Numerical Simulation on Thermal Performance of the Sinusoidal-Corrugated Solar Air Collector

Shuilian Li*, Hong Li¹ and Xinli Wei²

1. Zhengzhou Technical College, Zhengzhou 450121, China
2. Zhengzhou University, Zhengzhou 450000, China
Email: lotus427@126.com

Abstract. Solar air collector is a heating device of using air as heat medium, and can be widely applied to solar heating, ventilating, dehumidifying and other fields. However, these devices also set low efficiency and large heat loss. How to further improve the thermal efficiency is always the goal pursued by researchers. This article from the change of the absorb plate shape to begin, put forward sinusoidal-corrugated solar air collector, and the thermal performance of sinusoidal-corrugated solar air collectors was studied by numerical simulation with using CFD software, and conclusions shows that the thermal efficiency of parallel model is higher than that of vertical model by comparative analysis. Type S, type U and type X were studied by numerical simulation. Results show that type X is the best of three types.

Keywords. Sinusoidal-corrugated absorber plate, solar air collector, CFD.

1. Introduction
Solar air collector is a kind of solar heating device using air as heat medium, which can be widely used in solar heating, ventilation, dehumidification and other fields. The most commonly used structure is the flat plate solar air collector, which has the advantages of simple structure, low sealing requirements and no need of antifreeze, but it also has the disadvantages of low heat collection efficiency and large heat loss. In order to increase the efficiency of solar air collector, many researchers add baffles in the air passage between the absorbing plate and the insulating plate. For example, Yeh Ho-Ming et al. [1] designed the turbulent flow solar air collector; Dursun Pehlvan [2] designed the solar air collector with absorbing plate having cone; Abdul Malik and Ebrahim [3] made the solar air collector with V-shaped absorbing plate; Matrawy K. K [4] created an air collector with metal blades between the hot plate and the bottom plate; Lu Kun [5] designed a cylindrical array solar air collector, adding a metal cylindrical array to the heat collecting plate; Ye Hong [6] and others carried out experimental research on type I and type II solar air collectors with transparent honeycomb, and so on.

However, these devices also have the disadvantages of low heat collection efficiency and large heat loss. How to further improve the efficiency of solar air collector is always the goal pursued by researchers. In this paper, the sinusoidal-corrugated solar air collector is proposed by changing the shape of the plate, and its thermal performance is analyzed by numerical simulation.

2. Physical Model
The research object of this paper is the sinusoidal-corrugated solar air collector shown in figure 1. The geometric size of the cavity is 500×1000×120 mm. The total absorption rate of solar radiation can reach 0.97, and the long wave radiation emissivity is only 0.1 [7]. The maintenance structure around and at the bottom are insulated with 60 mm thick polyphenylene plate, and the upper cover plate is 4 mm ordinary single glass.
3. Calculation Model

3.1. Modeling and Meshing
ICEM software is used for modeling and meshing, as shown in figure 2. The near wall area was meshed and dimensionless wall distance was obtained to +30. According to the grid independence study, the calculation grid number of the parallel model is 550000 unstructured grids, as shown in figure 2(a), while the calculation grid number the vertical model is 520000 structural grids, as shown in figure 2(b), and the calculation grid number of the multi-inlet model is 340000 structural grids. The multiple import and export models are divided into type S, type U and type X, as shown in figure 3.

![Figure 2](image_url1)
**Figure 2.** The model of the sinusoidal-corrugated solar air collector.

![Figure 3](image_url2)
**Figure 3.** The multiple import and export models.
3.2. Boundary Conditions and Physical Properties
The flow in the collector is approximately pipe flow. By calculating its Reynolds number, it is judged that the internal flow is turbulent. The realizable K-\varepsilon model is selected as the turbulence model, which has more advantages in the prediction of negative pressure gradient flow, separated flow and complex secondary flow. Since the convection heat transfer is dominant, the radiation heat transfer between collector plate and glass cover plate, as well as radiation heat transfer between glass cover plate and external environment are not considered in the simulation [8]. Because of the low air velocity, it can be treated as an incompressible fluid, and the temperature changes greatly and leads to the change of density. Therefore, the Boussinesq hypothesis is adopted for its physical properties.

There is an angle of 45° between the solar air collector and the horizontal plane, so the buoyancy should be considered in the calculation. The boundary conditions and physical properties are shown in Table 1.

| Boundary condition          | Physical parameters       |
|-----------------------------|---------------------------|
| Inlet                       | T = 288K                  |
| Inlet velocity 2m/s         | Boussinesq                |
| Absorber plate              | Heat flux density 765W/m²  |
| Outlet boundary             | -                         |
| Mixed boundary conditions   | ρ=2500kg/m³               |
| Glass cover                 | Cp=800J/(kg·K)            |
| t₀=15°C                    | λ=0.077W(m·K)             |
| Other walls                 | Heat insulation            |

4. Result and Discussions
Fluent software package is used to simulate. The discrete scheme of convection term is second-order upwind, and that of diffusion term is first-order upwind. Simple algorithm is used. In the process of calculation, except for the energy equation, the residuals of other equations are reduced by 5 orders of magnitude.

4.1. Performance Comparison with Different Flow Patterns
4.1.1. Internal Flow Characteristics of Collector. The minimum distance between the collector and the wall can reflect the flow characteristics of the solid. Figure 4 shows the trace of the middle section, where (a) is the trace of the vertical model and (b) is the trace of the parallel model. It can be seen from the figure that in the vertical model, due to the influence of wave trough and wave crest, the air flow path results in eddy current area, which leads to higher temperature of glass cover plate and increases heat loss, and have adverse impact on heat collection efficiency. Therefore, eliminating various vortex regions is one of the effective ways to improve the heat collection efficiency. Because the air passage in the parallel model follows the trough, the vortex area is relatively small and the heat collection efficiency is high.

4.1.2. Temperature Distribution of Absorber Plate. The air flow in the collector has an important influence on the temperature distribution. Figure 5 shows the temperature distribution of the collector plate, where (a) is the temperature distribution of the vertical model collector plate, and (b) is the temperature distribution of the parallel model collector plate. The observation shows that the vertical model collector plate temperature distribution is relatively uniform; while the parallel model collector plate temperature distribution is uneven, and the temperature near the wall is higher, because of the wall blocking, air retention for a long time, leading to the local temperature rise, so we should try to reduce the local high temperature region of the collector plate in the parallel model.
4.1.3. Data Comparison under Different Flow Modes. Table 2 shows the performance comparison of sinusoidal corrugated collectors in vertical and parallel flow modes. It can be seen from the table that when the channel is parallel to the ripple, the heat collection efficiency is high because of less dead angle and sufficient heat transfer under this flow mode, while the channel is perpendicular to the ripple, the heat transfer efficiency decreases due to the influence of the dead angle at the trough, moreover, the outlet temperature of the parallel model is higher than that of the vertical model, the average temperature of the glass cover plate is lower than that of the vertical model, and the heat loss of the parallel model is less.

| Parameter (m) | Mode | Outlet temperature (K) | Absorb heat (W) | Heat efficiency (%) | Heat loss (W) | Pressure drop (Pa) |
|---------------|------|------------------------|-----------------|---------------------|---------------|-------------------|
| 0.5*1 | Vertical | 332.11 | 302.42 | 75.61 | 97.57 | 3.22 |
| | Parallel | 334.54 | 319.09 | **79.77** | 80.91 | 3.22 |
| Mode | Temperature on absorber plate(K) | | | | | |
| Vertical | Maximum | 461.34 | 370.44 | 314.07 | 326.95 | 297.91 |
| | Average | | 319.09 | | 297.91 | |
| | Minimum | | 314.07 | | 291.09 | |
| Parallel | Maximum | 419.28 | 373.56 | 312.57 | 322.28 | 296.43 |
| | Average | | 373.56 | | 291.09 | |
| | Minimum | | 312.57 | | 291.97 | |

4.2. Performance Comparison with Different Import and Export Modes

4.2.1. Internal Flow Characteristics of Collector. Figure 6 shows the trace diagram of the middle section under different import and export modes, where (a) is type S, (b) is type U, and (c) is type X. It can be seen from the figure that both S-type and U-type exist the eddy current regions, while the eddy current regions in X-type are relatively small, and the corresponding heat loss is small. It can be seen that X-type import and export mode is better.

4.2.2. Temperature Distribution of Collector Plate. Figure 7 shows the temperature distribution nephogram of the collector plate under different inlet and outlet modes. It can be seen from the figure that the temperature distribution of S-type and U-type collector plates is not uniform, while the
temperature distribution of X-type collector plate is relatively uniform. The main reason is the influence of eddy current area.

(a) Type S (b) Type U (c) Type X

Figure 6. The trace of the middle section.  Figure 7. Temperature distribution on the absorber plate.

4.2.3. Data Comparison with Different Import and Export Modes. Table 3 is the performance comparison of sinusoidal corrugated collector plates under different import and export modes. It can be seen from the table that the X-type inlet and outlet mode has the highest heat collection efficiency, the highest outlet temperature, the smallest heat loss and the smallest pressure drop. In this way, the heat transfer between the air and the collector plate is the most sufficient, the vortex area is the least, and the resistance in the air flow is the least.

Table 3. Performance comparison with different import and export modes.

| Parameter | Mode | Outlet temperature (K) | Absorb heat (W) | Heat efficiency (%) | Heat loss (W) | Pressure drop (P_a) |
|-----------|------|------------------------|----------------|---------------------|--------------|-------------------|
|           | Type U | 332.48 | 305.00 | 76.25 | 95.00 | 14.79 |
| 0.5*1     | Type S | 331.88 | 300.82 | 75.21 | 99.17 | 14.70 |
|           | Type X | 336.74 | 334.17 | 83.54 | 65.82 | 3.60 |
|           | Temperature on absorber plate (K) | Temperature on glass cover (K) |
| Mode      | Maximum | Average | Minimum | Maximum | Average | Minimum |
| Type U    | 533.18 | 380.07 | 329.68 | 326.78 | 297.40 | 289.42 |
| Type S    | 555.47 | 380.16 | 330.52 | 330.44 | 297.82 | 288.45 |
| Type X    | 547.48 | 377.09 | 315.16 | 337.06 | 294.48 | 289.28 |

5. Conclusions
The following conclusions can be obtained by numerical simulation of the sinusoidal corrugated solar air collector in different flow modes and different import and export modes. In terms of flow mode, the heat collection efficiency of parallel model is higher than that of vertical model, because of the large eddy current region and large heat loss of vertical model, while the parallel model is relatively small, the heat loss is small and the efficiency is high. From different import and export modes, the X-type inlet and outlet have the highest heat collection efficiency, the lowest pressure drop and the highest outlet temperature.
References

[1] Ho M Y and Lin T T 1995 The effect of collector aspect ratio on the collector efficiency of flat-plate solar air heaters Energy 20 (10) 1041-47.
[2] Dursun P 2003 The performance of a solar air heater with conical concentrator under forced convection Thermal Sciences 42 (6) 571-581.
[3] Ebrahim A M 2002 Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate Heat and Mass Transfer 45 (16) 3383-96.
[4] Matrawy K K 1998 Theoretical analysis for an air heater with a box-type absorber Solar Energy 63 (3) 191-198.
[5] Lu K 2004 Experimental Study on Cylindrical Array Solar Air Collector (Qingdao: Qingdao Institute of Architecture and Engineering).
[6] Ye H and Ge X S 2003 Experimental study on solar air heat collection with transparent honeycomb Acta Solar Sinica 24 (1) 27-31.
[7] Hüseyin B 2012 Experimentally derived efficiency and exergy analysis of a new solar air heater having different surface shapes Renewable Energy 50 58-67.
[8] Hu J J, Sun X S and Xu J L 2011 Internal flow and heat transfer analysis of solar flat air collector Thermal Power Engineering 26 (5) 615-620.