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Recycle Effect on Performance of Wire Mesh Packed Single Pass Solar Air Heater

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Abstract

A device performance of single pass solar air heater with and without recycle featured with wire mesh packed was investigated theoretically. The application of wire mesh intended to enhance rate of heat transfer. The comparison made among single pass flat plate solar air heater with and without recycling operations. A flat plate separates the recycle flow from inlet flow by dividing channel into two sub channels. The recycle ratio and mass flow rate varied from 0.5-1 and 0.03-0.05kg/s respectively. The results despites that the useful thermal energy gain was higher under recycling operation and it was increases with increasing recycle ratio.

Keywords:*Solar Air Heater; Recycling Operation; Wire Mesh Packed Bed; Recycle Ratio.*

1. Introduction

For the purpose of minimizing the uses of non-renewable energy and maximize the utilization of solar energy device was developed. Solar energy used to heat air that heated air used in residential, industrial and agricultural applications. Solar Air Heaters (SAHs) are simple in design and maintenance.
The design of SAH includes the glass fixed above the absorber plate and system insulated from other side to avoid heat loss. Air gets heated by radiation and convection at flat plate. Recycling operation enhance the thermal performance of SAH by increasing turbulence and fluid velocity. Only drawback with SAH is low heat transfer coefficient between flat absorber plate and air stream. As heat transfer coefficient is an important parameter to consider packed wire mesh used to improve heat transfer coefficient by increasing surface area.
Attempts have beenmade to improve performance of SAH by applying various design and flow arrangements. Sopian et al. [1]experimentally conducted investigation on thermal performance of the double-pass solar collector with and without porous media in the second channel. This study concluded that the presence of porous media in the second channel increases the outlet temperature, therefore increases the thermal efficiency of the systems. Naphon [2] developed the mathematical models which described the heat transfer characteristic of double-pass flat plate SAH were derived from the energy conservation equations.Thermal and thermo hydraulic performance of counter and parallel flow packed bed SAHs evaluated by Dhiman et al. [3]. The results showed that the thermal efficiency of the SAH was 11-17% more compared to the parallel flow Packed Bed SAH whereas, parallel flow system achieved a 10% higher thermo hydraulic efficiency when air steadily flowed at differential Mass Flow Rates (MFRs) in its upper and lower ducts compared to the counter flow system. It was also indicated that the peak values of the thermo hydraulic efficiencies of counter and parallel flow packed bed SAH were obtained when the MFR of air of flowing in each duct was 0.03 kg/s. Ravi and Saini [4] studied different techniques used for performance enhancement of double pass SAHs. . It was recommended to use packed bed material with the higher masses and low porosities for achieving maximum outlet temperature of the air. Counter flow system was more efficient than parallel flow system for MFR of 0.03kg/s. various inventors used different packed bed materials as sets ones sights on heat transfer coefficient [5-7]. Tiwari et al. [5] used iron chips as packed bed material with porosity of 0.652 and 0.816.Aldabbagh et al. [6] proposed analysis on single pass SAH and double pass SAHs with wire mesh as packing bed. The flow rate used in this work between 0.012 and 0.038 kg/s. Experimental investigations of thermal performance of a DPSAH having aluminium cans were reported by Ozgen et al. [7]. Experiments had performed for air MFRs of 0.03 kg/s and 0.05 kg/s. The highest efficiency was obtained for 0.05 kg/s was 47%.

It was brought up that recycle effect was a feasible way to increase the performance of SAH by increasing fluid velocity. Dhiman and Singh [8] proposed analytical models to predict the thermal and thermo hydraulic efficiencies of two different designs of double pass packed bed solar air heater under external recycle. . The recycle ratio and the mass flow rate were varied

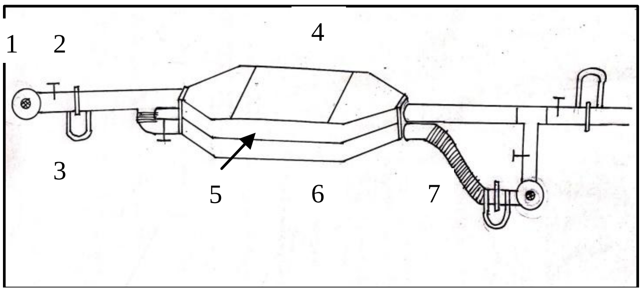
Nomenclatures

A area (m^2)**Subscripts**
$A_c$collector surface area (m^2)
$C_p$specific heat ($kj/kg\ K$) a ambient
$d$depth of channel (m) b back plate
$D_h$hydraulic diameter (m)c convective channel
$d_w$wire diameter (m) f fluid flow
Grecycle ratio g glass
$h$heat transfer coefficient (W/m^2k) i inlet
Iglobal radiations (W/m^2)m packed bed material
$k$thermal conductivity ($W/m\ k$)o outlet
Llength of the heater (m) p absorber plate
Mmass(kg) $r$radiative
$m$mass flow rate $\left(\frac{kg}{s}\right)$$w$ wind
N_u Nusselt number *1* first channel
$P_t$pitch of wire mesh (m)*2* second channel
Pr Prandtl number
$Q_u$thermal power output (W)**Greek symbols**
Re Reynolds's number$\propto$ absorbity
Ttemperature(°C)$\emptyset$ porosity
$u$velocity of air (m/s)ρ density
Vvolume(m^3)μ dynamic viscosity
$U_b$back loss coefficient (W/m^2k)
$w$width of the collector (m)

from 0.1 to 1 and 0.01-0.025 kg/s, respectively. The results of the study depict that the recycle ratio and the mass flow rate substantially increases the heaters efficiencies by increasing the fluid velocity. Ho and Chen [9] presented a theoretical prediction of the performance of a double-pass sheet-and-tube solar water heater with external recycle and comparison with that of a conventional type collector. Analytical results show that the recycle effect effectively enhance the collector efficiency compared with that in a single-pass device with the same flow rate. Ho et al. [10] studied an improvement in device performance of multi-pass solar air heaters with external recycle was carried out under counter current-flow operations. The effect of external recycle on the collector efficiency in solar air heaters investigated theoretically by Yeh and Ho. [11] The most important assumption was that except for the glass cover, all parts of the outside surface of the solar air collector, as well as the flow channel of recycle, were well thermally insulated. More than 80% of improvement in collector efficiency was obtained by recycle operation. Ho et al. [12] designed a device for inserting an absorbing plate into the double-pass channel in a flat-plate solar air heater with recycle. The collector efficiency improvement of the device with external recycle found to be about 28–95% series. The device performance of a solar air heater featured with recycling as well as wire mesh packed was deliberated by Ho et al. [13]. Comparisons were made among different designs including the single-pass, flat plate double-pass, and recycling wire mesh packed double-pass operations. Thakur et al. [14] developed correlations for heat transfer and friction factor characteristics.

2. Experimental Set up

The design involves two blowers, wooden duct, glass and aluminum plate. Wooden duct made up of plywood having two equal channels height and width of 0.05m and 0.45m respectively. Aluminum plate of 1.1m in length divides the two channels from each other. Wire mesh as packing material has been used. Blowers used for forced as well as recycle the air through ducts. It have arranged as shown in Figure 1. Three orifice meters have used to measure the inlet flow, outlet flow and recycle flow. For temperature and pressure measurement K-Type thermocouples and U-Tube water filled manometer have been used.



1 Blower 5 Absorber Plate
2 Flow control valve 6 Back plate
3 Orifice meter 7 Flexible plastic pipe
4 Glass

Figure 1: Experimental set up of SAH

3. Analytical Study

The schematic diagram of model show in Figure 2 and Figure 3 single pass SAH with recycle and without recycle. Proposed SAH model consist of absorber plate, glass cover and several layers of wire mesh as packing bed material. Blowers are used to regulate flow.
Following assumptions are made.

i. The system operates under steady flow operation.
ii. The flow is one dimensional.
iii. Heat loss to the surrounding from the sides of duct is very small.

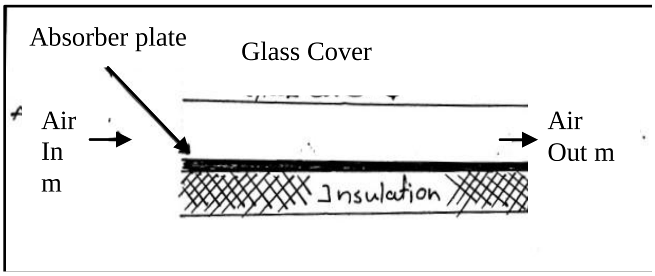


Figure 2: SAH without Recycle

3.1 Energy Balance Equation For The Various Elements of Given Model

For a glass cover

$$I_{gl}\alpha_{gl} = h_{r(gl-m)}\left(T_{gl} - T_m\right) + h_{c(gl-f1)}\left(T_{gl} - T_{f1}\right) \quad (1)$$

For air flowing in first channel

$$\left[\frac{(G+1)mC_p}{W}\right]\frac{dT_{f1}}{dx} = h_{c(gl-f1)}\left(T_{gl} - T_{f1}\right) + h_{c(m-f1)}\left(T_m - T_{f1}\right) + h_{c(p-f1)}\left(T_p - T_{f1}\right) \quad (2)$$

For the absorber plate

$$h_{r(p-b)}\left(T_p - T_b\right) = h_{r(p-m)}\left(T_p - T_m\right) + h_{c(p-f1)}\left(T_p - T_{f1}\right) + h_{c(p-f2)}\left(T_p - T_{f2}\right) \quad (3)$$

For air flowing in second channel

$$\left[\frac{GmC_p}{W}\right]\frac{dT_{f2}}{dx} = h_{c(p-f2)}\left(T_p - T_{f2}\right) + h_{c(b-f2)}\left(T_b - T_{f2}\right) \quad (4)$$

For the back plate

$$h_{r(p-b)}\left(T_p - T_b\right) = h_{c(b-f2)}\left(T_b - T_{f2}\right) + U_b\left(T_b - T_a\right) \quad (5)$$

Various heat transfer coefficients for different elements

$$h_{r(gl-m)} = \frac{\sigma\left(T_{gl}^2 + T_m^2\right)\left(T_{gl} + T_m\right)}{\left[1/\epsilon_{gl} + 1/\epsilon_m - 1\right]} \quad (6)$$

$$h_{r(p-m)} = \frac{\sigma\left(T_p^2 + T_m^2\right)\left(T_p + T_m\right)}{\left[1/\epsilon_p + 1/\epsilon_m - 1\right]} \quad (7)$$

$$h_{r(p-b)} = \frac{\sigma\left(T_p^2 + T_b^2\right)\left(T_p + T_b\right)}{\left[1/\epsilon_p + 1/\epsilon_b - 1\right]} \quad (8)$$

The convective heat transfer coefficient of air flowing outside surface of the glass cover by Naphon [2]

$$h_w = 5.7 + 3.8\,V \quad (9)$$

For wire mesh packing bed heat transfer coefficient $h_{c(m-f1)}$ calculated from correlations given by Thakur et al. [14].

$$j_h = 0.647\left[\frac{1}{n\emptyset}\left(\frac{P_t}{d_w}\right)\right]^{2.104} Re_m^{-0.55} \quad (10)$$

The 'j_h' is related to Stanton number by

$$j_h = St_m (Pr)^{2/3} \quad (11)$$

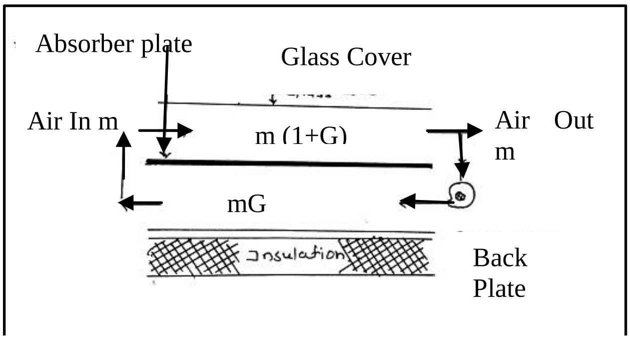


Figure 3: SAH with Recycle

Stanton number expressed by

$$St_m = {h_{c(m-f1)}}/{G_0 C_p} \quad (12)$$

The convective heat transfer between air flowing in first channel and glass cover $h_{c(gl-f1)}$ obtained as,

$$h_{c(gl-f1)} = \frac{Nu_m k_f}{\emptyset Dh_1} \quad (13)$$

Where Dh_1 is the hydraulic diameter of the first channel, given by.

$$Dh_1 = \frac{4A_{f1}}{p} = \frac{(wd1)}{(w+d1)} \quad (14)$$

Nu_m is Nusselt number for the packed bed and given by.

$$Nu_m = 0.2 Re_m^{0.8} P_r^{1/3} \quad (15)$$

Re_m is Reynold's number for packed bed channel calculated as Thakur et al. [14]

$$Re_m = \frac{r_H G_0}{\mu} \quad (16)$$

$$r_H = \frac{\emptyset d_w}{4(1-\emptyset)} \quad (17)$$

Where r_H is hydraulic radius and G_0 is the mass velocity

$$G_0 = \frac{m}{(A_{f1})\emptyset} \quad (18)$$

Where A_{f1} is a frontal area of channel 1
$\emptyset$ is the porosity of packed bed and given by Thakur et al. [14]

$$\emptyset = \frac{P_t^2 d - \left[\frac{\pi}{2}(d_w)^2 P_t\right] n}{P_t^2 d} \quad (19)$$

The convective heat transfer coefficient between absorber plate and air flowing in first channel $h_{c(p-f1)}$ is assumed to be equal to $h_{c(gl-f1)}$

For turbulent flow

$$Nu = 0.018 Re^{0.8} Pr^{0.4} \quad (20)$$

For air flowing in second channel

$$h_{c(b-f2)} = Nuk/D_{h2} \quad (21)$$

3.2 Formulation of the air stream temperature for model

For flowing air temperature in the first and second channel obtained as;

$$\frac{dT_{f1}}{dx} = R_0 + R_1 T_a + R_2 T_{f2} + R_3 T_{f2} \quad (22)$$

and

$$\frac{dT_{f2}}{dx} = S_0 + S_1 T_a + S_2 T_{f2} + S_3 T_{f2} \quad (23)$$

Where,

$$R_0 = \frac{h_{c(gl-f1)} Z_{11} + h_{c(p-f1)} Z_{16}}{v} \quad (24)$$

$$R_1 = \frac{h_{c(gl-f1)} Z_{12} + h_{c(p-f1)} Z_{17}}{v} \quad (25)$$

$$R_2 = \frac{h_{c(gl-f1)} Z_{14} + h_{c(p-f1)} Z_{19 - h_{c(gl-f1)} - h_{c(m-f1)} - h_{c(p-f1)}}}{v} \quad (26)$$

$$R_3 = \frac{h_{c(gl-f1)} Z_{15} + h_{c(p-f1)} Z_{20}}{v} \quad (27)$$

$$R_4 = \frac{h_{c(gl-f1)} Z_{13} + h_{c(p-f1)} Z_{18}}{v} \quad (28)$$

$$S_0 = \frac{h_{c(p-f2)} Z_{16} + h_{c(b-f2)} Z_{21}}{y} \quad (29)$$

$$S_1 = \frac{h_{c(p-f2)} Z_{17} + h_{c(b-f2)} Z_{22}}{y} \quad (30)$$

$$S_2 = \frac{h_{c(p-f2)} Z_{19} + h_{c(b-f2)} Z_{24}}{y} \quad (31)$$

$$S_3 = \frac{h_{c(p-f2)} Z_{20} + h_{c(b-f2)} Z_{25} - h_{c(p-f2)} - h_{c(b-f2)}}{y} \quad (32)$$

$$S_4 = \frac{h_{c(p-f2)} Z_{18} + h_{c(b-f2)} Z_{23}}{y} \quad (33)$$

All constants calculated by Dhiman and Singh [8]After some mathematical manipulations, the temperature of the air stream in the first channel, $T_{f1(x)}$ obtained as.

$$\frac{d^2 T_{f1}}{dx^2} + \xi_1 \frac{dT_{f1}}{dx} + \xi_2 T_{f1} = \xi_0 \quad (34)$$

Where,

$$\xi_1 = -(R_2 + S_3), \xi_2 = (R_2 S_3 - R_3 S_2),$$
$$\xi_3 = (R_3 S_0 - R_0 S_3), \quad (35)$$

With

$$R = R_0 + R_1 T_a, \ S = S_0 + S_1 T_a \quad (36)$$

Solution for equation (34) obtained as.

$$dT_{f1(x)} = C_i e^{m_i x} + \frac{\xi_0}{\xi_2} \quad (37)$$

The air stream temperature in the third channel obtained by

$$dT_{f2(x)} = \frac{(m_i - R_2) C_i e^{m_i x}}{R_3} - \frac{R_2 \xi_0}{R_3 \xi_2} - \frac{R_0}{R_3} \quad (38)$$

Following boundary conditions were applied for solution of above equations

$$T_{f1|_{x=0}} = T_a \quad (39)$$

The useful thermal output power Q_u for given model

For SAH under recycling operation

$$Q_u = m(1+G) C_p (\Delta T_{first}) + mG C_p (\Delta T_{second}) \quad (40)$$

For SAH without recycling operation

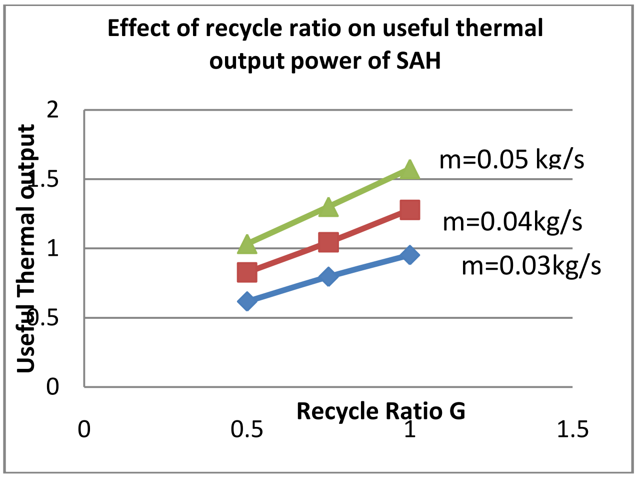
$$Q_u = m C_p (T_{f1,o} - T_{f1,i}) \quad (41)$$

4. Results and Discussion

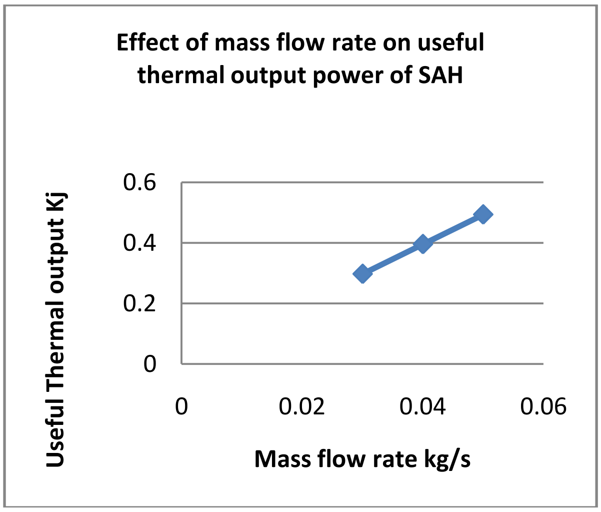
The theoretical predictions of performance for single pass packed bed solar air heater are investigated at fixed bed porosity of 95%. The mass flow rate and recycle ratio varied from 0.03-0.05kg/s and 0.5-1 respectively. Height of channel was also kept fixed.

4.1 Effect of recycle ratio on useful thermal output power of SAH

The useful thermal output power of SAH increases due to recycling operation. It was shown that the desirable effect of increasing the fluid velocity by recycle operation overcomes the undesirable effect of decreasing driving force for heat transfer due to remixing at the inlet. The useful thermal output of SAH under recycling operation increases with increasing recycle ratio as shown in figure 4.



(a)



(b)

Figure 3: (a)Effect of recycle ratio on useful thermal output power of SAH. (b) Effect of mass flow rate on useful thermal output power of SAH

5. Conclusions

- Model with recycle and without recycle analysed, with recycling operation SAH have higher performance than without recycling operation for same mass flow rates.
- The performance of SAH increases with increasing recycle ratio.

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