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# An analytical investigations on thermal and thermohydraulic performance of offset finned absorber solar air heater

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ABSTRACT

In this study, an analytical investigation on thermal and thermohydraulic performance of offset finned solar air heater have been evaluated. A parametric study was done to investigate the effect of variation of system and operating parameters i.e. fin spacing, fin height, air mass flow rate and insolation on the thermal and thermohydraulic (effective) efficiencies. Results indicate that the thermal efficiency increases continuously with increase in mass flow rate, whereas thermohydraulic efficiency increases upto an inception value of air mass flow rate (0.028 kg/s), attains a maximum and then decreases sharply for a given fin spacing and fin height. For higher value of the fluid temperature rise parameter, the effective efficiency values closely follow the thermal efficiency values. It is found that attaching offset fins below the absorber plate at lower mass flow rate can lead to appreciable enhancement of 106.9% and 67.38% respectively for the thermal and thermohydraulic efficiencies. It is also found that the maximum percentage enhancement in thermal and thermohydraulic efficiencies increases to 114.1% and 112.65% respectively with decrease in fin spacing and increase in fin height.



## 1. Introduction

Solar air heaters are simple contrivances that utilize incident solar radiation to obtain solar energy for wide utilization. The solar collector converts this radiation to the heat in air and distributes the air for use. Solar air heater are the most frugal and extensively used solar energy accumulation collector employed to distribute heated air at low mitigate temperature for space heating, drying agricultural product, seeds and vegetables and some modern applications. Thus, investigators have focused their research toward diverse performance amelioration methods. The corrugated wall channel has been extensively studied by Piao et al. (1994) to enhance the heat transfer rate. Goldstein and Sparrow (1977) showed that heat transfer rate for corrugated channels were moderately more astronomically immense than those for a smooth parallel plate channel in the laminar region. Further, reported for turbulent flow, the wall corrugation were responsible for dramatic increase in the heat transfer rate compared with the smooth wall channel. Liu et al. (1984) reported that efficiency of air heating flat plate solar air heater can be increases by decrease in the absorber plate temperature by providing it pin-fin surface. Investigations have been done at air mass flow rate ranging between 0.02 and 0.1 kg/s. Paisarn (2004) has been found that the thermal efficiency increases with increase in the number of fins. The entropy generation is inversely proportional to the number of fins. Irfan and Emre (2006) analyzed the rectangular form of fins having two different surface areas were located on absorber surface in free and fixed manners. There was a reverse relationship between exergy loss ratio and collector efficiency as well as temperature difference of fluid. Fixed fin collector is more effective than free fin collector. Abhishek and Prabha (2016) studied the thermal and thermohydraulic performance characteristics of wavy finned absorber solar air heater and evaluated the effect of mass flow rate, insolation and fin spacing. Ho and Chii (2009) presented that the enhancement in collector efficiency is obtained by recycle operation up to 65% improvement. Bahrehmand et al., 2015 evaluated the solar collector with fin and TMS (thin metal sheet) are more effective than other system collector which without TMS at higher Reynolds number and lower duct height/fin height. Mittal and Varshney (2006) suggested a design criterion for matrix selection by which packing the air flow duct of a solar air heater which gives the best thermal efficiency with minimum pumping power. Ho (2012) investigated the temperature difference between the outlet fluid flows and the ambient was decreased with increasing mass flow rate of air, for the same air mass flow rate the thermal efficiency increased with increasing the number of the fins. If the operation is carried out with an internal recycle to increase the fluid velocity,

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## Nomenclature

| | |
|---|---|
| $A_{sc}$ | surface area of the collector plate ($m^2$) |
| $A_t$ | total surface area of the fins ($m^2$) |
| a | aspect ratio $s_f/h_f$, dimensionless quantity |
| b | ratio $t_f/l_f$, dimensionless quantity |
| c | ratio $t_f/s_f$, dimensionless quantity |
| $C_f$ | conversion factor (0.18) |
| $C_p$ | specific heat of air (kJ/kg K) |
| $d_e$ | equivalent hydraulic diameter of solar collector (m) |
| $D_h$, Dh | duct height of the solar collector (m) |
| dx | elemental section of solar collector length (m) |
| $E_{feef}$ | percentage enhancement in thermohydraulic efficiency |
| $E_{fth}$ | percentage enhancement in thermal efficiency |
| $E_{f\Delta\theta}$ | percentage enhancement in temperature rise |
| $F'_c$ | collector efficiency factor of solar collector |
| $F_{HR}$ | heat removal factor of solar collector |
| $G_a$ | air mass flow rate (kg/h) |
| $h_{aa}$ | convective heat transfer coefficient between absorber plate and air ($W/m^2$ K) |
| $h_{cv}$ | convective heat transfer coefficient ($W/m^2$ K) |
| $h_f$, hf | height of offset fin (m) |
| $h_{fa}$ | convective heat transfer coefficient between offset fins and air ($W/m^2$ K) |
| $h_{ra}$ | radiation heat transfer coefficient between the absorber plate and the glass cover ($W/m^2 K^4$) |
| $I_o$ | global irradiance incident on solar collector ($W/m^2$) |
| $j_f$ | Colburn factor |
| $k_{air}$ | thermal conductivity of air (W/m K) |
| $k_{fin}$ | thermal conductivity of fin (W/m K) |
| $k_{is}$ | thermal conductivity of insulation (W/m K) |
| $l_f$, lf | length of the offset fin (m) |
| $L_{sc}$ | length of the solar collector (m) |
| $\dot{m}$ | air mass flow rate (kg/s) |
| M | quantity define by Eq. (13) |
| $N_{un}$ | Nusselt number |
| $P_{rn}$ | Prandtl number |
| $Q_{ug}$ | useful heat gain rate from solar collector (W) |
| $R_{en}$ | Reynolds number |
| S | solar energy absorbed by the collector ($W/m^2$) |
| $s_f$, sf | fin spacing of offset fin (m) |
| $t_{is}$ | thickness of insulation (m) |
| $t_f$, tf | thickness of offset fin (m) |
| $U_{bt}$ | bottom heat loss coefficient of solar collector ($W/m^2$ K) |
| $U_{tl}$ | top loss coefficient of solar collector ($W/m^2$ K) |
| $U_{OL}$ | overall heat loss coefficient of solar collector ($W/m^2$ K) |
| $v_{aa}$ | average air velocity in the solar collector (m/s) |
| V | wind velocity (m/s) |
| $W_{sc}$ | width of the solar collector (m) |

*Greek symbols*

| | |
|---|---|
| $\alpha_a$ | absorption coefficient of absorber plate |
| $\beta_t$ | solar collector tilt angle (°) |
| $\varepsilon_w$ | emissivity of bottom plate |
| $\varepsilon_a$ | emissivity of inner surface of absorber plate |
| $\varepsilon_g$ | emissivity of glass cover |
| $\eta_{fin}$ | fin efficiency |
| $\rho_a$ | air density ($kg/m^3$) |
| $\phi_{fin}$ | the effectiveness of fin |
| $\tau_c$ | transmissibility of solar collector |
| $\nu_d$ | dynamic viscosity of air ($m^2/s$) |
| $\sigma_{sb}$ | Stefan's Boltzmann constant ($W/m^2 K^4$) |
| $\mu_k$ | kinematic viscosity of air ($N\text{-}s/m^2$) air rise temperature ($\theta_{fo} - \theta_{fi}$) (K) |
| $\theta_2$ | bottom plate mean temperature (K) |
| $\theta_a$ | surrounding ambient temperature (K) |
| $\theta_f$ | air stream temperature in the solar collector (K) |
| $\theta_{fi}$ | inlet air temperature in the solar collector (K) |
| $\theta_{fo}$ | outlet air temperature from the solar collector (K) |
| $\theta_n$ | absorber plate mean temperature (K) |
| $\theta_s$ | sun temperature (K) |

leading to improve heat transfer coefficient. The enhancement in collector efficiency increase with increasing reflux ratio, especially for operating at lower air mass flow rate with higher inlet air temperature. Bhandari and Singh (2012) studied the various types i.e. conventional, double glazing single pass and double pass finned solar air heaters for the same mass flow rate, double pass finned solar air heater was having the highest efficiency.

Chabane et al. (2012) investigated experimentally the thermal performance and heat transfers of a single pass solar air heater with new design of the fins attached, the thermal efficiency increases with increase in solar intensity, and take the constant values of a thermal efficiency in during the time of the solar midday to afternoon. Youcef and Desmons (2006) numerically and experimentally studied the offset rectangular plate fins placed in a segmented manner, are directed parallel to the fluid flow and attached below the absorber plate. Results indicated that high heat transfer area per unit volume generated the loss pressure losses. Vimal and Sharma (2016) investigated the thermal performance of wire screen packed bed solar air heater, results show that the thermal performance is strong function of system and operating parameters. Ibrahim et al. (2013) investigated experimentally the forced-connectivity on a single pass solar air heater with fins attached below the absorbing plate to improve the thermal performance of the system. Thermal efficiency is increased proportion to solar radiation, mass flow rate. Shah and Prasad (2016) investigated on exergetic performance evaluation of solar air heater with arc-shaped wire rib roughened absorber plate. Results showed that the exergy analysis is one of the important method to evaluate the performance of solar air heater. In the present work, an analytical investigation on the thermal and thermohydraulic performance of offset finned absorber solar air heater has been reported. The effect of system parameters i.e. fin spacing and fin height and operating parameters viz. mass flow rate and insolation on the thermal and thermohydraulic performance has been also reported and results have compared with plane solar air heater.

## 2. Theoretical analysis

A solar air heater having offset finned below the absorber plate as shown in Figs. 1 and 2 has been considered. The channel of width '$W_{sc}$', duct height '$D_h$', and length of the collector absorber plate '$L_{sc}$', having one glass cover is uniformly heated from top by solar radiations transmitted through the glass cover. The height, length, thickness and spacing of the offset fin are'$h_f$', '$l_f$', '$t_f$', and '$s_f$' respectively.

The energy balance equations are written on the basis of following assumptions Duffie and Beckman (1980):

- Steady state performance of solar collector.
- There is no absorption of solar energy by glass cover.
- One dimensional heat flow through glass cover and back insulation.
- The covers are opaque to infrared radiation.