

A comparison between a conventional and a convergent collector of a solar chimney power plant

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Abstract—A numerical model is developed to assess the performance of a solar chimney power plant while varying the collector roof angle. A comparison between a convergent collector roof and a conventional setup of a solar chimney power plant is presented. A two-dimensional steady model has been developed using the commercial computational fluid dynamics (CFD) code "Ansys Fluent 17.0". For each collector roof configuration, the distribution of the magnitude velocity, the temperature, the pressure and the turbulent kinetic energy were presented and discussed. The obtained results present an interesting data which can provide the thermal characteristics of the air flow for the designers and the engineers to improve the overall efficiency of an existing solar setup.

Keywords—SCPP, convergent collector, conventional collector, geometric parameters, CFD, turbulent flow

I. INTRODUCTION

The conception of the solar chimney power plants (SCPP) are attractive techniques. The mainly function of the SCPP setup is to convert the solar energy into electrical energy. In this context, several researches have been presented to design and optimize the solar setup. Fasel et al. [1] studied the impact of the chimney height on the SCPP system. The chimney height was varied from the chimney height from $H=1$ m to $H=1000$ m. As a result, they have noted that the chimney height affects significantly the solar setup. Al-Kayiem et al. [2] conducted a numerical and mathematical analysis on the influence of the geometrical parameters of the roof top on the performance of the solar chimney. As a result, they have noted that the solar intensity is the most influential parameter. Zhou et al. [3] focused on the effect of the chimney height and the collector size on the power output using a mathematical model. The collector radius, the chimney height and the intensity of the solar radiation have been varied. As a result, the increase of the chimney height, the collector radius and the solar radiation intensity cause an increase in the power output. Koonsrisuk [4] presented a mathematical model based on the continuity, the momentum, the energy, and the state equations for the sloped solar chimney setups. Their work was focus on the performance of the sloped solar chimney. In another study, Koonsrisuk [5] compared a conventional solar chimney power plant and a sloped solar chimney power plant using the second law analysis while varying various configurations. As a result, they have noted that the sloped solar chimney power plant is thermodynamically better than the conventional solar chimney power plant for some configurations. Shiv et al. [6] analysed the performance of a SCPP which is composed of two circular areas. In their work, the title angle of the inner frame and the external frame are equal respectively to $\theta=10^\circ$ and $\theta=5^\circ$. They have presented the impact of the chimney height on the chimney

efficiency, the impact of the temperature of the chimney outlet on the mass flow rate and the impact of the solar radiation on the generated power. Ayadi et al. [7-12] have developed numerical simulations using Ansys Fluent software. The effect of the meshing and the turbulence models were presented and discussed. In their works, the authors have noted that the meshing and the turbulence models choice are important steps while using a commercial CFD code. Using the Ansys Fluent, the authors numerically modelled the turbulent flows inside the solar chimney in stationary and unsteady state. In addition, Ayadi et al. varied the geometric and energy parameters of the system to choose the most optimized geometry. The diameter of the collector was varied from $D = 1000$ mm to $D = 2750$ mm, the height of the collector was varied from $h = 50$ mm to $h = 200$ mm, the height of the stack was varied from $H = 1000$ mm to $H = 3000$ mm and the inclination of the collector was changed. Validations of the numerical models were done using the experimental results developed on their test bench. From these anterior studies, it has been noted that the most published works deal with the conventional solar chimney power plant. In this paper, we are going to compare a convergent collector roof with a conventional setup of a solar chimney power plant. A numerical study was carried out to highlight the impact of the collector slope angle on the thermal characteristics of the airflow.

II. STUDIED SYSTEM

Figure 1 presents the studied prototype which is built in Tunisia. The collector height and the collector diameter are equal respectively to $h=50$ mm and $D=2750$ mm. However, the chimney height and the chimney diameter are equal respectively to $H=3000$ mm and $d=160$ mm. In order to investigate the effect of the collector roof angles on the air flow characteristics, two configurations have been investigated. Figure 2 shows geometrical parameters of the solar chimney power plant. Two cases have been chosen in this study. For the first case, the angle is equal to 0 which is the conventional configuration. And, the second angle is equal to -1 which shows the convergent collector.



Fig. 1. Experimental setup

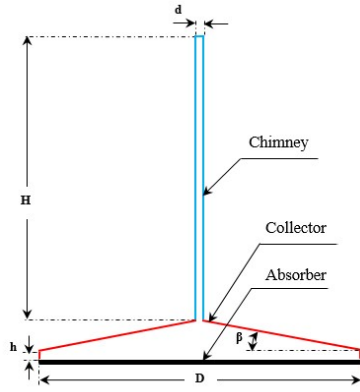


Fig. 2. Geometrical arrangements

III. NUMERICAL MODEL

A. Mathematical formulation

The CFD code "Ansys Fluent 17.0" is used to simulate the turbulent flow inside the SCPP system. The present application is governed by the continuity, the momentum and the energy equations which are presented in the cylindrical coordinate. Several researchers have presented the governing equations of the air flow within a solar chimney power plant [7:12].

B. Boundary conditions

For the boundary conditions of the solar setup, the ambient air temperature was applied for the wall of the SCPP prototype. The applied value of the air temperature was measured using our measurement devices (11th April 2016). Indeed, the value of the atmospheric pressure is applied for both the collector inlet and the chimney outlet. In fact, the collector inlet is assumed as the pressure inlet and the chimney outlet is assumed as the pressure outlet. The plastic covering of the collector is considered as a semi-transparent wall.

C. Choice of meshing and turbulence model

The meshing choice is an essential step before computational simulations. In fact, the choice of the best meshing causes accurate CFD results. The appropriate meshing was chosen to have the maximum number of nodes with a moderate run time. The turbulence model choice is an important step before validating numerical simulations. According to anterior works, a two-dimensional (2D) steady model with the standard $k-\epsilon$ turbulence model has been used. The air flow is governed by the continuity, the momentum and the energy equations. These equations are numerically resolved using the commercial computational fluid dynamics (CFD) code ANSYS Fluent 17.0.

IV. RESULTS

The obtained results are expected to provide information that will assist in the enhancement of the overall efficiency of the solar chimney power plant. In fact, Ansys Fluent 17.0 is used to present the distribution of the air flow.

A. Magnitude velocity

Figure 3 shows the distribution of the magnitude velocity in the whole volume of the SCPP system for the considered collector roof angles. According to these results, it has been noted that the air flow occurs from the collector inlet to the chimney outlet. In fact, the solar chimney setup uses the natural buoyancy of air heated. Indeed, it has been noted that the maximum value location is located in the chimney bottom for both configurations. Over the chimney, the air velocity values decrease from the bottom to the top. This fact is due to the difference of pressure which is maximum in this zone. Along the collector, the magnitude velocity reaches a very weak value in the collector inlet away from the chimney axis. Comparing the conventional and the convergent collector, it has been noted a difference in value and in shape. The maximum value of the magnitude velocity is equal to $V=2.13 \text{ m.s}^{-1}$ and $V=2.31 \text{ m.s}^{-1}$ for the conventional and the convergent collector, respectively. The comparison between these results confirms that the collector roof angle has an impact on the magnitude velocity of the air flow. In fact, the convergent collector positively affects the magnitude velocity.

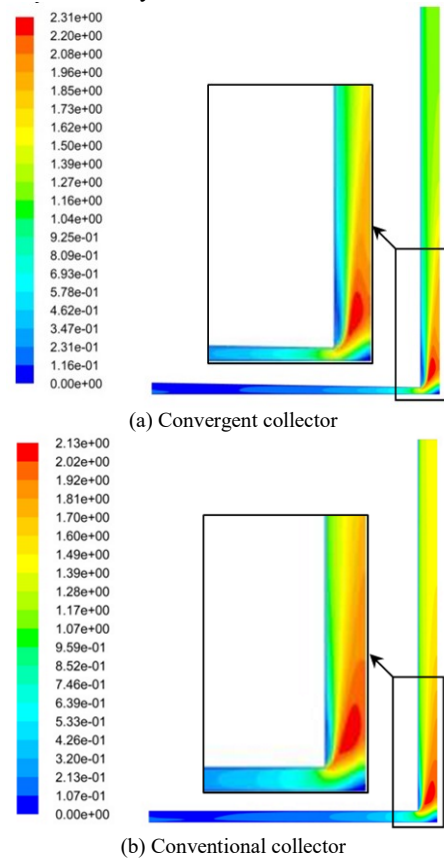


Fig. 3. Distribution of the magnitude velocity

B. Temperature

Figure 4 shows the distribution of the temperature for the considered collector roof angles. From these results, it has been noted that the considered configurations practically present the same distribution of the air temperature inside the solar chimney power plant. In fact, it has been noted that the maximum value of the air temperature is located near to the absorber and this is the fact of the heat transfer exchange between the absorber and the airflow inside the collector.

Indeed, it has been noted that the minimum value of the air temperature is located at the collector inlet and is equal to the ambient temperature. Comparing the conventional and the convergent collector, it has been noted a negligible difference in value and in shape. In fact, both configurations are expected to the same solar radiation and the ambient temperature.

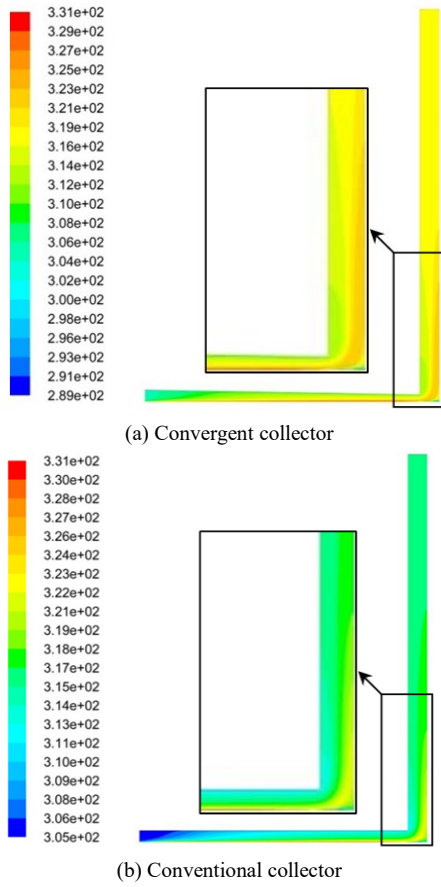


Fig. 4. Distribution of the static temperature

C. Static pressure

Figure 5 presents the distribution of the static pressure for the considered designs. From these results, it is clear that the static pressure presents the same distribution for all considered collector roof angles. The value of the static pressure is minimum at the chimney inlet near the wall where the magnitude velocity is maximum. However, it has been observed a difference in the shape of the depression zone for each configuration. The comparison between these results confirms that the collector roof angles have a direct impact on the static pressure inside the SCPP.

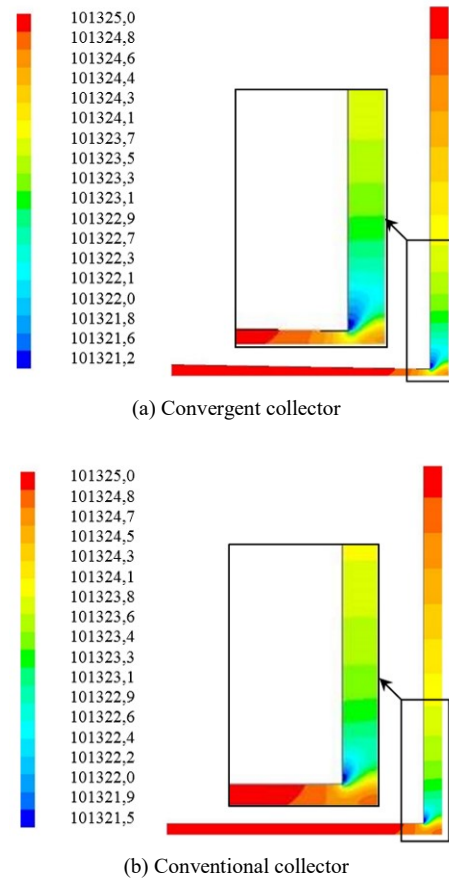
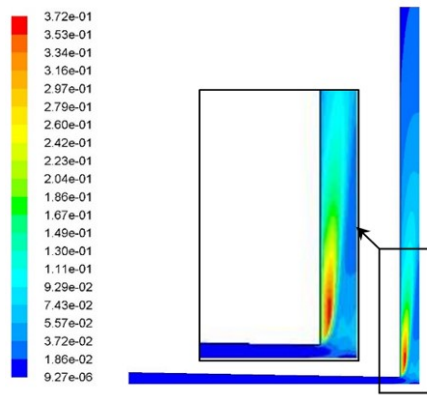


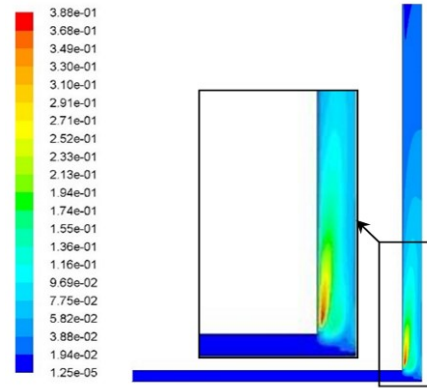
Fig. 5. Distribution of the static pressure

D. Turbulent kinetic energy

The distribution of the turbulent kinetic energy is presented for the considered collector roof angles. From figure 6, it has been observed that the turbulent kinetic energy distribution appears similar for the different configurations. In fact, the maximum value location of the turbulent kinetic energy is the same for the different considered cases. Comparing the conventional and the convergent collector, it has been noted a difference in value and in shape. The most extended wake zone appears for the convergent collector. The comparison between these results confirms that the collector roof angles have a direct effect on the turbulent kinetic energy in the SCPP. In fact, the maximum value of the turbulent kinetic energy recorded in the whole volume of the SCPP varies and is equal to $k=0.388 \text{ m}^2 \cdot \text{s}^{-2}$ and $k=0.372 \text{ m}^2 \cdot \text{s}^{-2}$ for the conventional and the convergent collector, respectively.



(a) Convergent collector



(b) Conventional collector

Fig. 6. Distribution of the turbulent kinetic energy

E. Validation of the numerical findings

Figure 7 shows experimental and numerical evolution of the air temperature over the collector. From these results, it has been noted a small difference between numerical results and our experimental results. This difference between the experimental and numerical results can be explained by the measurement error of the devices, the variation of the wind velocity, the numerical model and the heat transfer coefficient. Globally, this comparison presents a good agreement and confirms the validity of the numerical method.

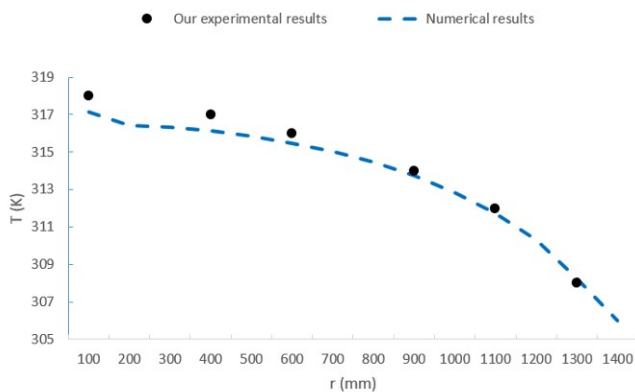


Fig. 7. Comparison with experimental results

V. CONCLUSIONS

In this paper, the influence of the collector roof inclination was carried out using the commercial code Ansys Fluent 17.0. Comparing the conventional and the convergent collector, it has been noted that the performance of the solar plant increases using a convergent collector of a solar chimney power plant. In fact, the value of the magnitude velocity could be raised for a variation of collector slope. The convergent collector is an efficient solution for engineers to be investigated to increase the generated power of an existing conventional solar chimney power plant. In the future, we are going to focus on the impact of some geometric parameters on the efficiency of the solar systems.

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