Simulation and experimental study of novel cascade solar still

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Abstract. In this paper, a new design of inclined solar still with steppe absorber plate, slope surfaces and baffles were proposed, fabricated, tested and modeled using ANSYS FLUENT software, in order to develop the simple and the cheapest type of desalination. The simulation has been carried out and validated with experimental data for climate conditions of Rabat-Morocco (34°47'N) obtained from our existing prototype. It has been found that the simulation results are in good agreement with the experimental data. It was also examined that the productivity of the cascade Solar Still was higher from 12:00 to 15:00 hrs. The results indicate that the new design ensures higher productivity.

Introduction

Water is a basic necessity for all living species including humans, animals and plants. it is essential for producing food, turning out power, cooling our planets and keeping up our ecosystem services. The earth surface is covered [1] about 71% of water which 96.5% is found in the ocean, 1.4% in groundwater and 1.7% as glaciers and ice caps, for the drinkable water on the earth, is only 2.5%.

The growth of population, water pollution, bad water management, and others big problems [2] related to water lead to an increase in consumption and prospection of drinkable water. There are different methods to purifying brackish water, such as electrodialysis, multi-stage flash desalination, multi-stage heating. Generally, the mentioned processes [3] are used for freshwater production in an industrial scale and not used in a domestic scale due to high cost and high energy consumption.

the world has high solar potential and an abundance of undesirable groundwater resources [4]. Therefore, in these regions, the direct solar desalination can be an appropriate way to produce fresh water in a domestic scale. Solar desalination is one of the economical applicable techniques to purify brackish water because it's offering a simple construction and fabrication. The main advantage of using solar stills it is clean and has no adverse effect on the environment, however, in comparison with other methods the productivity is very low.

Therefore, many researchers executed different techniques to enhance the productivity of this type of desalination. It observed that the depth of saline water in the absorber plate has a big effect on the yield of solar still. The freshwater production efficiency of stepped cascade solar still is more than the basin solar still [5].

The proposed techniques to enhance the productivity of this type of desalination, According to Kabeel et al. [6], productivity reaches almost 57.3% while using a number of trays with different widths and depths. R. Sammul Hansen et al [7] used various wick materials on different absorber plats; the production rate was increased by 48.9% to 72.2%. Mohammed and Tabrizi [8] increased productivity by 32%, by the integration of PCM in cascade solar still. Awad and Agzouz [9] used stepped solar still with humidification and dehumidification, increasing productivity by about 57% and the efficiency by 47%. Yadav et al. [10] used a Stepped and weir type solar still increases the distillate output around 60–80%. Zoori et al. [11] used energy and exergy in weir type cascade solar still, the efficiency of energy and exergy increases by 83.3% and 10.5% respectively.

As a contribution of seeking an improvement of the productivity of a solar still, our work presents a 3D CFD model of novel cascade solar still design developed with ANSYS Workbench then simulated by fluent in order to validate the proposed design. A comparison was made with experimental results and simulation ones of cascade solar still.

2 Structure of Solar Still

The new device was developed by Bouzaid et al. [12] and has an inclined glass cover with an angle of 30°, the absorber plate is formed with a number of steps. Baffles were joined to horizontal and inclined surfaces of 35°

and weirs to minimize the velocity of saline water. See Figure 2.

The details of different elements and parts of this device are explained by Bouzaid et al. [14] and presented in figure1.
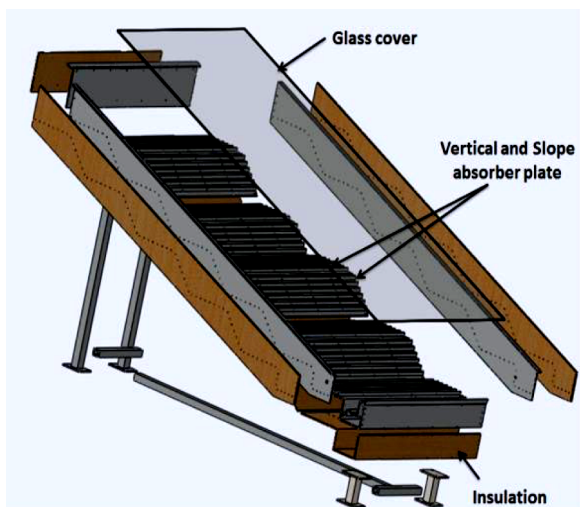

Fig.1. Elements and parts of new design for cascade solar still.

The glass cover functions are:

- Transmit the radiation.

- Blocked the radiation to be-transmitted by the inner face of the basin.

- Condensing surface of the steam.

The glass is inclined over than 25° for better orientation relative to the sun and to facilitate the runoff of condensate water to the collector.

The main advantages of the new construction of the absorber plate are:

- Better absorption of solar radiation.

- Minimum depth of water.
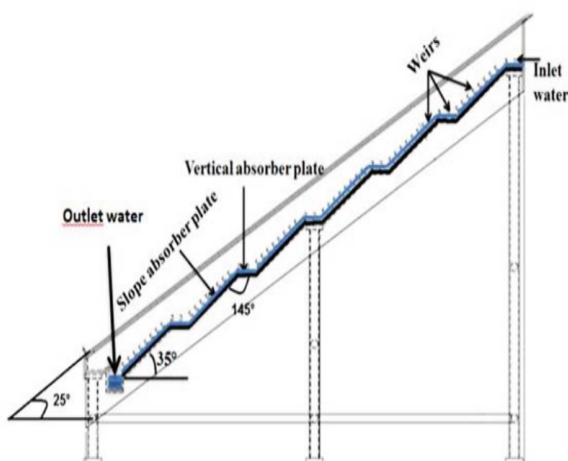
- Quick water heating.

Fig .2. The simplified design of the stepped absorber plate.

3 Design Modeling With ANSYS

The 3D geometry of solar still was modeled using ANSYS Design Modeler with all the geometrical constraints same as in the experimental setup.

It's the gate to the geometry manipulation for analysis with software from ANSYS and it necessitates special care for defining surfaces and boundaries.

3.1 ANSYS Meshing:

The most critical part of the simulation is mesh generation. Too many cells may result in long solver runs, and too few may lead to inaccurate results. Meshing technology of ANSYS provides balancing requirements and get the correct mesh for every simulation with the most automatic possible way. The most powerful parts of these tools are transported in a single environment to obtain a powerful meshing.

3.2 ANSYS solution processor:

The solution obtained by using this process for the finite element model generated in the preprocessor, the important tasks in this processor are:

- Define analysis type and analysis options.

- Specify boundary conditions.

- Obtain a solution.

- The numerical studies were based on the following assumptions:

- Thermo-physical properties of aluminum, glass, and air remain constant during the process.

- Thermal contact between the glass and the walls of cascade solar still and their environment is perfect.

- Cascade solar still wall temperature is considered equal and undisturbed.

3.3 Boundary conditions

The boundary conditions are specified to solve the continuity and momentum equations. The running simulation was about 10 hours, due to a high number of time steps and computer time constraints. the received solar radiation by the basin, the ambient temperature, the water and glass temperatures based on the solar calculator in fair weather conditions. The solar intensity was based on the absorption factor and the emissivity of the glass, the bottom, and the water. The heat transfer coefficient of the side walls was calculated and maintained constant for the overall process.

4 EXPERIMENTAL PROCEDURE

The experiment was realized from 8 am to 6 pm; for each 1- hour time interval an average temperature was set as the boundary condition.

The cascade solar still is fed with 25 liters of saltwater linked to a saline storage tank. Six thermocouples are installed at the inner face of the absorber plate and 3 on the external face of the glass cover. Three measurements were carried on the absorber, the top, middle and bottom. The solar intensity and the ambient temperature are collected during the experimental process which is realized at the Higher Normal School of Technical Education in Rabat-Morocco (34 °47'N).

5 SIMULATION RESULTS

The results obtained from the simulation analysis and experimental study of a cascade solar still presented in this section.

The main objective of the study, was to develop a CFD model of a Simple Solar Still to validate the results with experimental. A multi-phase model has been developed in ANSYS which accounts for all the three phases present in the solar still, (air, liquid water, and water vapor). The simulation results have been linked with the experimental data.

Figure 3 shows the temperature experimental and simulated of the basin, as can be seen; the simulation outcomes have been compared with the experimental data. The readings don't exactly match, but they follow similar patterns. The likely reason for this variation is that the intensity of solar radiation in the simulation doesn't account for natural attenuation.
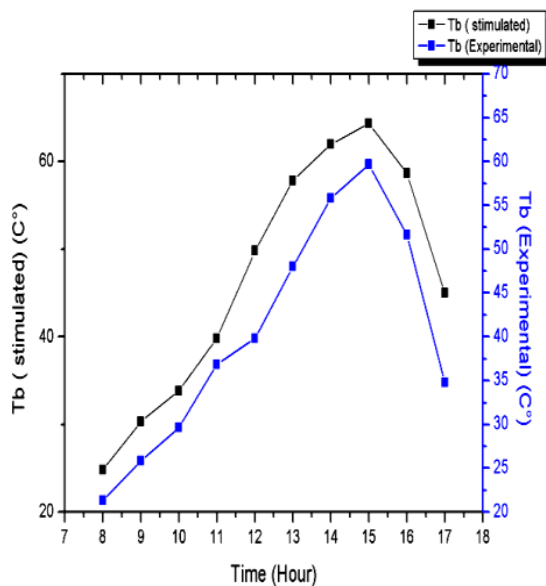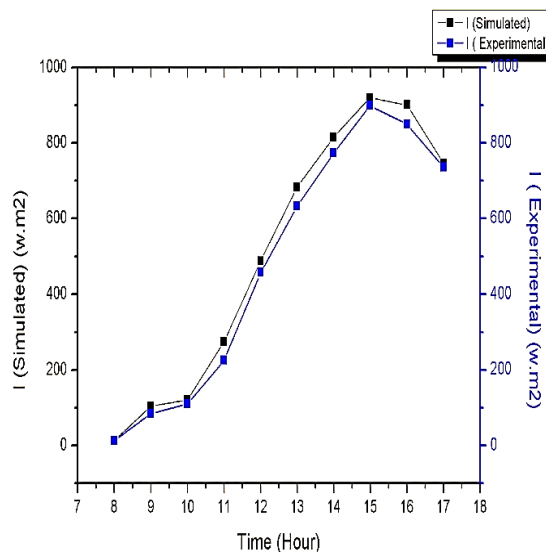

Fig.3. The absorber plate temperature Simulated and Experimental Results.

In the figure 4, the simulation results of solar intensity have been compared with the experimental

data, the results compare are well perfectly match and it

follows a similar pattern.

Fig.4. Solar intensity variation of simulated and experimental data.

Figure .5 shows the variation of the absorber temperature has a similar variation to the solar intensity. The absorber plate temperature and the solar intensity have achieved the maximum at mid-noon. The solar radiation increases, and it increases the absorber
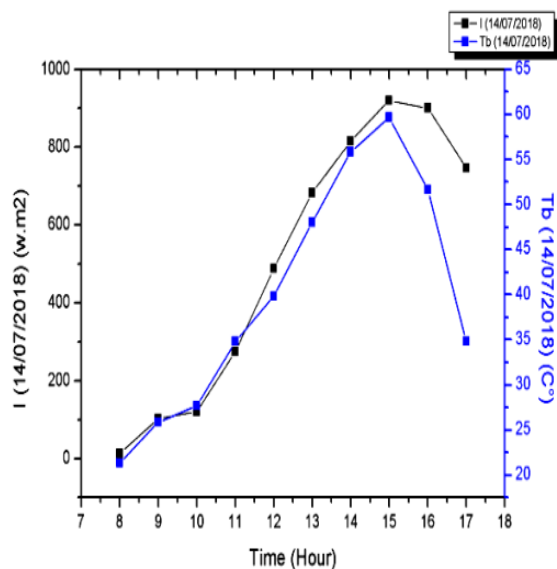
temperature, for a maximum more than 60 °C and 900 w.m^2 of solar intensity.

Fig.5. Hourly variations of the absorber plate temperature measured on the 14th of July2018.

The water productivity as shows in figure 6 has achieved a maximum of 1.66 kg/m2 hr, after mid-noon, when the intensity of solar radiation increases, more distilled water is produced due to a higher temperature. After reaching its maximum, the productivity decreases as the intensity of Solar radiation drops.
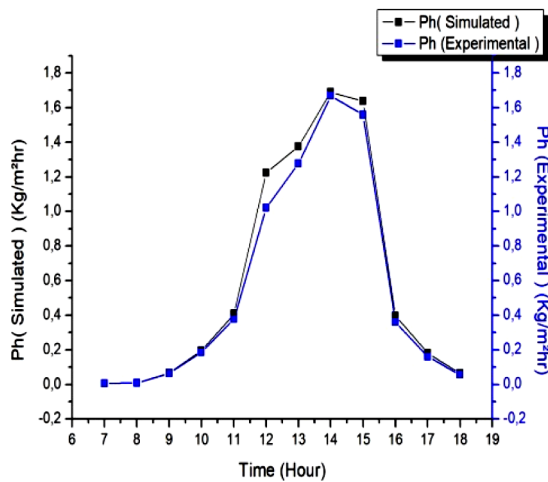
Fig.6. Hourly Productivity of the solar still (simulated/experimental).

An experimental analysis was done, the results show that the absorber plate temperature and productivity can reach more than 60 °C and 1.6 kg/m2 hr respectively. Important values proved the productivity of the new design, in comparison with the experimental results of the single basin presented by O.O. Badran [15], the absorber plate temperature and productivity reach more than 50° and 0.6 kg/m2 hr respectively. That proves the effect of water depth on the productivity of the still basin.

6 Conclusion

This paper presents a new design of solar still with stepped absorber plate, sloped surfaces, for minimizing the depth of saline water due to enhance the productivity of this cheapest type of desalination.

A comparison is made between simulation results and experimental data of the absorber plate. The simulation model has been tested to validate the quality and capability of the experimental model.

Simulated results show that computational fluid dynamics is a powerful tool for design parametric for cascade solar still. For the future work can be done by integrated more baffles to the absorber plate in consideration of other different design parameters.

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