Thermal Analysis on Solar Air Heater with Corrugated Absorber Plate and Amul Cool Aluminum Cans

Mr. Vivek B. Patel	Mr. Sailesh N. Chaudhary
14, SOMESHWAR RESIDENCY, NEAR RAJDHANI TOWNSHIP,RADHANPUR ROAD, MEHSANA-384002	14, SOMESHWAR RESIDENCY, NEAR RAJDHANI TOWNSHIP,RADHANPUR ROAD, MEHSANA-384002

ABSTRACT Solar air heater is a solar operated device used to increase the temperature of air with help of convection process. Many researchers have worked on solar air heater to increase thermal efficiency. Double pass solar air heater is also fall in category of solar air heater, which is latest and has higher thermal efficiency. To increase thermal efficiency zigzag way created on the way of air with help of Amul Cool Aluminium cans. This research experimentally investigates a double pass solar air heater with aluminium cans with corrugated absorber plate. Aluminium cans are very cheap and easily available. Here, mass flow rate remains constant (0.05 Kg/s) but solar insolation is varied and whole experiment has conducted in climate conditions of Mehsana (23°12' N, 72°30). Research shows that double pass air heater with corrugated absorber plate gave considerable increase in thermal efficiency as well as absorber plate temperature.

1. INTRODUCTION:

With the rapid rise in the population and the living standards, the world seems to engulf into major crisis, called energy crisis. If this growth continues with the same pace the condition would go from bad to worse. The reverse of conventional sources of energy like coal, petroleum and natural gas are depleting at a very fast rate to fulfil the demand of the growing population. So there is a need to look for some other energy sources that could meet this growing demand. One such source is solar energy, which is cheap available in abundance. Solar energy has been utilized in many ways.

Some of its thermal applications are as follows:
1. Water heating

Fig 2.1 Experimental set up of Modified Solar air heater with Amul Cool Aluminium Cans and Corrugated Absorber Plate

Fig 2.1 Shows experimental set up of double pass solar air heater. In this study, absorber plate made of stainless steel with black chrome as a selective coating material to increase absorptivity of solar radiation. Dimension of solar air heater is 2 meter × 0.75 meter × 3 m respectively. Instead of normal window glass, toughened glass has utilized in this research work. Thermal losses of cover due to convection as well as radiation process are assumed as constant. Due to corrugated shape of absorber plate, easily air flow will occur so no vent is required in solar air heater. 40 Amul cool Aluminium cans have used to create obstruction on the way of air and to increase temperature as well as thermal efficiency of solar air heater. Each Amul cool Aluminium can was opened on top as well as bottom to receive air flow from it. There surface get sealed to absorber plate with help of M seal. Here, Ther-

mocouples were positioned evenly, on top of surface of absorber plates, at identical position along the direction of flow, for both directions. Intel as well as outlet temperatures were measured with help of two K Type thermocouples. Insulation is made with help of thermocole of 5 mm thickness. Ambient temperature was measured by Mercury thermocouple. Total sun radiation measured by pyrenometer. For even flow of air inside the solar air heater, 3 strains have placed inside solar air heater. Here, blower is placed to flow to flow the hot air inside solar air heater, Test began at 10 am and ended at 5 pm. Solar air heater performance tests were conducted on days with clear sky condition means without clouds in the sky, hence the amount of Direct radiation will be more. The angle of slope is 40 degree which is suitable for geographical condition of Mehsana. Here, mass flow rate remains constant, and that is 0.5 Kg/s but solar insolation is variable inside the solar still.

3. THERMAL ANALYSIS:

In this section, a review has been done on the theoretical modelling of Single glazing and double pass solar air heater. Theoretical modelling of this solar air collector is derived comprehensively in this section.

3.1 Energy balance of the collector:

In order to define the energy balance of the solar air collector the following equation shall be used:

$$Q_u = A_c F_R [S - U_L (T_{fm} - T_a)] \text{ [Watt] (3.1)}$$

Where:

A_c – collector area [m2],

F_r – heat removal factor,

S – absorbed solar radiation per unit area [W/m2],

U_L – collector overall heat loss coefficient [W/ (m2·K)],

T_{fm} – mean fluid temperature [K],

T_a – ambient temperature [K].

3.1.1 Heat removal factor:

Heat removal factor – relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature.

In order to calculate the heat removal factor some partial equations need to be solved.

Radiation heat transfer coefficient: $h_r = \dfrac{4 \times \sigma \times T_{fm}^{3}}{\dfrac{1}{\varepsilon_g} + \dfrac{1}{\varepsilon_p} - 1}$ [W/m2K] (3.2)

Where:

σ – Stefan-Boltzmann constant [W/m2K4],

Tfm – Mean air temperature [K],

εg – Emittance of glass,

εp – Emittance of plate.

Convective heat transfer coefficient:
Reynolds number

$$R_e = \frac{\dot{m} \times D_h}{A_f \times \mu} \quad (3.3)$$

Where:

$\dot{m}$ – Flow rate [m3/s],

Dh – hydraulic diameter; for flat plates is twice the plate spacing [m],

Af – fluid area (air channel depth times width) [m2],

μ – Dynamic viscosity [kg/(s·m)].

Nusselt number

Nu = 0.0158 × Re0.8 (3.4)

Convective heat transfer coefficient

$$h_c = N_u \times \frac{K}{D_h} \quad \text{[W/m2K] (3.5) Where:}$$

K – Thermal conductivity [W/m·K].

Heat removal factor:

$$F_1 = \left[1 + \frac{U_L}{h_c + \left(\dfrac{1}{h_c} + \dfrac{1}{h_r} \right)^{-1}} \right]^{-1} \quad (3.6)$$

$$F_2 = \frac{\dot{m} C_p}{A_c U_L F_1} \left[1 - \exp\left(-\frac{A_c U_L F_1}{\dot{m} C_p} \right) \right] \quad (3.7)$$

Where:

$\dot{m}$ – Flow rate [Kg/s],

Cp – Specific heat [KJ/Kg K].

Heat removal factor

$$F_R = F_1 \times F_2 \qquad (3.8)$$

3.1.2 ABSORBED SOLAR RADIATION:
S = (τα) GT (3.9)

GT is the incident solar energy per absorber plate area unit; (τα) is effective product transmittance-absorptance that is equal to the optical efficiency o.

3.1.3 Collector overall heat loss coefficient:
$U_L = U_t + U_b + U_e$ [W/m2K] (3.10) Where:

Ut – top loss coefficient [W/m2·K],

Ub – the energy loss through the bottom of the collector [W/m2·K],

Ue – edge losses [W/m2·K].

3.1.3.1 TOP LOSS COEFFICIENT (Ut):
The top loss coefficient is evaluated by considering convection and reradiation losses from the absorber plate in the upward direction. For the purpose of calculation, it is assumed that the transparent covers and the absorber plate constitute a system of infinite parallel surfaces and that the flow of heat is one-dimensional and steady. It is further assumed that the temperature drop across the thickness of the covers is negligible and the interaction between the incoming solar radiation absorbed by the covers and the outgoing loss may be neglected. The outgoing re-radiation is of larger wavelength. For these wavelengths, the transparent cover is assumed to be opaque. This is a very good assumption if the material is glass.

Heat transferred by convection and re- radiation as suggested by Sukhatme between:

In a steady state, the heat transferred by convection and radiation between (a) the absorber plate and the cover (b) the cover and the surroundings must be equal.

$$U_t = \left[\frac{N}{\dfrac{C}{T_{pm}} \left[\dfrac{T_{pm} - T_a}{N + f} \right]^e} + \frac{1}{h_w} \right]^{-1} + \left[\frac{\sigma \left(T_{pm} + T_a \right) \left(T_{pm}^2 + T_a^2 \right)}{\left(\varepsilon_p + 0.00591 N h_w \right)^{-1} + \left(\dfrac{2N + f - 1 + 0.133 \varepsilon_p}{\varepsilon_g} - N \right)} \right] \quad (3.11)$$

Where:

Ut – top loss coefficient [W/m2·K],

N – number of glass covers,

f = (1 + 0.089hw – 0.1166hwεp) (1 + 0.07866N),

C = 520(1 – 0.000051β2),

e = 0.430(1 - 100/Tpm),

β – Collector tilt (degrees),

εg – Emittance of glass,

εp – Emittance of plate,

Ta – ambient temperature [K],

Tpm – mean plate temperature [K],

hw – wind heat transfer coefficient [W/m2·K],

V = Wind speed [m/s],

σ – Stefan – Boltzmann constant [W/m2·K4].

Wind Heat transfer coefficient at the top cover:
The convective heat transfer coefficient (hw) at the top cover has been generally calculated so far from the following empirical correlation suggested by McAdams,

hw = 5.7+3.8V (3.12) Where V is the wind speed in m/s.

3.1.3.2 BOTTOM LOSS COEFFICIENT (Ub):
The bottom loss coefficient is calculated by considering conduction and convection losses from the absorber plate in the downward direction. It will be assumed that the heat flow is one dimensional and steady. In most cases, the thickness of thermal insulation is provided such that the thermal resistance associated with conduction dominates. Thus, neglect-

ing the convective resistance at the bottom surface of the collector casing.

$$U_b = \frac{K_i}{\delta_i}$$ (3.13) Where:

Ub – Bottom loss coefficient,

ki – Insulation thermal conductivity [W/m·K],

δi – Thickness of insulation [m].

3.1.3.3 EDGE LOSS COEFFICIENT (Ue):

Here also the same assumptions, which are applied for bottom loss coefficient, i.e., conduction resistance dominate and that the flow of heat is one dimensional and steady state.

$$U_e = \frac{(L_1 + L_2)L_3 K_i}{L_1 L_2 \delta_i}$$ (3.14)

Where:

L1 – Length of Collector [m],

L2 – Width of collector [m],

L3 – Height of collector [m],

Ki – Thermal Conductivity of Insulation [W/mK],

δi – Thickness of edge insulation [m].

3.2 EFFICIENCY OF SOLAR AIR HEATER:

Efficiency of the solar air heater is calculated by the following equation,

$$\eta = \frac{Q_u}{A_p G_T} \times 100$$ (3.15)

Where:

Qu – Useful heat gain [Watt],

Ap – Cross-sectional area of absorber plate [m2],

GT – Incident solar radiation per unit area of the absorber plate [W/m2].

4. RESULTS AND DISCUSSION:

Due to use of constant air flow thrown by the blower, mass flow rate remains constant and due to it, uniform temperature rise occurs inside the solar air heater consist of absorber plate as well as Amul Cool Aluminum Cans. With help of Amul Cool Cans, aluminum as material, it has good heat transfer coefficient, hence temperature rise will occurs, this is main reason for increasing temperature of absorber plate inside solar air heater. Fig.4.1 shows relation between Time versus solar insolation. It shows that, when time goes, solar insolation increases from morning 10 am to evening 5 pm. It also shows that, Insolation is lowest at 17 pm and highest at 13: 00 pm then gradually decreases. Fig.4.2 shows relation between time and Thermal efficiency. Thermal efficiency is also play vital role in performance of solar air heater. Because it is nothing but the ratio of work done per heat supplied in form of solar insolation as well as blower. Hence, it is seen that, thermal efficiency gradually increases from morning to evening because it depends on solar radiation.
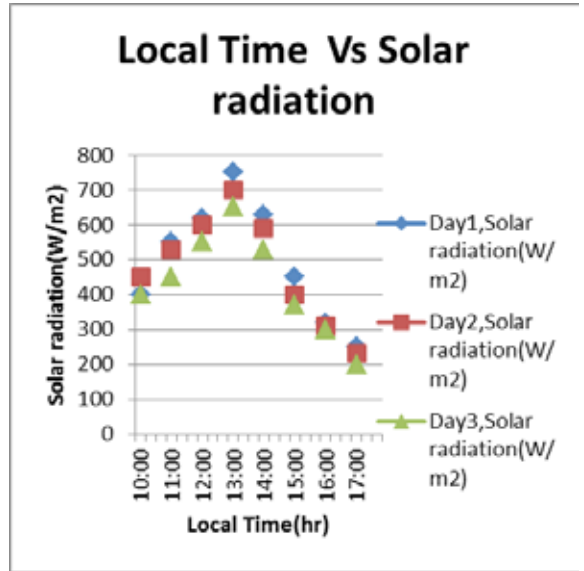

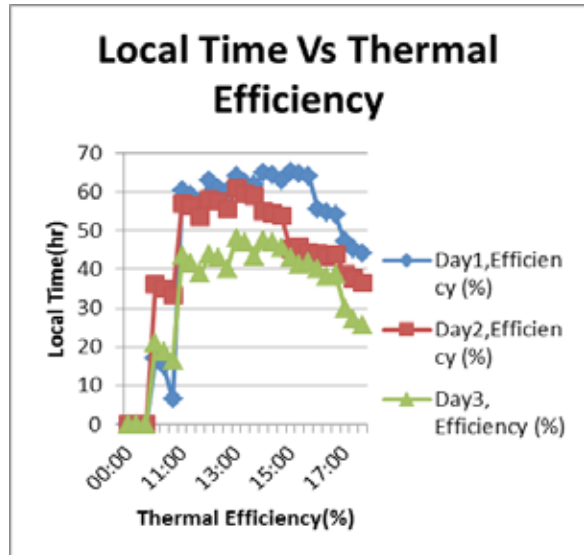Figure 4.1 Chart of Local Time Vs Solar Radiation.

Figure 4.2 Chart of Local Time Vs Thermal Efficiency.

5. CONCLUSION:

Detailed experiment study on absorber plate as well as Amul Cool Aluminum cans shows following points:

- Solar air heater Absorber plate temperature increases with increase of Solar insolation when mass flow rate remains constant of 0.05 Kg/s.
- Solar air heater having thermal efficiency of varying from 0.32 to 0.78 during morning 10 am to 1 pm then it gradually decreases.
- Solar air heater using Amul cool Aluminum cans as well as Corrugated absorber plate is also cost effective.
- Thermal efficiency of solar air heater greatly depends on time, solar insolation and mass flow rate.

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