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Numerical study of heat exchange processes in solar air collectors with Turbulizers

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Abstract

This article presents the results of the change in the temperature of the air moving through the air duct of the solar air collector by the length of the collector when turbulizers are used to accelerate heat-hydrodynamic processes in solar air collectors. The results of this study were obtained using the software tool COMSOL Multiphysics 6.1, which is recommended to be used in numerical research and design of heat exchange processes in turbulizer solar air collectors.

Keywords: Solar energy; Solar air collector; Turbulizer; Air flow; Air temperature; Heat exchange

1. Introduction

Currently, a large number of scientific studies have been conducted and innovative developments have been proposed to increase the thermal efficiency of solar air collectors (SACs). An effective way to increase the thermal efficiency of SACs by accelerating the convective heat exchange process in SACs is to install turbulizers in the air flow channel and create turbulence [1,2]. It is known from the information presented in the above chapters that the creation of artificial roughness on the surface of the absorber plate significantly increases the heat transfer rate in SACs. Karmare and Tikekarlar [3] showed that when roughness with metal ribs of different cross-section shapes was installed on the absorber plate, the heat transfer rate for a square-shaped plate was up to 30% higher than for a simple SAC. EI-khawajah et al. [4] used wire mesh cross ribs as absorbers in a two-way SAC, and the maximum FIC of the SAC with 2, 4 and 6 ribs was 75.0%, 82.1% and 85.9%, respectively, with an air mass flow rate of 0.042 kg/s. EI-Sawi et al. [5] used a "fir"-shaped absorber plate prepared by continuous placement method in the SAC. The "fir"-shaped absorber plate, the simple plate and the V-shaped plates were compared. According to the results, the efficiency of the SAC with the "fir"-shaped absorber plate increased by 20% and the outlet air temperature increased by 10°C. Amraoui and Aliane [6] conducted a numerical study of the SAC using three-dimensional modeling (CFD), which significantly reduced the time and cost of the study. The purpose of this study was to first compare theoretical results with experimental results, and then conduct in-depth studies on a SAC with transverse and longitudinal turbulators. The authors presented results on the distribution of air flow temperature, velocity, and turbulence.

In the research work of Jassim and Shbailat [7], different states of air flow in SAC were studied. In this, the authors developed five types of SACs through numerical modeling and conducted thermodynamic studies. The authors selected the k-ε turbulence model and numerically studied the temperature and velocity distribution in each type of SAC using the ANSYS CFX software tool and proposed a governing equation for SAC. In the research work of Karim and Amin [8], a comparative study was made of SACs with smooth absorbers and V-shaped absorbers, and MATLAB was used to obtain temperature values and energy equations in the calculation. According to the results of the temperature values, it was found that the V-shaped absorber SAC has a high thermal efficiency and that the flow rate has a strong effect on the thermal efficiency of SAC. When Khorasanizadeh et al. [9] studied SACs with different absorber plates (triangular,

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rectangular and wavy), it was found that the corrugated model performed better throughout the year. The sinusoidal model had the highest efficiency compared to other models. According to the results, the optimal Reynolds number value in terms of temperature rise and high efficiency criteria for all studied models was 2500.

As can be seen from the literature analysis presented above, insufficient research has been done on turbulizer sac to change the airflow temperature, Nusselt number, and thermal efficiency by SAC length at different airflow rates. In the research work, it is necessary to model the heat exchange processes in Sac in order to research air temperature, Nusselt number and thermal efficiency in the models being studied.

2. Material and methods

A numerical model was developed using COMSOL Multiphysics 6.1 software to theoretically study the variation of air temperature along the length of the SAC in a smooth absorber and turbulizer SAC [10-12]. Theoretical studies based on the numerical model were carried out at different air velocities (u=4,8,12,16,20 m/s) and solar radiation intensity in the range of 700...1000 W/m². In the numerical model, a heat transfer interface in solids and liquids was selected. This interface is used to model conductive, convective and radiative heat transfer in solids and liquids. The following heat transfer equation was used to model the heat transfer, taking into account the material, area and source properties:

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u \nabla T + \nabla q = Q, q = -k\nabla T \dots\dots(1)$$

where $\rho -$ is the density, kg/m³, c_p- is the specific heat capacity ; u- is the velocity field determined at the Moving Mesh node when the flow moves through the model parts, m/s; k- is the heat transfer coefficient, Vt/(m·°C).

Thermal insulation is the standard boundary condition for all heat transfer interfaces. This boundary condition means that there is no heat flow across the boundary:

$$-nq = 0 \dots\dots\dots\dots(2)$$

In our condition $T = T_0$, where T_0- is the fixed marginal temperature.

The wall node contains a set of boundary conditions that describe steady, moving, and wall-flow conditions. For turbulent flow, the description includes wall functions and asymptotic expressions for certain turbulence variables. A no-slip wall is a standard boundary condition for modeling rigid walls. A no-slip wall is a wall where the fluid velocity is zero relative to the wall velocity, for a steady wall $u = 0$. From this:

$$u \cdot n = 0 \dots\dots\dots..(3)$$

$$Kn = -\rho \frac{u_\tau}{u^+} u_t \dots\dots\dots\dots..(4)$$

$$u_t = u - (u \cdot n)n \dots\dots\dots\dots(5)$$

$$\nabla k \cdot n = 0, \varepsilon = \rho \frac{C_\mu k^2}{k_v \delta_d^+ \mu} \dots\dots\dots\dots..(6)$$

The input parameter is the flow velocity $u = -nU_0$, where n is the normal boundary pointing outside the domain and U_0 is the normal flow velocity, in this case $U = U_0$.

3. Results and discussion

In the numerical model developed using the COMSOL Multiphysics 6.1 software tool, a theoretical study was initially made of varying the air temperature by SAC length in a smooth absorber sac with varying airspeed and solar radiation intensity (Figure 1). From the results presented in Figure 1, it can be seen that the airspeed and the intensity of solar radiation have a significant effect on the change in air temperature. When the air velocity changed in the range of 4...20 m/s, the air outlet temperature decreased. In this range, when the solar radiation intensity was 700 Vt/m^2, the air outlet temperatures changed in the range of 50.7...35.4°C, 57.9...40.5°C at 800 Vt/m^2, 65.2...45.6°C at 900 Vt/m^2, and

72.4...50.6°C at 1000 Vt/m^2, respectively. The results show that the air outlet temperature was maximum at an air velocity of 4 m/s, and the air outlet temperature decreased as the air velocity increased.

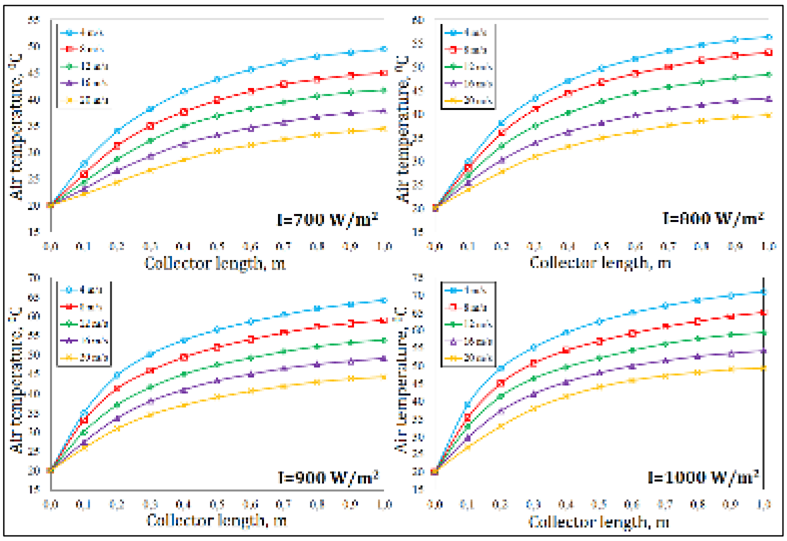

Figure 1 Results of air temperature changes in a SAC with a smooth absorber

The results of the air temperature change in the T4 model when the air speed and solar radiation intensity varied are shown in Figure 2. As can be seen from the results, the air outlet temperature also changed significantly with the change in the air inlet speed and solar radiation intensity. It was found that the air outlet temperature increased with the decrease in air speed and the increase in solar radiation intensity. When the air speed changed in the range of 4...20 m/s and the solar radiation intensity was 700 Vt/m^2, the air outlet temperatures changed in the range of 52.0...36.4°C, when the air speed was 800 Vt/m^2, it was 59.5...41.6°C, when the 900 Vt/m^2 was 66.9...46.8°C, and when the 1000 Vt/m^2 was 74.3...52.0°C, respectively. The maximum air temperature detected in this model was 74.3°C, which was found to be 2.6% higher than that of the smooth absorber SAC.

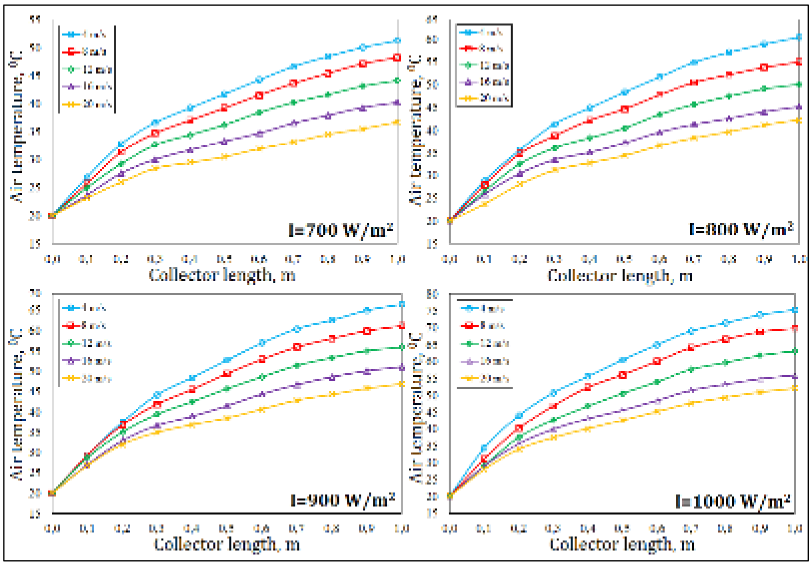

Figure 2 Results of air temperature changes in the T4 model

The results of changing the air temperature in the T5 model with different airspeed and solar radiation intensity are shown in Figure 3.

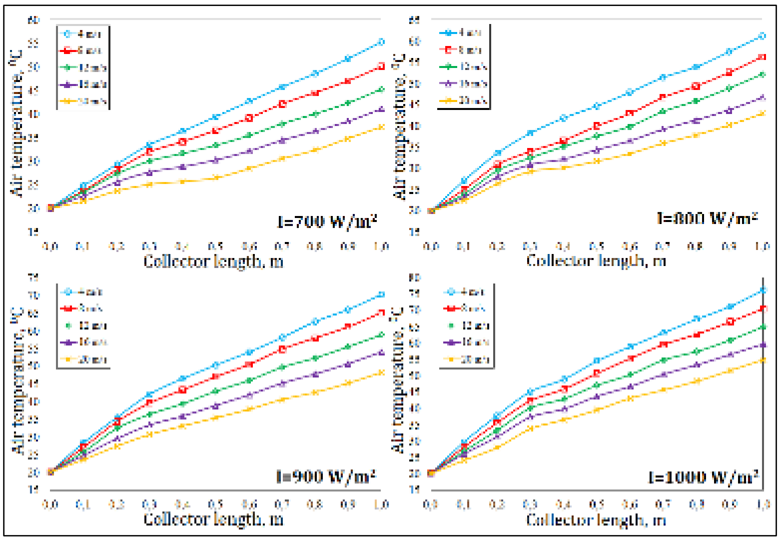

Figure 3 Results of changing the air temperature in the T5 model

As can be seen from the results presented in Figure 3 above, the nature of the air temperature change in this model was different from the T4 model. In the T5 model, it was also found that the air outlet temperature increased with a decrease in air speed and an increase in solar radiation intensity. When the air speed changed in the range of 4...20 m/s and the solar radiation intensity was 700 Vt/m^2, the air outlet temperatures changed in the range of 53.6...37.5°C, 61.2...42.8°C at 800 Vt/m^2, 68.9...48.2°C at 900 Vt/m^2, and 76.5...53.5°C at 1000 Vt/m^2, respectively. The maximum air temperature determined in this model was 76.5°C, which was 5.7% higher than that of the smooth absorber SAC and 3.0% higher than that of the T4 model.

4. Conclusion

The following conclusions were made on the numerical study of the heat exchange process in a turbulizer SAC:

A mathematical model was developed that allows for theoretical study of the heat exchange processes in a smooth absorber and turbulizer SAC, taking into account the parameters of the transparent coating of the SAC, air flow, absorber and turbulizers. A computer model was developed and numerically studied to determine the change in air temperature along the length of the SAC in a turbulizer SAC when the air flow velocity varies in the range of 4...20 m/s and the solar radiation intensity varies in the range of 700...1000 Vt/m^2. According to the results, the air outlet temperature is the highest at an air velocity of 4 m/s and a solar radiation of 1000 W/m2, and it was determined that it was 72.4°C in a smooth absorber SAC, 74.3°C in the T4 model and 76.5°C in the T5 model

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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