

Assessment of effectiveness of hollow fins for performance enhancement of solar still device using simulation approach

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Abstract: Unavailability of relatively clean water for several industrial, domestic and agricultural purposes is a serious concern to many regions of the world today. This challenge is growing worse with the increasing world global warming and human population. Therefore, there is need to research into an innovative, sustainable and/or improved technology for an efficient and effective solution, such as desalination. Desalination of freely available sea water is considered a promising source of fresh water. Solar radiation is abundant and can be used to desalinate water, using a solar still device. Also, it is important to increase the productivity of the solar still device through hollow fin modification. Therefore, the effectiveness of this improvement was investigated in this study, using an analysis system (ANSYS) Fluent computational fluid dynamic (CFD) simulation. Appropriate models were used to describe the physical processes, including condensation, evaporation, multiphase flow, surface tension and solar radiation. A close agreement between the simulation values of solar energy and the water temperature in the basin was observed when compared with the experimental data from the literature. Velocity of 0.259 m/s, pressure of 55.8 Pa, temperature of 57.85 °C and mass transfer rate of 1.41 kg/m³/s were obtained in the mid-plane of the improved double slope single basin (DSSB). The degree of improvement was 5-7% when compared with the existing models. Importantly, this process is economically efficient and can support the concepts of sustainability and healthy living, especially in rural areas.

Keywords: Hollow fins; solar still; sustainability; rural areas; simulation approach.

1. Introduction

A solar still is a device or apparatus used for solar-powered thermal desalination. The efficiency of these devices is often low, and many changes are being proposed to increase it. Therefore, several studies are currently being conducted on the production of distilled water to address the scarcity of pure water sources. Solar stills [1-4] are one of the most common technologies for water distillation that use solar energy without causing environmental problems. The different construction designs of solar stills are shown in Fig.1.

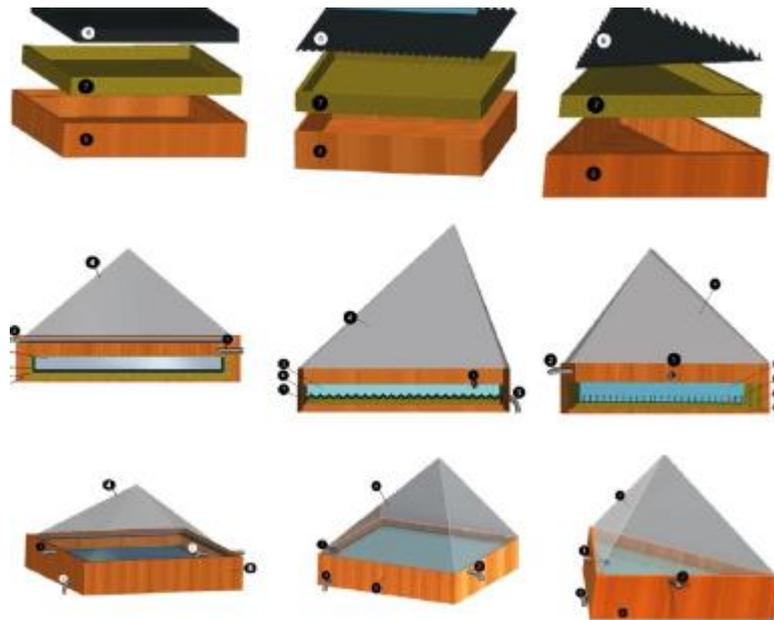


Fig. 1. Different construction designs of solar stills.

Moving forward, Abdelal and Taamneh [5] conducted research to improve water productivity in pyramid solar stills, using a carbon fiber/non-materials modified epoxy composite absorber. The output of the new modified pyramid was higher than the conventional one. According to Jordanian metrological data, Altarawneh et al. [6] studied the performance of pyramid solar stills both practically and theoretically throughout the year. The solar still performance and the availability of solar radiation are theoretically simulated. Kabeel et al. [7] investigated into a new design of pyramid solar still in an experimental setting. The still contained both V-corrugated and phase-change material (PCM). The results showed that the new design resulted to a higher productivity than the conventional counterpart. Manokar et al. [8] improved the performance of the pyramid solar still by using insulation to raise the basin water temperature. The water depth was increased from 1.0 to 3.5 cm, and the productivity of the solar still was calculated with and without insulation. In addition to the neural artificial network, Sharshir et al. [9] investigated into the thermal performance of pyramid solar stills, using an alternate prediction approach. The research was done in two ways: theoretically and experimentally, using neural artificial network and alternative prediction method, respectively. Kabeel et al. [10] used nanoparticles to the black absorber paint to improve the performance of the pyramidal basin type solar still. TiO_2 nanoparticles were mixed with the black paint of the basin to test the performance under a wide variety of water depths. Velmurugan et al. [11] observed that attaching strip fins to the absorber plate boost the productivity of a single slope single basin (SSSB) solar still device by 45.5%. Pebbles, sand, black rubber and sponges were also added to improve the efficiency of the solar still device with fins. Omara et al. [12] studied the use of fins and corrugations on the absorber surface to boost freshwater production. 40% improvement was recorded with fins and a 21% improvement with the corrugations.

Besides, there are other varieties of solar still devices, but the double slope single basin (DSSB) was chosen for this research, because it is more efficient than the SSSB and produces fresh water at a faster rate. Because fins are passive and require little maintenance, there in

need for a further research on relevant technology. Fins come in a variety of shapes and sizes, including solid fins with varied cross-sections and diameters, as well as pin-fins. These fins, on the other hand, have been investigated extensively using CFD. However, there are very few or no literature on CFD studies of hollow fins. Therefore, analysis system (ANSYS) simulation was used to determine the efficiency of hollow fins in this present study in an attempt to improve the performance of the solar still device. The objectives of the current study include: (i) application of ANSYS to create a model of a solar still device with hollow circular fins, as a productivity-enhancing change, (ii) selection of acceptable models for solar radiation, evaporation-condensation, multiphase flow and surface tension, as physical phenomena, (iii) simulation and its comparison with the experimental data from literature and (iv) assessment of the effectiveness of the fin adjustments by analysing the simulation results using appropriate contour plots.

2. Methodology

2.1 Model

The geometry of the DSSB with hollow circular fins was modelled, using ANSYS integrated computer-aided design (CAD) modeler, called space claim (Fig. 2). The absorber plate with hollow circular fins from the bottom, the galvanised iron box on the side and the glass cover on the top were used to simulate and contained the DSSB fluid domain. The geometry of real world DSSB is shown in Fig. 3.

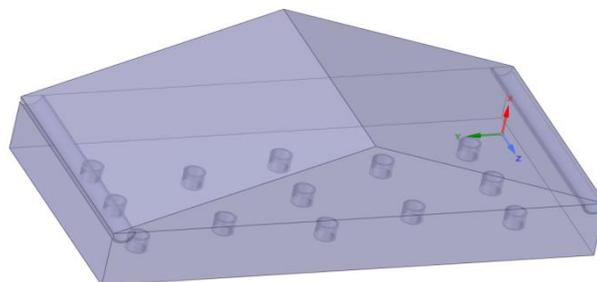


Fig. 2. Fluid domain of the DSSB with hollow circular fins and condensate water collecting channels



Fig. 3. Real-world DSSB.

The volume of fluid (VOF) model was chosen with the two Eulerian phases to model the multiphase behaviour of the fluids in the DSSB. The primary phase was water vapour and the secondary phase was water. Modelling of the solar load was performed using the Rosseland radiation model and the solar ray tracing technique. The ANSYS Fluent material database was

used to incorporate the material properties of the fluid and solid materials. Two dimensional (2D) and 3D models were used for both steady state and transient simulations.

3. Results and Discussion

Figs 4 and 5 show the pressure contours in the mid-plane for steady-state and transient simulations, respectively. The maximum gauge pressure was initially around 27.2 Pa, but due to the evaporation of the water, it increased to 55.8 Pa. The pressure contour of the transient simulation showed increased pressure in the basin region above the water level. Comparatively, the pressure contour of the solar still device with hollow fins exhibited a better performance than other conventional solar still model with 22 Pa [13].

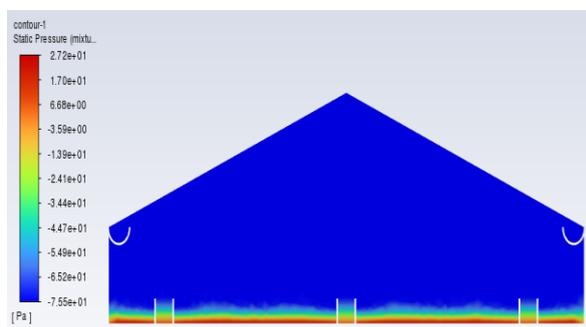


Fig. 4. Pressure contour on the mid-plane for steady state 3D simulation.

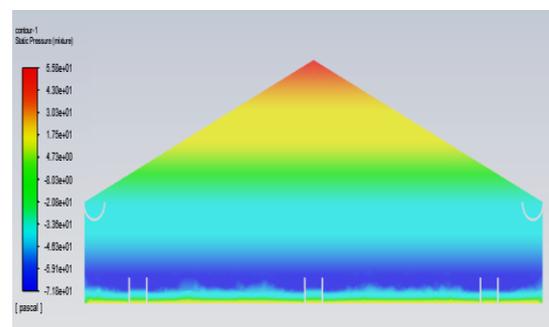


Fig. 5. Pressure contour on the mid-plane for transient 3D simulation.

The static temperature contour at the mid-plane for the steady state and transient 3D simulations of the improved DSSB are shown in Figs 6 and 7, respectively. The initial maximum temperature was around 336 K (62.85 °C) and the water temperature was around 331 K (57.85 °C). The performance temperature of solar still device with hollow fins was lower than solar still device with single slope solar [14]. Therefore, solar still device with hollow fins recorded higher effectiveness than the single slope solar.

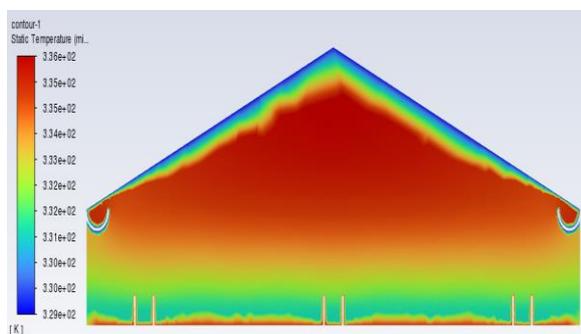


Fig. 6. Static temperature contour on the mid-plane for steady state 3D simulation

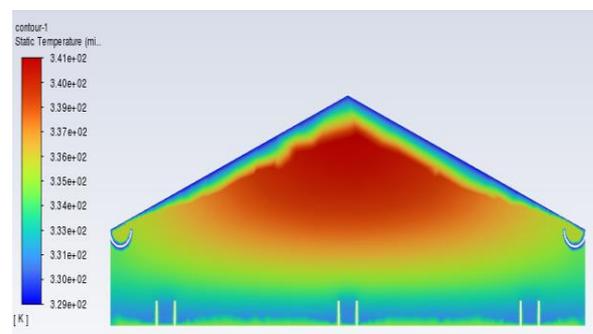


Fig. 7. Static temperature contour on the mid-plane for transient 3D simulation.

The maximum temperature in the transient simulation contour was around 341 K (67.85 °C), and the water temperature near the collector increased to 335 K (61.85 °C). This value was very close to the water temperature obtained in the experiments shown in Fig. 8. Evidently, Fig. 8 shows the results obtained from the modified DSSB. Saline water recorded maximum temperature of 64.5 °C, which was close to the current study.

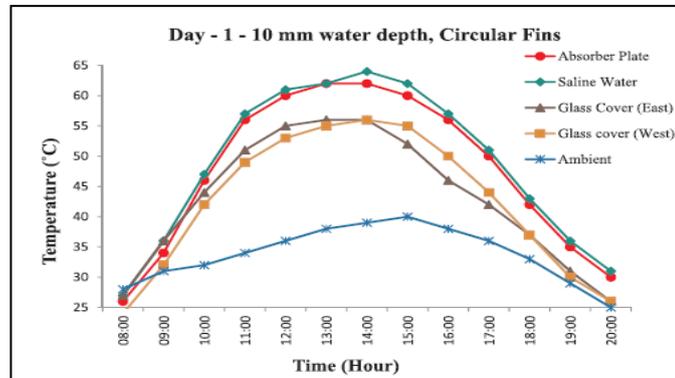


Fig. 8. Experimental results for temperature variation in the modified DSSB [15].

In addition, the mid-plane velocity magnitude contours for the steady state and transient 3D simulations are shown in Figs 9 and 10, respectively. Due to the evaporation process caused as a result of the heating of water by solar radiation, higher velocity was recorded along the interface of the water and vapour phase. It was observed that the effectiveness of solar still device with hollow fins in term of velocity was more efficient than the traditional solar still desalination model. Moreover, velocity of solar still device with hollow fins was better than the velocity of tubular solar still operating under vacuum with velocity of 0.13 m/s [16].

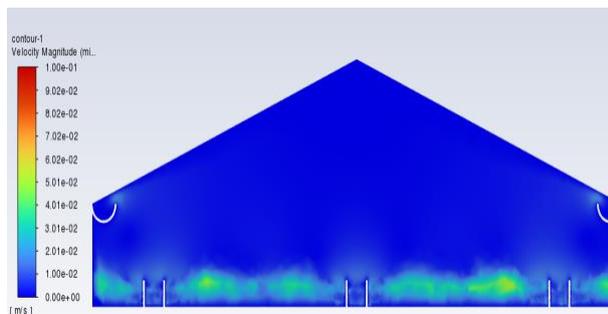


Fig. 9. Velocity magnitude contour on the mid-plane for the steady state 3D simulation.

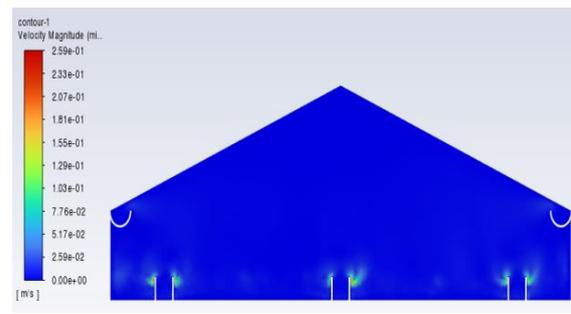


Fig. 10. Velocity magnitude contour on the mid-plane for transient 3D simulation.

In the transient simulation, as shown in Fig. 10, the velocity increased and reached a maximum value of 0.259 m/s. Due to the blockage of the fin flow and the increased heat transfer from the fins to the surrounding fluid, high velocity values were observed near the upper edge of the fins. Using the contour and the velocity vector plots, Fig. 11 depicts a detailed phenomenon at the velocity magnitude near the fins.

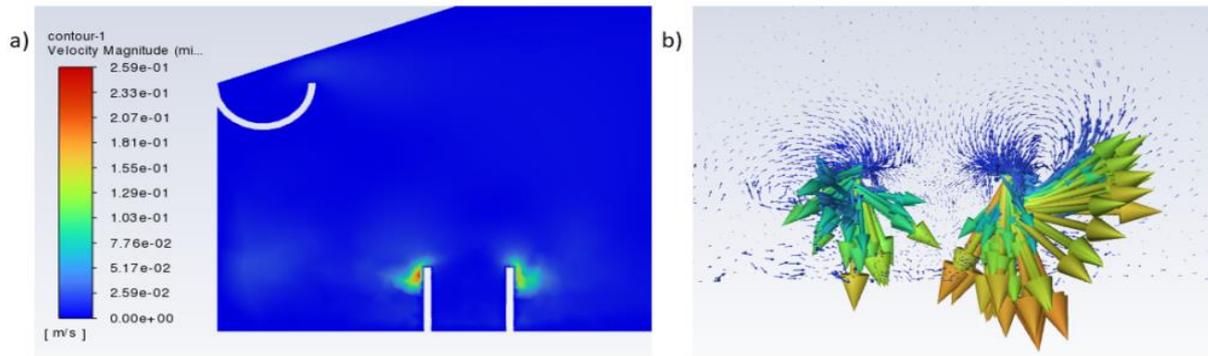


Fig. 11. Closer visualisation of (a) velocity magnitude contour near the fin and (b) the velocity vectors near the fin.

Figs 12 and 13 depict the mass transfer rate contours in the mixture, due to evaporation and condensation processes for steady state and transient simulations, respectively. The mass transfer rate in the water phase region was low, whereas the mass transfer rate in the vapour phase region was high. In the transitory case, the mass transfer rate increased, and the water inside the hollow fins evaporated to a greater extent than the surrounding water. The mass transfer rate of solar still device with hollow fins was greater than the solar still device without fins.

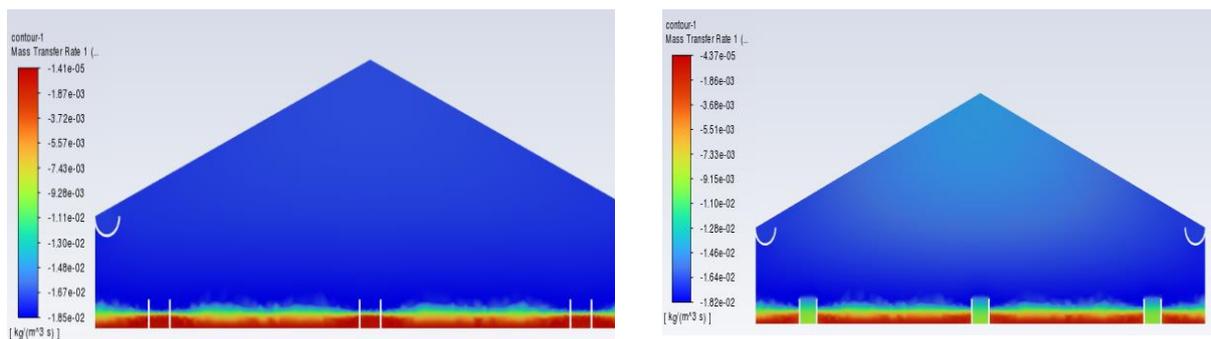


Fig. 12. Mass transfer rate contour on the mid-plane for steady state 3D simulation.

Fig. 13. Mass transfer rate contour on the mid-plane for transient 3D simulation.

4. Conclusion

The current study has investigated into the effectiveness of hollow fins towards improving the effectiveness of DSSB. From this study, the following summarised remarks can be deduced:

- The values of solar radiation and water temperature observed in the simulation were close to the experimentally measured values, as the temperature of the water inside the basin was observed at the mid-plane.
- The variation in values from the initial condition to the transient simulation value was observed in pressure and velocity contours at mid-plane.
- The mass transfer rate near the hollow fins was examined, indicating the usefulness of fins towards improving heat transfer and more significantly, production of fresh water.

Lastly, the importance of this proposed sustainable and cost efficient model or design cannot be underestimated, considering its significance in conversion of dirty water to a clean water for domestic, agricultural and industrial applications, especially in rural areas.

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