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Numerical Investigation of Solar Updraft Tower for Different Collector Inlet Heights and Absorber Materials

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ABSTRACT

In this paper, performance characteristics of the solar updraft tower were investigated using a numerical analysis. Simulations were carried out using ANSYS FLUENT to create a realistic shape and mesh for the flow model. The governing equation was solved using a combination of turbulent, realizable (k–ε), and discrete ordinate radiation approaches. Maximum air velocity and air temperature were recorded in the SUT model using GI sheet ground materials for collectors at lower collector intake heights, higher maximum air velocity.

1. Introduction

The rapid increase in fossil fuel consumption contributes directly to global warming. Converting solar radiation to electrical power, the solar updraft tower (SUT) is an entirely sustainable energy method. The SUT technology is a viable alternative to the current carbon-based energy system. The effectiveness of the SUT setup is determined by the height and diameter of the chimney, the height and diameter of the collector roof, the prototype materials, the meteorological conditions, and the location of the setup. Various prototypes have been created over a number of years to test their performance [1-5]. Because of the major differences in weather conditions, the performance of solar chimney power plant (SCPPs) differs from place to place, necessitating unique design work for various locations. Furthermore, there has been minimal effort put forward to analyze the SCPPs in a straightforward and exact manner. As a result, a software based on TRNSYS was created in this paper to simulate the performance of SCPPs [6]. Solar chimney power plants are numerically examined using ANSYS Fluent. In order to get an understanding of the fluid dynamics and heat transfer processes, time-dependent high-resolution simulations of the flow in the collector and chimney of the model were conducted [7]. Conception and building of the first SCPP prototype at Manzanares, Spain, began in the late 1970s. From 1982 through 1989, this SCPP facility supplied energy to the local grid.

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Estimate the output power of (SCPPS). Recently, numerous mathematical models of SCPPS were developed, analyzed, and compared to CFD computations over a wide range of boundary conditions [8-10]. In theory, increasing the size of the chimney tower relative to the chimney collector may enhance the driving potential of the solar chimney (SC) system. The diverging chimney, the cylindrical chimney with a divergent outlet, and the cylindrical chimney with a divergent intake are numerically studied in this work based on this idea to expose their aerodynamic properties and power production potential [11, 12]. Many researchers also conducted experimental studies on the model's performance. Temperatures and air velocities were observed at a SCPP with varying the geometrical dimensions. To study the temperature and velocity, observations were taken at various locations in the collector and chimney, with certain parameters changing on different days [13-16]. Najm and Shaaban [17] mathematical and CFD model were developed and applied for various geometric and operational conditions, determine the best collector radius that optimizes the power density of SCPP. Nasraoui H, Driss Z, Kchaou H *et al.,* [18] a novel collector design with a double-pass counter flow mode is suggested in this research. CFD approach was used to compare three models: conventional collector, double-pass collector with parallel flow, and double-pass collector with counter flow.

2. Current Study

Most prior studies did not take into account the influence of geometric form on the power density of SCPP. As a result, the goal of this study is to obtain the appropriate collector inlet and absorber material to optimize the power density of the SCPP. To achieve this goal, an accurate axisymmetric numerical simulation of a typical SUT employing a radiation model was initially performed. Later that, the collector inlet and absorber material were varied, and to obtain maximum SUT power density. The physical properties of the various materials used are summarized in Table 1. These features were gathered from several sources of literature. Models of physical systems are used to better understand how the systems respond under real-world settings and to make predictions about how the systems will behave in the future. An improved understanding and application of the solar updraft tower model will be aided by the findings of the study. This study's climatic conditions were based on a location in the Sultanate of Oman, with an ambient average temperature of 37° C, atmospheric air pressure, and solar radiation.

Table 1
Different types of absorber plate

Physical property(unit)	Ground under collector (soil)	Ground under collector (Black Color GI Sheets)
Absorption coefficient	0.8	0.9
Density (kg/m^3)	1900	7800
Specific heat (J/kg·K)	2200	470
Thermal conductivity (W/m·K)	1.83	52
Emissivity	0.89	0.9

The selected chimney diameter is 66 mm. It was determined that velocity increases with chimney height for a 66-mm diameter chimney [2]. The steady state k−ε turbulence model with the Reynolds-Averaged Navier-Stokes equations (RANS) is utilized for modelling. The Bousinesq approximation accounts for the air density change in the buoyancy flow.

Because curvatures dominate flat surfaces in total geometry, triangular meshes perform better in CFD simulations. The element size is changed to match the desired skewness and smoothing function. The elements produced range from 124166 to 1037952. The dependence on cell counts for the two key performance metrics, maximum air temperature and maximum air velocity, is shown in Table 2. The percentage change in maximum air velocity caused by changing cell count is less than 8%. This cell count was chosen for the CFD study because the above-mentioned results are comparable to those of previous studies. The CFD model's correctness is then validated by examining the maximum air velocity values in the SUT model that were changed by the discrete ordinate (DO) non-grey radiation model.

Table 2
For a given domain, the solution is mesh-independent

Number of Elements	Max. Velocity
1037952	1.36
244714	1.14
124166	1.05

3. Results

Figure 1 depicts velocity contours in a 66 mm solar chimney. The velocity increases from the chimney's entry zone to the center, eventually reaching the chimney's height. The air velocity between the chimney intake and the chimney outlet has increased. The maximum velocity for a 1 m high chimney is 2.58 m/s, and increasing with chimney height (Figure 2).

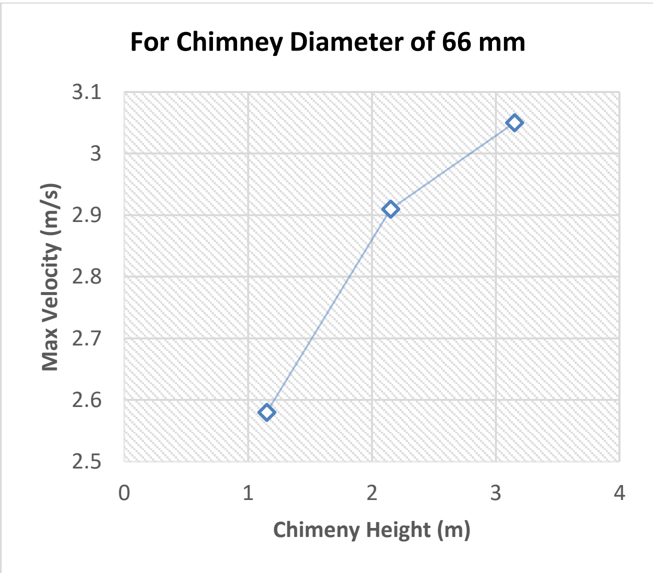
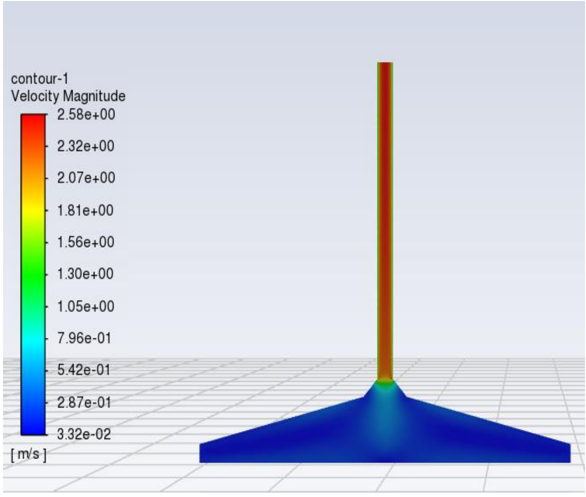
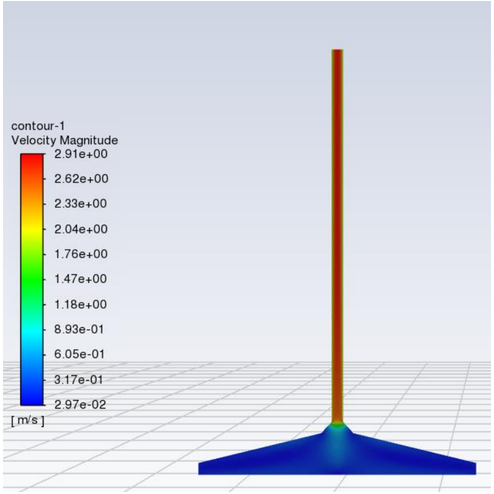


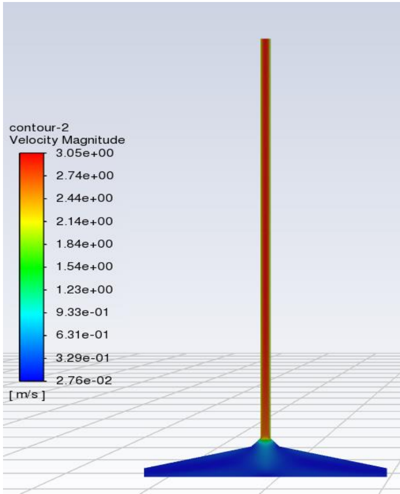
Fig. 1. Variation of maximum velocity with chimney heights



(a)



(b)



(c)

Fig. 2. Contours of velocity magnitude for tower height of (a) 1 m, (b) 2 m and (c) 3 m height

3.1 Case-1 for Different Collector Ground Materials

Hot air, being lighter than cold air, rises into the tower. The cold air enters the collection via the ground gap. The hot air rises slowly through the collector and into the vertical tower. As seen in Figure 3, the solar chimney's velocity contours vary with collector ground materials. The velocity gradually increases from the chimney's entrance zone to the chimney's centre. The air velocity between the chimney intake and the chimney outlet has increased. The highest velocity for the SUT model with collector black color GI sheet is 2.58 m/s, whereas the velocity with soil ground materials is lower. Figure 4 shows the maximum velocity contours for soil (a) and black color GI sheet (b).

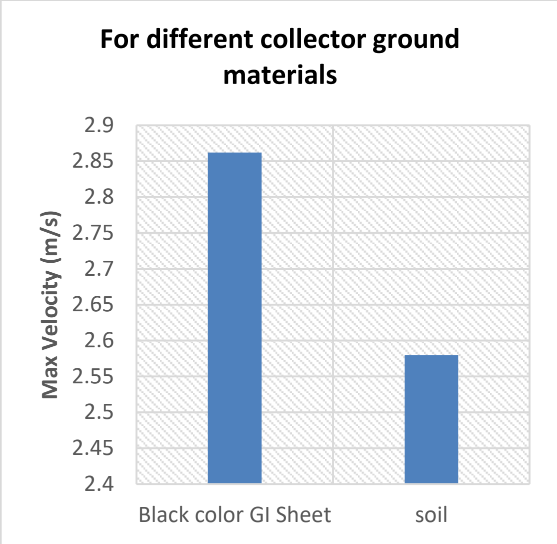
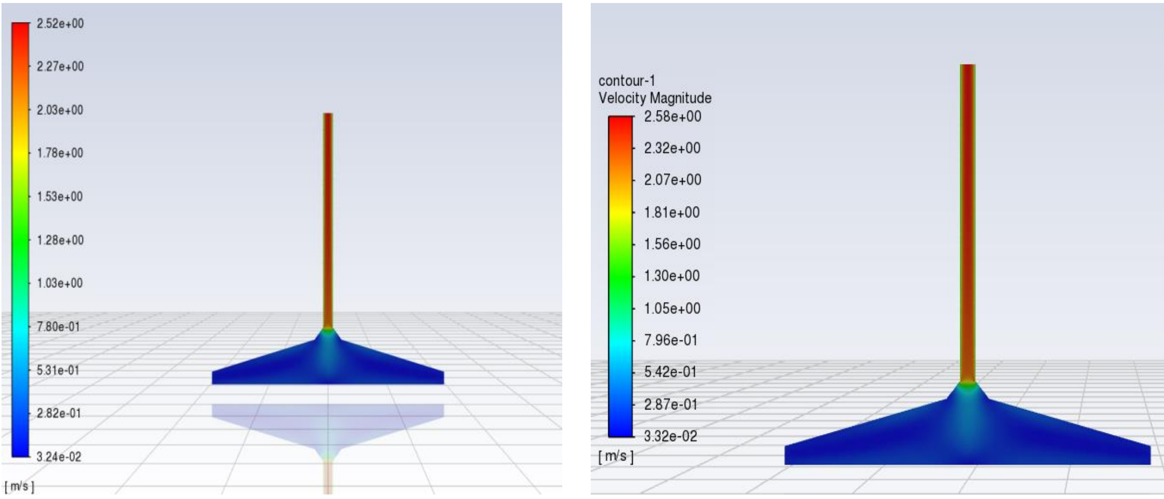


Fig. 3. Variation of maximum velocity with different collector ground materials



(a) (b)

Fig. 4. Contours of velocity magnitude for different collector ground materials

3.2 Case-2 for Different Height Collector Inlets

As seen in Figure 5, the solar chimney's velocity contours vary with collector ground materials. The velocity gradually increases from the chimney's entrance zone to the chimney's centre. The air velocity between the chimney intake and the chimney outlet has increased. The highest velocity for the SUT model with collector inlet height 45 mm is 2.58 m/s, whereas the velocity with inlet height is lower. Figure 6 shows the maximum velocity contours for inlet 45 mm (a) and inlet 68 mm (b).

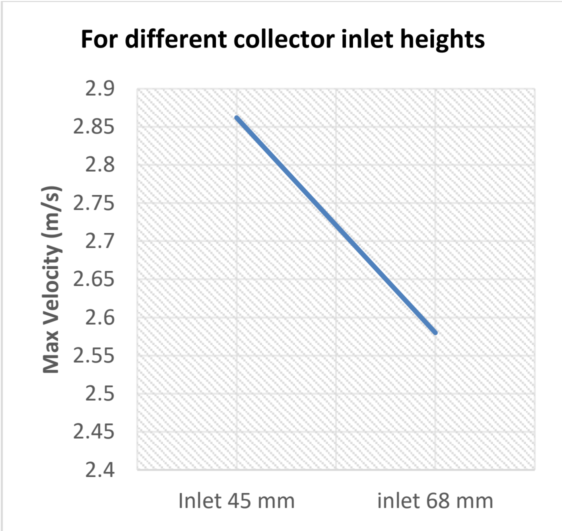
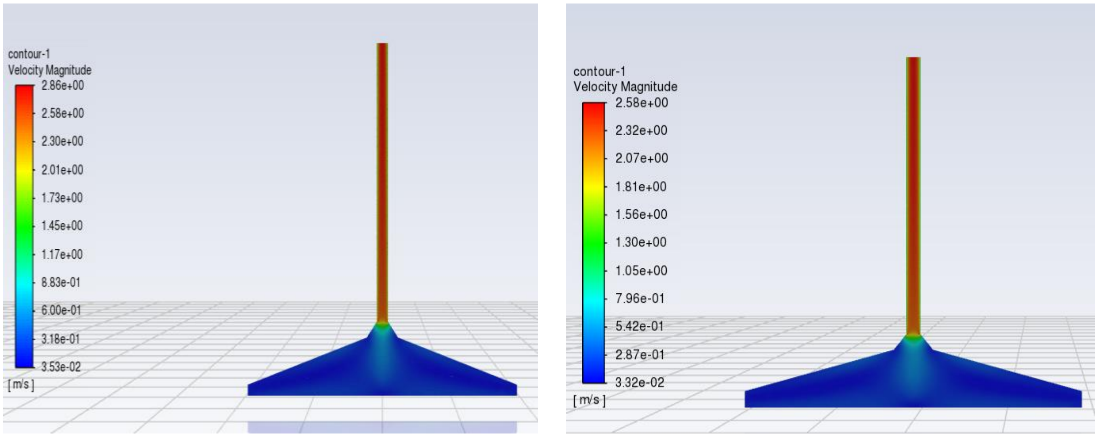


Fig. 5. Variation of maximum velocity with different collector inlet heights



(a) (b)

Fig. 6. Contours of velocity magnitude for different collector ground materials

The model was verified using experimental data from Adamsab K *et al.,* [1] (Figure 3) on the effect of temperature and simulated velocity data from Adamsab K *et al.,* [2] (Figure 6). The current study's findings for CFD and experimental tests are in good agreement with those found in the literature [1,2].

4. Conclusion

The current study focuses on numerical modelling and optimization of SUT performance under various collector ground materials and inlet heights. The solar radiation was modelled using a discrete ordinates (DO) radiation model. The following conclusions can be drawn. The larger the temperature difference, the faster the air moves, and hence the more power. The findings suggest that GI Sheet outperformed soil in terms of heat storage.

Furthermore, in the SUT model, decreasing the collector inlet height increases temperature and velocity, while increasing the inlet height decreases temperature and velocity.

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