Analysis of thermophysical parameters of solar water desalination plant with an external camera

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Abstract. In this work, an analysis of the thermophysical processes taking place inside a specially designed chamber with a geometry different from other works was carried out. This process is designed in COMSOL Multiphysics software. Boundary conditions were investigated for ambient temperature of 293.15 K and solar radiation of 1000 W/m². The process was taken as natural convection. In this case, the flow of air with high humidity inside the solar water heater was analyzed. It can be seen that the air temperature rises to 450 K. At the same time, the speed of moist air inside the chamber, heat flow and other thermophysical quantities were determined and analyzed.

1 Introduction

The growing industrialization, particularly in developing nations, coupled with a heightened concern for environmental preservation, has led to an escalated desire for clean and environmentally friendly renewable energy sources. This demand specifically includes wind and solar energy, aimed at generating both freshwater and electricity [1]. Solar energy can meet the energy needs of the world using a few percent of uninhabited areas [1-5]. In a prior study, it was found that around 40% of the global energy production is dedicated to heating purposes [5]. At the same time, despite the fact that 97% of the Earth's surface is covered with water, most of the water is located in the oceans and seas, which are considered unsuitable for drinking. The increasing pollution of surface and underground water from year to year shows that this problem is more urgent. Based on the above, desalination of salt water is important in solving the problem of drinking water. The industrial application of salt water desalination technology began in the 1950s [6]. However, the high energy consumption of desalination, the large amount of greenhouse gases, the increase in the amount of salt waste, and the high operating costs prevented this technology from being widely adopted [7]. Currently, the use of renewable energy is an effective way to solve this problem. Among them, solar energy is clean, harmless, available in any region and stable[8,9]. At present, a large number of research works have been carried out to improve the efficiency of solar water purifiers. For example, in AE et al. [10], the methods of improving the design of horizontal and vertical solar water purifiers are

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considered. According to it, it was determined that the price of water for one kilogram in tubular solar water dispensers is between 0.0061 and 0.2 US dollars. Mariem et al. [11] only studied the geometrical dimensions of solar water desalinations, the wick material. Swellam et al. [12] conducted a study on thermal analysis and device performance improvement on a tubular solar water heater. Arunkumar et al. [13] only studied and classified solar water heaters with efficiencies greater than 5 L/m² and also considered the heat transfer mechanism in the devices. Hemant et al. [14] analyzed different sloped solar stills and found that active sloped solar stills have the highest efficiency for fresh water. Inspired by the work analyzed above, CFD analysis of the solar water desalination device was found to be appropriate.

2 Methods and materials

The initial phase in conducting a Computational Fluid Dynamics (CFD) analysis for any issue involves developing a geometric model that aligns with the design specifications. In this context, the designated problem domain encompasses the area enclosed by the surface of the saltwater within the still basin, the surrounding side walls, the front and back boundaries, and the transparent cover of the solar still. A schematic view of the solar water purifier is shown in Figure 1. The dimensions of the main camera are width-1 m, depth-1 m, height-0.9 m. The section where salt water is poured consists of width-1 m, depth-1 m, height-0.1 m. A separate section connected to the main chamber is a chimney and its height is 2 m. The 3D geometry of the two-chamber solar water heater was created in COMSOL Multiphysics software, and Figure 1 shows the schematic model of the designed 3D model.

![Fig. 1. Schematic view of the solar water desalination. 1- chamber for the exit of moist air, 2-separate compartment, 3- the main transparent-walled camera, 4-Cut Line 3D for results, 5- hole connecting the main chamber and the chamber, 6- hole for incoming air flow from the outside, 7- section with salt water poured under the active element [15].](image)

Establishing accurate boundary conditions and their types played a crucial role in achieving precise solutions for fluid flow problems [16-22]. While certain boundary conditions were determined based on physical phenomena, others were set using the simulation software COMSOL Multiphysics. Table 1 provides a comprehensive overview of

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Gas</th>
<th>Property</th>
<th>Boundary condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Air</td>
<td>Ambient temperature</td>
<td>210°C</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Acceleration</td>
<td>Gravity acceleration</td>
<td>9.71 m/s²</td>
</tr>
<tr>
<td></td>
<td>Heat capacity</td>
<td>Heat capacity</td>
<td>4200 J/(kg·K)</td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>Density</td>
<td>1000 kg/m³</td>
</tr>
<tr>
<td></td>
<td>Thermal conductivity</td>
<td>Thermal conductivity</td>
<td>0.6 W/(m·K)</td>
</tr>
<tr>
<td></td>
<td>Coefficient of thermal expansion</td>
<td>Coefficient of thermal expansion</td>
<td>2.0 × 10⁻⁶ 1/K</td>
</tr>
<tr>
<td></td>
<td>Ratio of specific heats</td>
<td>Ratio of specific heats</td>
<td>0.0034 kJ/(g·K)</td>
</tr>
<tr>
<td></td>
<td>Heat capacity at constant pressure</td>
<td>Heat capacity at constant pressure</td>
<td>4.18 J/(kg·K)</td>
</tr>
</tbody>
</table>

Table 1. The thermophysical properties of materials and boundary condition.
Choosing appropriate boundary conditions is a crucial aspect of CFD simulation. Every CFD tool resolves the equations inherent in the modeling based on the constraints imposed by the specified boundary conditions. The actual or physical boundary conditions are conceptualized and simplified to incorporate them into the simulation. For example, in this investigation, the side walls of the solar water desalination, designed as insulated, were treated as adiabatic in the simulation. Three-dimensional numerical simulations were performed in the COMSOL Multiphysics program at laminar flow, turbulent flow, heat transfer in solid and fluids physics interfaces, and the FEM (finite element method) method was used for the solution. The boundary conditions in Table 1 above were given and the following results were obtained.

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<td></td>
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<td>Density [kg/m³]</td>
<td>Solar radiation</td>
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<tr>
<td>4200</td>
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<td>1.29</td>
<td>1000 W/m²</td>
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<tr>
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</tr>
<tr>
<td>4.18</td>
<td>1.4</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

### 3 Results and Discussion

COMSOL Multiphysics employs the finite element method, and in adherence to the software's Multiphysics concept, four interconnected “application modules” are employed to simulate the phenomenon of three-dimensional diffusive double convection. These modules address fluid flow, heat transfer, and mass transfer. Model was simulated with stationary state and boundary conditions are given in the table 1. Results were obtained according to Cut Line 3D see the Figure 1.

![Image](image-url)
Fig. 3. Temperature distribution over the entire volume of the solar water desalination.

In Figure 2, the generated mesh is depicted. The choice of mesh applied to model geometry is crucial in influencing the model’s resolution process. Additionally, from figure 3, it can be observed that the maximum surface temperature of the SWD (Solar Water Desalination) system reached approximately 450 K, while the minimum temperature was recorded at 370 K.

Fig. 4. Velocity distribution for water vapor over the entire volume of the solar water desalination.

Examining Figure 4 in detail, it illustrates the variation in air velocity within the SWD system, ranging from 0 m/s to 0.6 m/s in natural convection mode. Figure 5 presents the variation of the Reynolds number in the SWD system. It was determined that the Reynolds number varied from $0$ to $250$.

Fig. 5. Variation of the Reynolds number according to the volume of the solar water desalination.

Fig. 6-9. 3D Cut Line Graph: Kinematic viscosity (m$^2$/s).

Fig. 7. 3D Cut Line Graph: Dynamic viscosity (Pa*s).

Figure 6-9 show the results obtained for the 4-Cut Line shown in figure 1. Kinematic viscosity of the air coming out through the chimney reaches from $1.86 \times 10^{-5}$ m$^2$/s minimum to $2.13 \times 10^{-5}$ m$^2$/s maximum (Figure 6). And in figure 7, Dynamic Viscosity is defined, we can see that it changes from $2.23 \times 10^{-5}$ Pa*s to $2.57 \times 10^{-5}$ Pa*s.
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Fig. 8. 3D Cut Line Graph: Cell Reynolds number (1).
Fig. 9. 3D Cut Line Graph: Turbulent Prandtl number (1).

Figures 8 and 9 show the results of variation of Reynolds number and Prandtl number along the 3D Cut Line, where the Reynolds number varies from 0-280 along the 3D Cut Line, and the Prandtl number was found to vary from 0.6865 to 0.6930.

For Heat Transfer in Solids
Following equation is utilized for solving the Heat Transfer in Solids Interface.

$$\rho C_p \left( \frac{\partial T}{\partial t} + u_{\text{trans}} \cdot \nabla T \right) + \nabla \cdot (q + q_r) = -\alpha \nabla T \cdot \frac{dS}{dt} + Q \quad (1)$$

where, $\rho$ is the density (kg/m³), $C_p$ is the specific heat capacity at constant stress (J/(kg·K)), $T$ is the absolute temperature (K), $u_{\text{trans}}$ is the velocity vector of translational motion (m/s), $q$ is the heat flux by conduction (W/m²), $q_r$ is the heat flux by radiation (W/m²), $\alpha$ is the coefficient of thermal expansion (1/K), $S$ is the second Piola-Kirchhoff stress tensor (Pa), $Q$ contains additional heat sources (W/m³).

For Heat Transfer in Fluids
The Heat Transfer in Fluids Interface solves for the following equation

$$\rho C_p \left( \frac{\partial T}{\partial t} + u \cdot \nabla T \right) + \nabla \cdot (q + q_r) = \alpha_p T \left( \frac{dp}{dt} + u \cdot \nabla p \right) + \tau : \nabla u + Q \quad (2)$$

4 Conclusions

These analysis leads to following conclusion:

This study employs a 3-dimensional prototype to conduct thermal analysis of a solar water desalination system. The investigation encompasses variations in surface temperature, velocity magnitude, and absolute pressure within the system. Convective heat flux is manipulated across a range from 200 W/m² to 1000 W/m², with an observed concurrent increase in temperature, transitioning from 293.15 K to 450 K. Additionally, examination indicates that the outlet temperature of the freshwater vapor reaches approximately 400 K, considering an initial saltwater temperature of around 293.15 K. In natural mode, there is a slight change in velocity from 0 m/s to 0.6 m/s. Variation of Reynolds number and Prandtl number along the 3D Cut Line, where the Reynolds number varies from 0-280 along the 3D Cut Line, and the Prandtl number was found to vary from 0.6865 to 0.6930.
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