Computational fluid dynamics study of a single stage solar still for water treatment

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Abstract. The freshwater is only 2.5% of the total water on this earth and rest is the brackish. At present, the human being is facing a serious problem of availability of potable water. The amount of potable water can be enhanced by translating brackish water into drinkable through solar distillation in solar stills. Different geometries of solar stills are being designed to serve the distillation purpose. The performance of a solar still is mainly influenced by its design parameters and wall material. In the presented work, a 3-dimensional geometric modeling of a solar still was carried out by using k-epsilon model in ANSYS-FLUENT. The objective was to study the effect of the design parameters on performance of a solar still through CFD modelling followed by the experimental validation. ANSYS-FLUENT 14.0 package was used to simulate the solar still system. The simulated work was compared with the experimental data and a good agreement was seen among the experimental and simulated data.

1. Introduction
The depleting fresh water sources is a global issue. The uses of polluted water may result in numerous diseases. About thirty thousand individuals die daily because of water-borne diseases [1]. Population of the globe is increasing exponentially in the underdeveloped countries and so does the demand of pure water. For the existence of living organisms, the water is the most vital component. The most parts of Punjab and Sindh in Pakistan have saline to brackish ground water. By processing the saline water through solar distillation, it can be fairly converted into drinkable water [2]. Through convection, heat is transferred from the basin to the water, from the glass cowl to the atmosphere and from vapors to the glass cowl. From a solar still, heat flows to the atmosphere through the clear glass cowl and also the walls by physical phenomenon. But heat flows from the sun to the solar still through radiations [3, 4]. A better design of solar still can significantly improve the conversion process.

Passive and active solar stills are two major categories of solar distillation systems. In passive solar stills, lowering the depth of water in the basin may increase the conversion efficiency and the daily production rate of the single basin solar stills [5, 6]. To improve the simple basin stills, different techniques & modifications are reported in the published literature [5-8]. These modifications and techniques are helpful in increasing the efficiency and life of the solar stills.

Computational fluid dynamics (CFD) is a well know approach used to analyze and solve the fluid flow problems under different situations. Computing machines are responsible for this analysis, which is based on a simulation process [9]. For multipart configurations, due to large grid points, the computational time increases, which is difficult to manage. In this study, the water temperature and
production rate of drinkable water were predicted and simulated results were compared with the experimental results. Further comparison has been made between simulation and experimental results of water temperature and glass cover temperature.

2. Materials and methods

This research deals with CFD study of single stage solar still by using ANSYS simulation software. The solar purification system on experimental side was consisted of a rectangular top glass-cover, wooden box with square shape base and a metal tray sheet. The surface area and volume of single stage solar still was 16.472 m$^2$ and 4 m$^3$, respectively. A 0.02 m thick glass sheet to cover the top surface of the solar still. A 0.05 m thick metal try sheet was used to increase the solar intensity and a wooden box was used to reduce the damages due to rising temperature. The glass-cover was fixed at an inclination angle of 24º. When the solar still having saline water was exposed to sunlight, the condensation and evaporation of saline water taken place. The experiments were performed during May 2018 in the University of Agriculture Faisalabad, Pakistan. From 9 am to 5 pm daily, the temperature of the basin water and glass cover were monitored continuously.

The geometry of the solar still was designed in ANSYS workbench, as shown in figure 1. The free stream temperature of upper and lower surfaces was set to 403 K and 293 K, respectively. The rest of the walls were considered thermally insulated. The maximum height of the rear and front walls of the cubic solar cell were set at 1.5 m and 2 m, respectively, and the glass lid was fixed at an inclination angle of 24º. The fine cell meshing of the geometry was performed, as shown in figure 1. The unstructured tetrahedral meshing was used for the reported solar still. The equations of continuity, energy and momentum for the fine meshed geometry were solved using ANSYS FLUENT 14.0 package. k-epsilon model was used to simulate the solar still process. The cell zone and boundary conditions were set according to the experimental design. k-epsilon model has been implemented in most general purpose CFD simulations and is considered as an industrial standard model. It is a stable and numerically robust simulation tool. It has well-established regime of predictive capability. For general purpose simulations, the model offers a good compromise in terms of accuracy and robustness. Within FLUENT, the turbulence model uses the scalable wall-function approach to improve robustness and accuracy when the near-wall mesh is very fine. The scalable wall functions enable solutions on arbitrarily fine near-wall grids, which is a significant improvement over standard wall functions.

![Figure 1. 3D meshed geometry of a solar still.](image)
3. Results and discussion

The computation time per simulation, required to reach quasi steady-state conditions, was about 3-5 hour. Figure 2 shows temperature distribution on the glass cover of the solar still. This glass contour shows a range of colors according to the changing temperature. At bottom, the red color shows maximum temperature as compared to upper surface area. The lower part of glass cover was closer to the saline water. The vaporized water condenses in this glass area of maximum temperature. Kinetic energy of vapors increases at lower surface as compared to upper glass surface. A distance between upper and lower surfaces of glass plate and tilt angle was the reason of temperature difference between these surfaces. The absorber side plate was of Aluminum, which absorbs temperature from the coming rays through the transparent glass cover. Table 1 shows temperature of both absorber plate and transparent glass top [7-9].

![Figure 2. Temperature contour of glass plate cover.](image)

| X-axis | Temp. of glass plate (K) | Temp. of absorber plate (K) |
|-------|--------------------------|----------------------------|
| 1     | 6.31E+02                 | 6.17E+02                   |
| 2     | 6.29E+02                 | 6.35E+02                   |
| 3     | 6.26E+02                 | 6.40E+02                   |
| 4     | 6.38E+02                 | 6.44E+02                   |
| 5     | 6.38E+02                 | 6.41E+02                   |
| 6     | 6.34E+02                 | 6.37E+02                   |
| 7     | 6.29E+02                 | 6.37E+02                   |
| 8     | 6.23E+02                 | 6.37E+02                   |
| 9     | 6.10E+02                 | 6.27E+02                   |
| 10    | 6.20E+02                 | 6.35E+02                   |
| 11    | 6.32E+02                 | 6.35E+02                   |
| 12    | 6.34E+02                 | 6.34E+02                   |
The outer side walls were made of wood to prevent heat loss. Figure 3 shows the contour plot of the wooden side walls. A comparison of temperatures of front glass wall and side walls is given in Table 2. There is no big difference between side and glass plate temperatures, but difference gradually increases with time.

![Contour plot of wooden side walls.](image)

**Figure 3.** Contour plot of wooden side walls.

**Table 2.** Temperature of front glass cover and side walls.

| X-axis | Temp. of Glass plate (K) | Temp. of side walls (K) |
|-------|--------------------------|-------------------------|
| 1     | 6.31E+02                 | 6.02E+02                |
| 2     | 6.29E+02                 | 6.11E+02                |
| 3     | 6.26E+02                 | 6.15E+02                |
| 4     | 6.38E+02                 | 6.15E+02                |
| 5     | 6.38E+02                 | 6.15E+02                |
| 6     | 6.34E+02                 | 6.19E+02                |
| 7     | 6.29E+02                 | 6.06E+02                |
| 8     | 6.23E+02                 | 6.08E+02                |
| 9     | 6.10E+02                 | 6.10E+02                |
| 10    | 6.20E+02                 | 6.12E+02                |
| 11    | 6.32E+02                 | 6.14E+02                |
| 12    | 6.34E+02                 | 6.18E+02                |

Figure 4 shows a change in temperature in upward direction. Due to fixed temperature of the lower surface and the upper surface, the temperature changes rapidly near the vertical front wall. In the glass centre and the front wall, the water enthalpy is also high in the absorption plate. Near a shorter height along the vertical wall, high heat transfer coefficient was observed due to high temperature gradient as shown in Figure 5.
On the experimental side, the fabricated solar still was tested during summer season. The data was generated for 30 days on daily basis. The experimental data was compared with simulated results. Figure 6 provides a comparison of experimental and simulated data. A good agreement was seen among the production rates of potable water predicted through experiments and simulation with the error as small as 8.7 percent.

**Figure 4.** Vertical temperature rendering of the tested solar still.

**Figure 5.** Coefficient of heat transfer in the tested solar still.
4. Conclusion
The evaporation and condensation happened at reasonably good speed in the fabricated solar still. The saline water was converted into drinkable water using the solar still. The experimental data was compared with simulated results. Comparison of experimental and simulated data as shown by figure 6 has a good agreement among the production rates of potable water through experiments and predicted through simulation with the error of 8.7 percent.

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