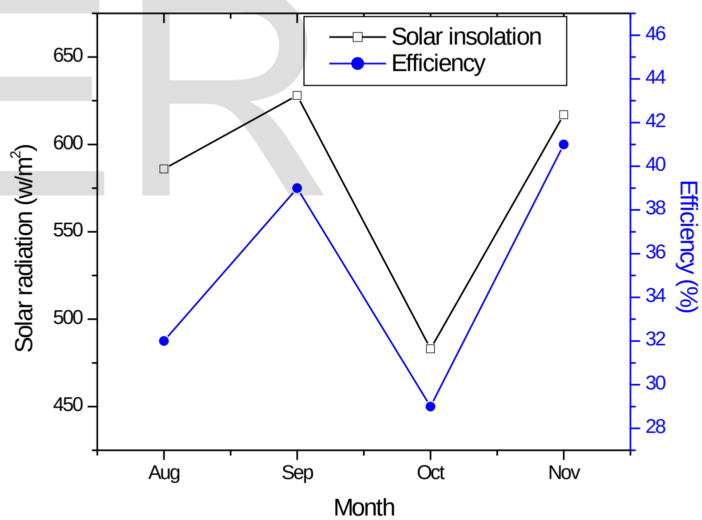


Fig 4 : Variation of Solar radiation and Efficiency with months

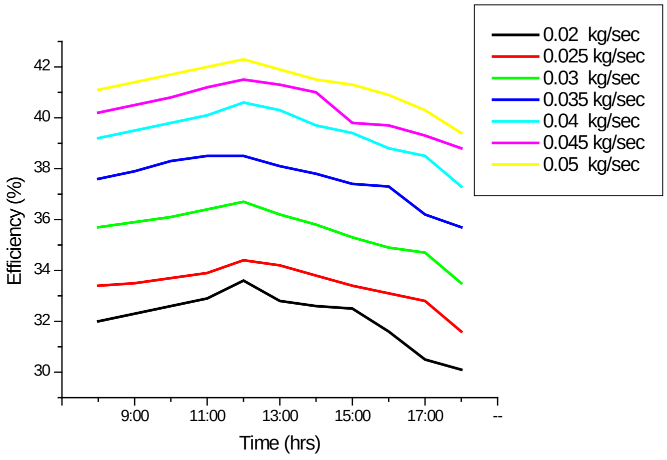


Fig 5: Variation of efficiency with different mass flow rate

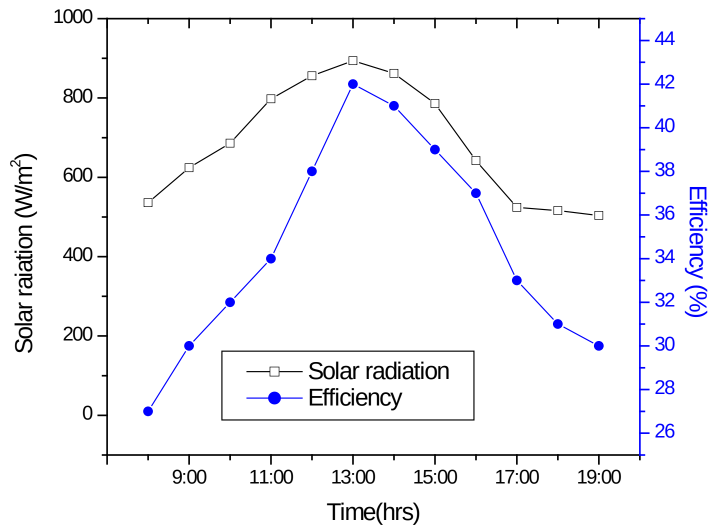


Fig 7: The Collector Efficiency and solar radiation as a function of day times for 0.05kg/sec mass flow rate on 16th September 2012

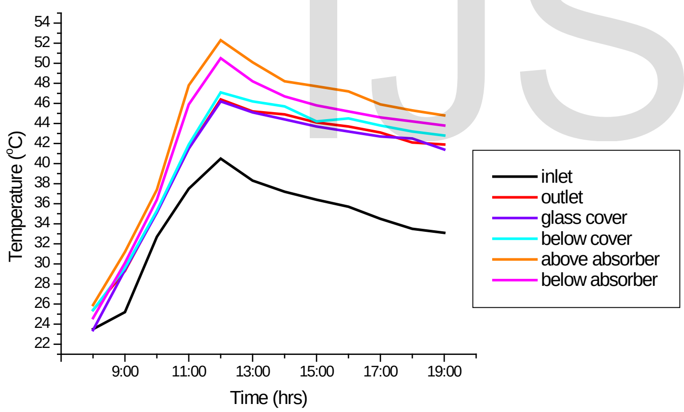


Fig 6 : Variations of different temperatures for on 21st October 2012

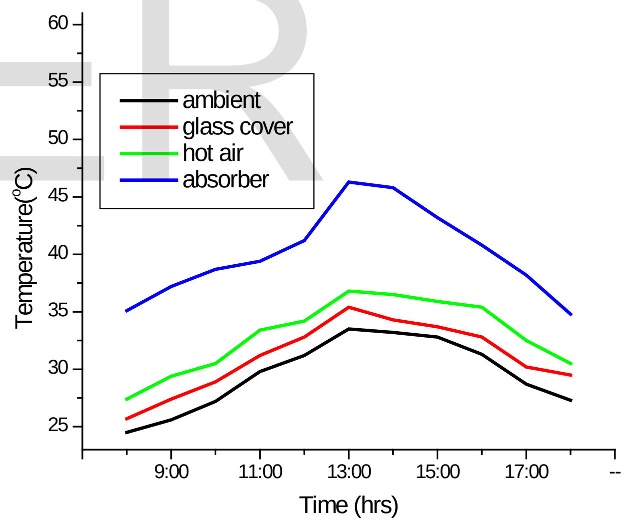


Fig 8 : Variation of temperatures with Time on 30th August 2012 with flow rate 0.035 kg/sec.

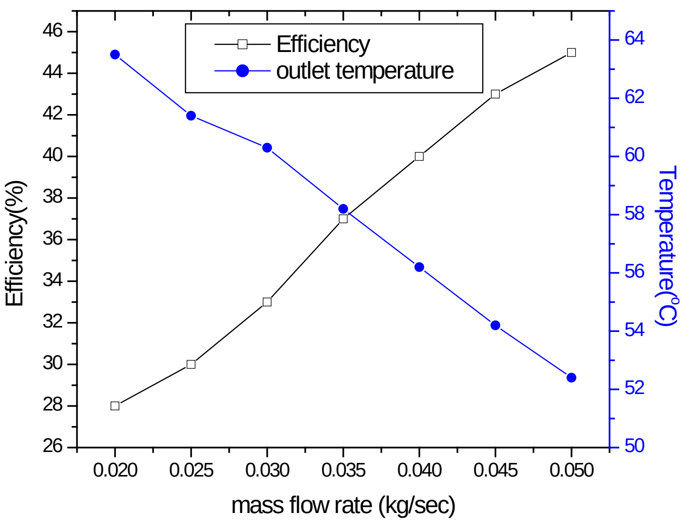


Fig 9: Variation of Efficiency and outlet temperature with mass flow rates

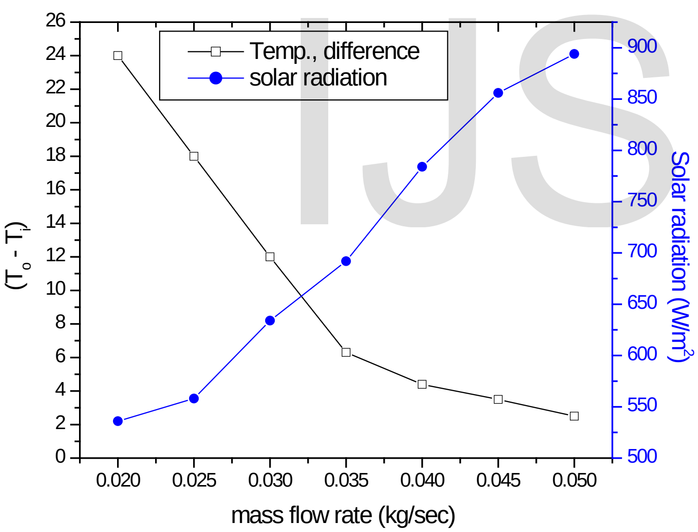


Fig 10 : Variation of solar radiation and temperature difference with mass flow rate

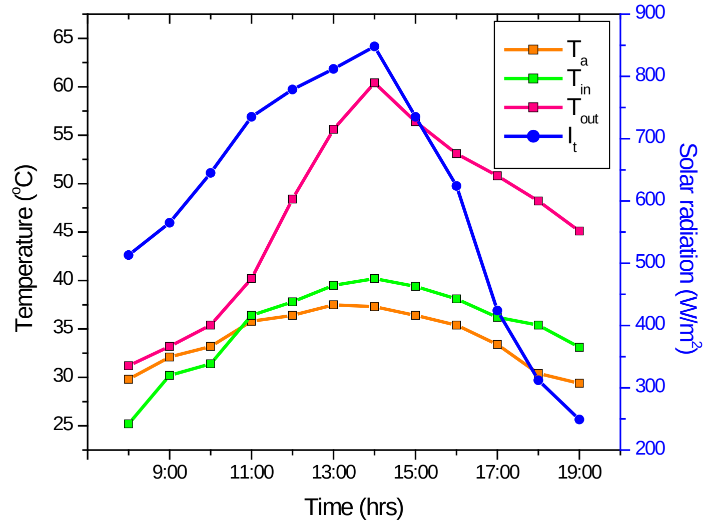


Fig 11 : Variation of Temperatures and solar radiation with time on 17 November 2012.

Nomenclature

I -Rate of total radiation incident on the absorber's surface (Wm–2).
A_c- Collector area (m²).
Ap -area of the absorber plate
Q_u -Rate of useful energy collected by the air (W).
Q_{cond} - Rate of conduction losses from the absorber (W).
Q_{conv} - Rate of convective losses from the absorber (W).
Q_R - Rate of long wave re-radiation from the absorber (W).
Q_p - Rate of reflection losses from the absorber (W).
N- no of glass covers,
S - radiation absorbed flux by unit area of the absorber plate
T_p - Mean plate Temperature (˚ C)
T_a - ambient temperature (˚C)
Tin - fluid inlet(˚C)
Tout - outlet temperature(˚C)
I_T - Incident solar energy per unit area of the absorber plate.(W/m²)
h_w - wind heat transfer co –efficient(w/m²)
ε_g - Emittance of glass
ε_p - emittance of plate
L- distance between glass cover & absorber(m)
V - wind velocity(m/sec)
β - Collector tilt (degree)
K - Thermal conductivity of insulation*(W/m.K)*
L - Thickness of back insulation(mm)
D - Collector side depth(m)
P - Collector perimeter(m)

Ae - edge area(m^2)
ṁ - mass flow rate (kg/sec)
U_L - the overall loss coefficient(W/m^2)
$(\tau\alpha)$ - effective product transmittance–absorptance

Conclusions

A comprehensive parametric study has been carried out on the thermal performance of a v-groove absorber collector under a wide range of configurations and operating conditions. The aim of the use of the v-groove absorber is to enhance the heat transfer rate inside the air flow channel by increasing the heat transfer surface area, which will result in a better thermal performance and a high efficiency.

- The v-groove absorber solar air collector has a significantly good thermal performance with 35% more achievable efficiency under the typical configurations and operating conditions.
- To achieve better thermal performance for the collectors, it is essential to; use a small size of the v-groove absorber for the v-groove absorber collector
- The collector length, the distance between the cover and the absorber, the solar insolation rate incident on the collectors, the inclination of the collectors, and the emissivity of thermal radiation on the bottom plate are found to have negligible effects on the efficiencies of the collectors, although they may have significant effects on the temperatures on the cover, absorber, and bottom plate, and on the heat transfer rate between various plates and the fluid.

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