Numerical Investigation of Thermal Performance for Air Solar Collector with Multi Inlets

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Abstract. Over the years, there has been rigorous modification of solar collectors for the thermal needs of the era to be efficiently served. A variety of design innovations have paved their way into the invention of novel ways of securing more solar energy as useful heat. Primarily, this study investigates the effects of multi air inlets on the transfer of heat between air flow and the absorber of flat plate collector. Computational Fluid Dynamics was employed to simulate a flat plate collector with 1, 2 and 3 inlets to evaluate the thermal performance with more than one inlet. The results showed that the 3 inlets case has the highest exit temperature followed by 2 inlets and then 1 inlet. Also higher exit air temperature can be obtained for higher heat flux and slower inlet velocity.

Keywords: Keywords: multi-inlets; CFD; solar collector; flat plat collector; heat transfer.

Nomenclature

T Temperature (K)
ΔT Wall temperature difference.
U Velocity in x direction (m/s)
V Velocity in y direction (m/s)
W Velocity in z direction (m/s)
x Coordinate (m)
y Coordinate (m)
z Coordinate (m)

Greek symbols

Φ Dependent variable used in discretization equation.
ΓΦ Diffusion coefficient used in discretization equation.
ρ Density of the fluid (kg/m³)
∂x, ∂y, ∂z grid space (m)
1. Introduction

Through utilization of solar energy, solar air heaters are employed in a variety of applications, space heating and crop drying for instance, requiring heat of low to moderate temperatures below 60 °C. The main heaters are the single pass with rear duct, front duct, double duct and double pass [1]. Ambient temperature, solar radiation, and inlet temperature strongly affect the performance of the solar collector. There has been no substantial progress for cooling systems despite previous research in FPCS focusing on heating applications. In most of the research in this field, inlet temperatures were within range of ambient temperature in solar heating systems [2]. In actuality, the thermal efficiency of a simple solar air collector is found to be very poor. This is due to the low convective heat transfer coefficient of air as well as the thermophysical property of air. Consequently, viscous sub-layer formation appears on the absorber which is resistant to the heat transfer rate. In light of this, many techniques are available, active or passive, to enhance the efficiency of the solar collector. A multi air flow inlet could be used which results in the enhancement of thermal heat transfer. The enhancement is achieved through increasing the temperature difference between the collector and fluid (inlet air) [3].

A number of researchers are aiming to refine the air heater by incorporating the flat plate collector with packed bed and energy storage systems. The performance of FPC was investigated by Zhang et al. [4]. Their findings were used to verify a mathematical method used to calculate the FPC collector’s thermal performance. Geometrically speaking, the width of the collector was 1m, 2m in length; with a thickness of 0.065m. Researchers found that the mass flow rate was a central component impacting performance and outlet temperature. The temperature of the inlet ranged between 21.1 and 45.1 °C. The ambient temperature was between 15.5 and 23.9 °C, and the outlet temperature was in the scope of 37 to 55.4 °C. Mohammad et al [5] investigated the effects of flow rate (m') and inlet temperature (Tin) on thermal efficiency (hth) of flat plate collectors (FPC). Computational Fluid Dynamics (CFD) was used to stimulate an flat plate collectors (FPC), and experimental data derived from literature was used to authenticate the results. An examination of the high and low level flow rates in addition to the inlet temperatures (298 to 373 K) was conducted in the FPC. At 298 K and 370 K, there was a thermal efficiency of 93% and 65% respectively. The thermal efficiency of a double pass solar air heater was researched by Gonzalez et al., [6]. The inlet’s air temperature rose to 35°C with a solar radiation of around 900 W/m2. It was concluded that the average daily efficiency is 34%. A study by Kareem et al [7] presents the performance of a forced convective multi-pass solar air heating collector (MPAH). Guillermo et al [8] brought forth the notion of flexible operation while designing the solar thermal utility systems for low temperature processes. The purposes of the design were: (A), Supply of the process's thermal needs (minimum required temperature and heat duty) and (B), Inflation of the operating time during the day. This method showed that the network structure is defined by altering the mass flow rate and the inlet temperature of the working fluid to obtain the smallest collector surface area. The study conducted by Foued et al. [9] examined the solar performance of the double flow and found that double pass operation increases solar collector efficiency. Using a single pass solar with double flow enhances the thermal system’s performance which may be higher than the single flow model based on the same rate of flow (Ozgen et al.) [10].

Gleaning from previous research in solar air collector, there are no studies related to use of multiple air inlets. In this paper, the influence of multiple air inlets (1, 2 and 3) on thermal performance of air stream flowing inside collector with different locations will be studied with different velocities and solar flux.
2. Numerical Formulation

The collector has one, two or three inlets. Glass cover on the top and collector walls are insulated on the other sides. The mathematical formulation of the airflow problem is governed by basic conservation of mass, momentum and energy equations. In the present study, the flow is turbulent according to Reynolds number values, (Re > 2800).

Assumptions:
1- Three-dimensional (3D) of conservation equations.
2- Steady state incompressible flow.
3- All the properties are calculated at an average temperature.

2.1. Governing Equations

Numerically solving the governing 3D elliptic PDEs (partial differential equations) allowed the predications of turbulent flow field duct to be obtained. FORTRAN program was used to conduct simulations. Using the Boussinesq approximation, the fluid flow in a duct equations were calculated. The following form usually applies to generic partial differential equations, otherwise known as transport equations, for turbulence scalars $k$, $\varepsilon$, temperature, momentum, and continuity:

$$
\frac{\partial}{\partial x}(\rho U \phi) + \frac{\partial}{\partial y}(\rho V \phi) + \frac{\partial}{\partial z}(\rho W \phi) = \frac{\partial}{\partial x} \left( \Gamma_x \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left( \Gamma_y \frac{\partial \phi}{\partial y} \right) + \frac{\partial}{\partial z} \left( \Gamma_z \frac{\partial \phi}{\partial z} \right) + S_\phi
$$

Convection terms are displayed by the three expressions shown on the left, whereas on the right hand side, the four expressions show source expression and diffusion. The diffusion coefficient $\Gamma_e$, (diffusivity) is stated in the following equation:

$$
\Gamma_e = \frac{V_e}{\sigma_e} + \frac{V_e}{\delta_t}
$$

Here, the effective Prandtl number is $\sigma_e$ and this includes the turbulent dynamic viscosity as well as the turbulent diffusion coefficient. Three kinds of inlet (one, two and three) were studied. The duct length was 1.5 m. The cross section area was 0.8 * 0.04 m$^2$ and the absorber area is 1.5 * 0.8 m$^2$.

2.2. Boundary conditions

At the outlet, inlet, and walls, the conditions of boundary applied to the collector must be categorised. Specification details are shown below. Furthermore, All scalars and vectors variables (U, V, W, T, k and $\varepsilon$) arrangements’ estimates can be seen, as well as the inlet’s conditions of boundary for the CFD domains in the following equation:

$$
U(0, y, z) = U_{in}, \quad V(0, y, z) = W(0, y, z) = 0, \quad T(0, y, z) = T_{in}
$$

A change was applied in the values (1.5, 2.0 and 2.5 m/s) of inlet air velocity U. Setting the normal gradients to zero is common practice and the outlet boundary condition can be presented as follows:
\[ \frac{\partial \phi(x, y, z)}{\partial x} = 0 \]

For the absorber and glass, 3d energy equation in solid was used to calculate the temperature distribution in the class and absorber. Three cases will be examined with the same mass flow rate. Case 1 with one inlet, case 2 with two inlets and case 3 with three inlets.

3. Result and discussions

The current program used in this paper was validated for different cases in previous studies so it used in this paper without validation. Fig. 1 shows the flow field for three cases, 1, 2 and 3 inlets. The building of the boundary layer is clear in the three plots. In one inlet, the boundary layer was built early, while in two inlets, the building of the boundary layer was delayed in the lower surface because of the new fresh air inlet. In three inlets, more delay was observed in the lower surface because of two new fresh inlets in the second and third inlet.

Figure 1 Flow Field for 1, 2 and 3 inlets for 1.5 m/s.
Fig. 2 indicates the variation of temperature along the length of the 2 inlets for three different velocities 1.5, 2.0 and 2.5 m/s. The behaviour is clear, the temperature increases along the length until the position of the second inlet where the temperature decreases sharply because of the new fresh air, then it increases with high rate till the end of the length. Lower velocity 1.5 m/s will usually have highest temperature than the higher velocity.

![Figure 2](image-url)

**Figure 2** Temperature variation along the length of the collector for different velocities (1.5, 2, 2.5 m/s) at 700 W/m² and 2 inlets.

Fig. 3 shows the variation of temperature along the length for 2 inlets and 1.5 m/s for three different values of solar irradiations 500, 700 and 900 W/m². The behaviour is similar to Fig. 2, the temperature increases until the starting of the second inlet where the temperature decreases sharply because of the entrance of the fresh air. Higher solar irradiation usually has highest temperature so 900 W/m² will have highest exit temperature than 500 and 700 W/m².
Fig. 3 Temperature variation along the length of the collector for 1.5 m/s and different solar flux (500, 700 and 900 W/m²).

Fig. 4 shows the variation of temperature along the length for 1.5 m/s and 500 W/m² for three different cases (1, 2 and 3 inlets). The purpose of this research was appeared in this figure. In the beginning, 3 inlets case has highest temperature then 2 inlets case and then 1 inlet case because of the small value of flow rate of the three inlets case comparing to two and one inlets cases. Low value of mass flow rate means more heat can diffuse into the core of the flow. In each new inlet, a new fresh air will disturb the boundary layer and allows more heat can diffuse into the core of the flow and the temperature increases sharply. At the end, 3 inlet case has highest exit temperature the other two cases. Similar behaviour in Fig. 5 for 2.0 m/s and 700 W/m² and Fig. 6 for 2.5 m/s and 900 W/m².
Figure 4 Temperature variation along length of the collector for the three cases (1, 2 and 3 inlets) for 1.5 m/s and 500 W/m2.

Figure 5 Temperature variation along length of the collector for the three cases (1, 2 and 3 inlets) for inlet velocity 2.0 m/s and 700 W/m2.

Figure 6 Temperature variation along length of the collector for the three cases (1, 2 and 3 inlets) for inlet velocity 2.5 m/s and 900 W/m2.

4. CONCLUSIONS

1. Air temperature at the exit is increases with higher solar flux and lower velocity.
2. Divided the main inlet into two or three inlets will improve thermal performance of the collector so higher exit air temperature will be obtained.

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