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Modelling and Analysis of a Single Slope Solar Still for Desalination of Water

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Abstract

Nowadays, brackish water/seawater desalination is a subject of concern to many researchers all over the world. Solar desalination is a renewable energy-driven method that produces freshwater from saline/brackish water. Many coastal countries suffer from a scarcity of freshwater. Solar-driven desalination is an optimistic and sustainable method to reduce the shortage of potable water in remote regions. Solar desalination is a viable way to produce potable water from any type of non-drinkable water. The recourse to use of solar energy in desalination by distillation, represents as appreciable part of water resources and is realizable, simple, cost-effective, operational solution technically. In this work, Modelling and simulation analysis of single-slope solar still for desalination of water is investigated in CFD-Ansys by considering solar radiation data at 12.8852°N, 77.572625°E in Bengaluru, Karnataka, India. The simulation results found that, the solar still yields the distillate at the rate is 2 litres/m2 for 10 litres of saline water that runs for 12 hours a day (from 7:00 am to 6:00 pm). A comparison between various inclination angles were performed. Solar still yields thermal efficiency of 24% at the inclination angle of 38° when compared with the inclination angles of 22°, 28°, 32° and 44°.

Keywords: *Solar Energy, Solar Still, Fresh Water, Thermal Efficiency*

1.0 Introduction

Desalination is the process of getting freshwater/ potable water from brackish water/ seawater for our daily needs to meet in the regions where communities face inaccessibility of freshwater. Desalination using renewable energy sources like solar energy has become the prominent solution to mitigate the scarcity of freshwater. In every day terms, aggregate desalination capacity of India is about 840 million liters (correspondingly distributed predominantly in Tamil Nadu, Gujarat and Andhra Pradesh) aimed at responding to communal water requirements as well as commercial purposes. Furthermore, another 330 million liters capacity through additional plants are at

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the construction stage. To alleviate urban water stresses holistically and dependably, this country will have to raise its total desalination capability to 4000 million liter per day by 2030. And also it is observed that most parts of the country are facing a lack of access to fresh water which affects millions of people for their requirement of clean and good quality water for drinking purposes. Sea water is a major part of water resources across the globe. It has the potential to fulfil water demand to a greater extent. Sea water desalination has evolved as a promising process to mitigate the scarcity of freshwater. Brackish/seawater desalination technology is the latest trend to meet freshwater demand with no emissions. Gulf countries facing an imbalance between water supply and demand, which tends to a dramatic decline in the availability of groundwater. For such, solar energy for water desalination is an agreeable option in this region, where the climate is sunny thought the year. A very basic solar device called a single basin solar still is commonly used to convert available seawater into drinkable water.

In the coming days, energy demand in India will go higher than in any other country. To accomplish net zero emissions by 2070, it is inevitable to adopt green energy technologies powered by renewable energy sources. Due to the increase in population and industrialization, most countries face major water scarcity challenges largely because of water pollution caused by human activities. Most human illnesses are because of contaminated drinking water. Freshwater sources like rivers, ponds, lakes and wells are becoming extinct.

Solar desalination techniques involve the use of solar energy to produce fresh water. There are few techniques applicable in solar desalination, among them are the following;

(i) Reverse Osmosis (RO): RO can be used in conjunction with solar power sources and pumps that generate pressure to make this technique work. If adopted, the RO has the capability of reducing operational costs by replacing fossil fuel reliance with sunlight while also making desalination process more sustainable.

(ii) Solar distillation: The method of solar distillation employs a solar still, a straightforward device shaped like a box, in order to make salt water potable by evaporation and condensation. It is impractical using solar stills to create large quantities of fresh water, though they are cost-effective and require low maintenance.

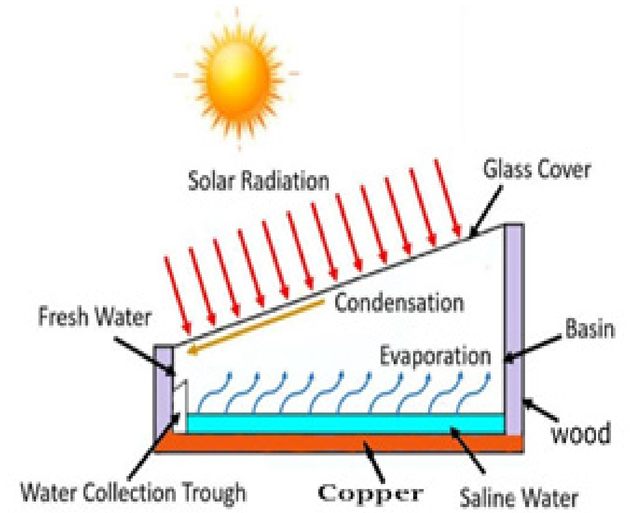

Figure 1. Schematic of a typical single slope Solar Still.

(iii) Thermal desalination: In this method, uses thermal energy from the solar ponds to run a desalination plant.

(iv) Electrodialysis (ED): Salinity from brackish/salty water is removed by using DC electricity and Solar PV modules directly connected to the desalination process.

(v) Indirect solar desalination: Also known as solar stilling, this technique is often used in remote areas where it is tough and expensive to install distribution systems or transport fresh water by vehicle.

(vi) Vapour compression distillation: This technique involves vapor compression heat energy, which causes a liquid called feed water to produce fresh water. This technique is often used for small to medium scale purposes, such as industries, resorts, and petroleum drilling sites.

Among the all the possible techniques, solar distillation by solar stills are becoming the most reliable method to eradicate the scarcity of freshwater which is most economical and requires less maintenance.

1.1 Working Principle of Single-Slope Solar Still

Figure 1 shows a schematic diagram of single slope solar still which is insulated containing brackish water and at the top, it is being covered with a transparent material. Generally, the basin is made of copper and the top cover is transparent made of glass or plastic. Generally, the top cover is slanted with a collecting tray for the collection of distillate output. The principle of working solar still is the same as the hydrological cycle happens in nature. The incoming solar radiation falls on the glass cover is made to strike the inner surface of the basin which is black-lined thereby absorbing most of the radiation. The saline/brackish water in the basin gets heated up and starts to evaporate. The formed vapors rise leaving behind the salinity/impurities at the base. The accumulated water vapours on the inside surface of the glass cover get condensed into water and run along the slope under gravity to the collecting tank. The distilled water/freshwater is then drawn out from the collecting tank for direct use.

Ibrahim M. Al-Helal, *et al.,*[1] investigated an Optimization of single slope solar still for freshwater production under various surface areas and air gap distances and water depths, results showed that reduction of water salinity by a greater amount by highlighting the potential of solar desalination for sustainable development in arid regions. Akashdeep Neg, *et al.*[2] studied a method to enhance distillate output by increasing salt concentration in basin water for a single slope titled wick solar still and achieved a higher evaporation rate for the 2% salt concentration. Zahraa A. Faisal, *et al.,*[3] showed an increase in the daily yield of distillate by a considerable amount by pairing single slope solar still with a pre-heating water tank. Rajesh Kumar, *et al.,*[4] presented simulation findings that the efficiency was enhanced remarkably in solar stills equipped with copper plates with different tilt angles. It was evident that the tilt angle of the cover had a substantial impact on the output. A. Nagamani Prabu, *et al.,*[5] showed that the still with the parabolic trough collector performs more efficiently than the still without the collector with an increase in efficiency of 12%. M. Varun, S. Subhani, *et al.,*[6] investigated a modified stepped basin to enhance the evaporation rate by exposing a surface area of water to radiation by a greater amount. Results showed that stepped basin solar still gave better production than single slope solar. It was also shown that due to this increase in surface area radiation boosts natural heat transfer rate. Mehta Vijay, *et al.,*[7] studied single slope solar still integrated with Phase Change Materials (PCM). From this study, it was concluded that enhancement in its daily yield production of solar water distillation using PCM and nanomaterial in active as well as passive solar still. Subramanian Kumaravel, *et al.,*[8] research has shown that the presence of copper scrap in the basin, combined with a shallow layer of salt water, has a significant impact on the distillate output. The thermal efficiency was also increased. Eslam Ahmed Abdel-Aziz, et al.,[9] presented experimental tests that were performed to increase the performance of single slope solar still integrated with paraffin wax as PCM. The highest rate of freshwater production was obtained using paraffin wax at 65°C. And observed the mitigation of CO_2 emissions. Saif Salim Saif Al-Mezeini, Mohd Asim Siddiqui, *et al.,*[10] Experimental results showed that the single slope solar still yields more freshwater production at 4cm water depth with 30% efficiency and further its efficiency was improved to 35% by incorporating an additional mirror. Maneesh Kumar Shivhare, *et al.*[11] studied design parameters of single slope solar stills, results were presented that in areas with greater salinity levels, the most preferred type of solar stills with wick on the side walls of the basin enhances the rate of freshwater production rate. A.S. Abdullah, Fadl A. Essa, *et al.,*[12] discussed and suggested reliable ways of water purification systems by employing current trends of nanotechnology such as using nanofluids, phase change materials and thermal storing materials, glass cooling, water preheating, rotating cylinders, various absorber shapes etc. to optimize performance of tubular solar stills to get productivity of 11 L/m^2 and efficiency of 80%. Mohamed Elashmawy, Swellam W. Sharshir, *et al.,*[13] studied a method of producing freshwater from saline water by recycling plastic waste bottles for meeting freshwater needs using solar desalination technique thereby reducing carbon dioxide emission by a significant amount with a thermal efficiency of 30.28% and 2.95L/m^2-day freshwater productivity. Also, this method reduces the cost per litre of freshwater productivity. Nguyen Van Dung, *et al.,*[14] presented that V-type still gives the better volume of freshwater production and heat transfer coefficient in comparison with single slope, and greenhouse stills. Haider Ali, Sajid Ali, *et al.,*[15] investigated the potential aspect of solar stills for freshwater production. And emphasized on the development of domestic solar stills, and commercial aspects particularly considering design improvements for meeting the scarcity of freshwater. Gopi P and Muthusamy C[16] examined enhancement in productivity of freshwater in a stepped solar still providing glass wall reflectors internally along with attached fins to increase the area for incoming radiation. And showed that coating of the basin with black-painted iron chips, and stones could be used for absorption of heat. M. Yuvaperiyasamy, *et al.*[17] Developed an integration of single basin fin type solar still with finned solar desalination system was the most effective way of producing fresh water from seawater. And presented that enhancement in the performance of seawater desalination with this combination was shown as possible. Ajay Kumar Kaviti, *et al.*[18] studied the productivity augmentation of solar still with the integration of various components to enhance the yield output of a Double-Slope Solar Still (DSSS) by incorporating copper tubes and parabolic fins in the basin liner. Copper Tubes with Parabolic Fins (CCTPFs) have shown greater productivity increase outperforming the other combinations. Total dissolved solids and pH concentration were decreased by a significant amount by the developed system. Lujain S. Hyal, *et al.,*[19] presented a review study interpreting the advantages of using phase change materials, wicks and different absorber plates for the continuous production of freshwater since solar energy is intermittent. It was evidenced that enhancement in the performance of solar still in all the works summarized. T.E.M. Atteya, Faheem Abbas[20] experimental study was carried out on stepped solar still with sand beds used as a storage material with reflecting mirrors. The outcomes revealed that the sandy layer improves the stepped solar still productions. The cost incurred for 1L production of freshwater with this arrangement is more economical than by conventional solar still. Sonia Z. Issaq, *et al.*[21] highlighted a decrease in solar still yield and thermal efficiency with water depths exceeding 6cm.

2.0 Methodology

Figure 2 shows the pathway of methodology followed in this work. To begin with 3D modelling of a single slope desalination unit according to the dimensions and the design specifications then meshing of the model using a suitable domain. The hexahedral type of mesh was adopted in this condition because finer meshing conditions could be obtained from the hexadral type which makes sure that accurate mesh results are obtained. Once the meshing was effectively completed, the model was composed of

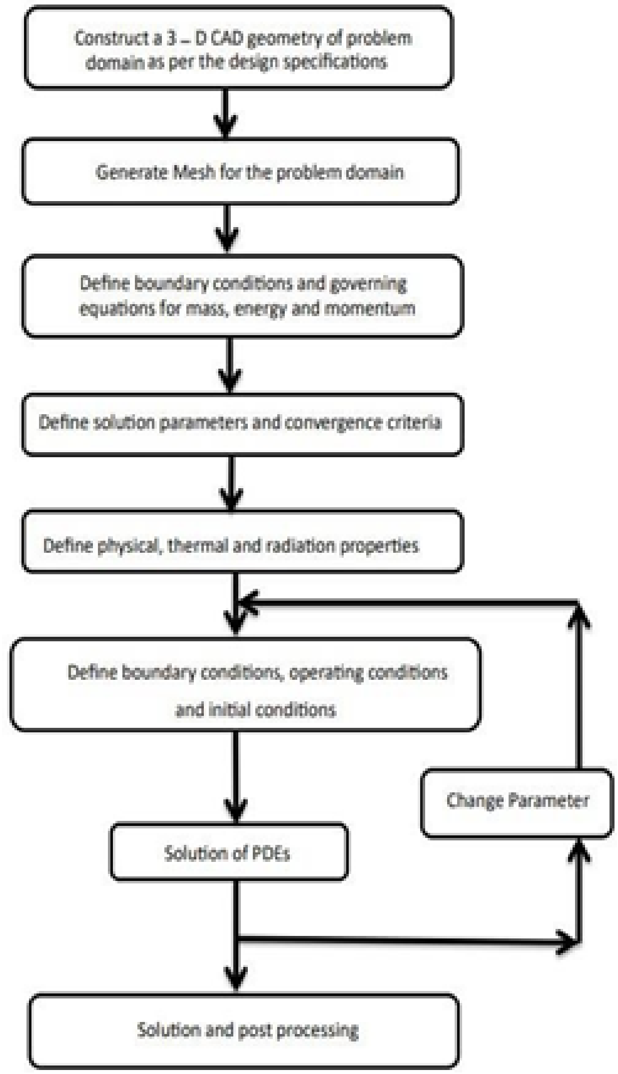

Figure 2. Methodology.

76,550 elements and 82,518 nodes. After which, boundary conditions are imposed where the walls of the model are defined i.e. materials of walls and their properties. In this case, the upper cover is glass with a thermal index and the base is made of copper which offers better corrosion resistance to the seawater and also its properties than the walls of the basin are made of wood so that there is no possibility or chances of heat to pass through wood and its properties after the boundary conditions are defined then the solution parameters are determined using the software itself then the operating conditions and the radiation properties are defined with the location coordinates as well and then the solution is initialized by

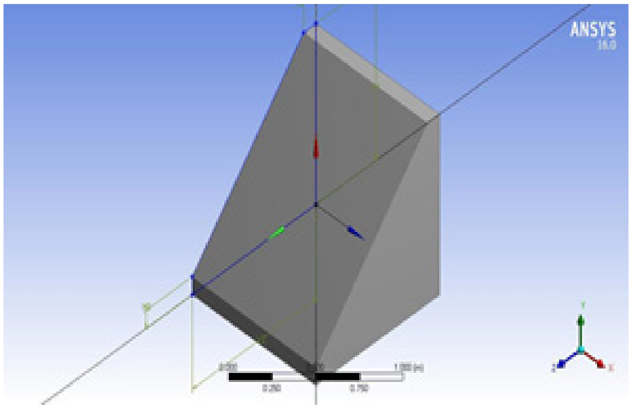

Figure 3. 3D Model of the solar still designed.

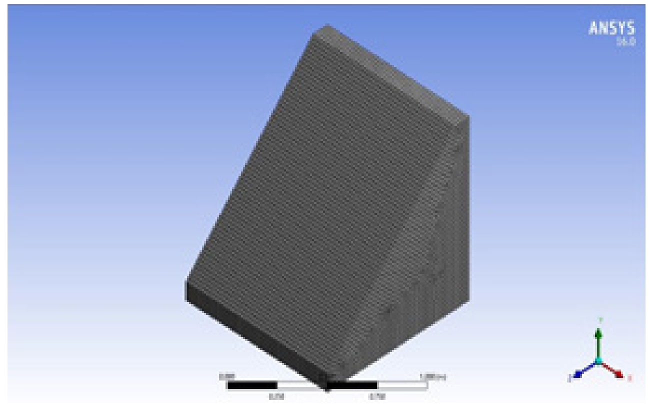

Figure 5. Model meshed.

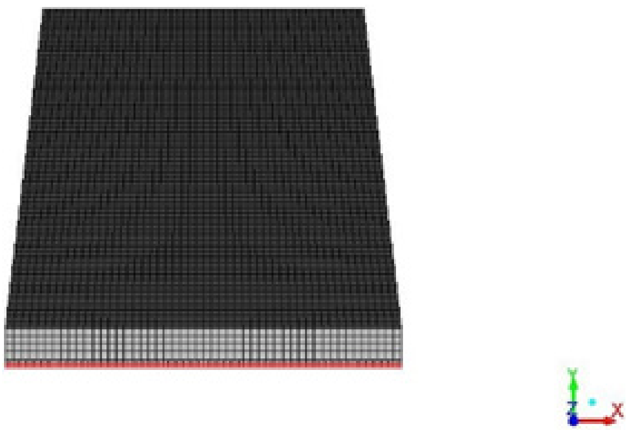

Figure 4. Adaption markings (front view).

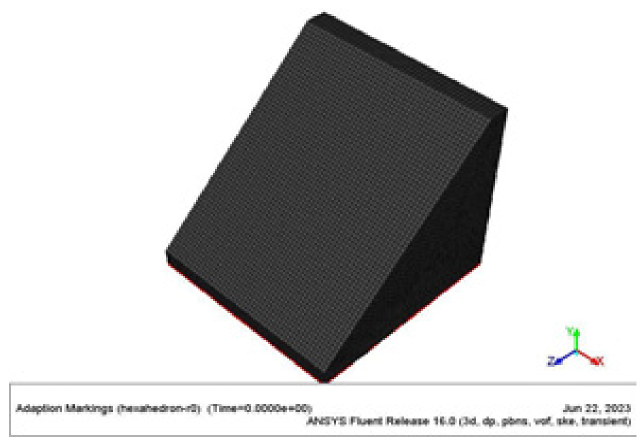

Figure 6. Adaption markings (isometric view).

running or processing the applied conditions and then the required results and parameters are obtained in the form of graphs and plots.

The test was conducted for various tilt angles and the best angle (tilt angle) was found to be 38°. The efficiency of the tilt was found to be much higher with the tilt angle of 38°. There were lesser efficiencies with angles greater than 40° and less than 36°. Hence the ideal angle for the tilt was found to be 38°. Hence all the calculations and the simulations are carried out only for the model or the desalination basin with a slope angle of 38°. There is a certain procedure involved in the analysis of the single slope basin type desalination and it is explained briefly in the following steps with their respective images as well.

A hexahedral type of mesh with smooth transitions was employed. After meshing, the model consisted of 76,550 elements and 82,518 nodes.

Following the meshing process, the next step is the "setup" phase, where the meshed model is prepared. During this phase, various aspects are defined, including the phases involved and the necessary boundary conditions. The desired water depth at which the model operates is also specified. Additionally, other parameters requiring input values are defined.

Once the model is set up with all the input data, the next step is to initialize the solution. In this step, additional factors such as the period, iterations, and other relevant values are specified. The solution is then initialized, and the desired phase for obtaining the results is patched accordingly. In this case, the bottom plate is patched with the previously defined saline water, considering the fluid properties provided, and the corresponding curves are generated.

2.1 Mathematical Approach

To begin with, a numerical approach for this study a few assumptions were made as follows; (i) heat dissipation from the sides of the solar still is neglected (ii) no internal heat generation (iii) the height of water in the basin is constant and (iv) thermo-physical parameters are determined at the average temperature of condensation and evaporation surface temperatures of the solar still.

Mahmoud Roshdy, Salama Abd Elhady, Mohamed Shaban, Mohamed F.C. Esmail the maximum daily rate of evaporation of the solar still can be computed by using[22]:

$$mev = \frac{G\ X\ A\ X\ Time\ of\ sunshine}{hfg} \qquad \text{(i)}$$

Where, A- an area of solar still; h_{fg}- the latent heat of vaporization of water and G- average incident solar radiation during the sunshine hours.

The following approach was considered for the estimation of freshwater production by considering the condensation of water vapour[22].

Dunkle model:

$$qev = hev\ (Tw - Tg) \qquad \text{(ii)}$$

There are numerous formulae exist for estimating the coefficient of evaporative heat transfer, hev, but the expression proposed by Dunkle is given by;

$$hev = 0.016273\ X\ hcw\ X\ \frac{Pw - Pg}{Tw - Tg} \qquad \text{(iii)}$$

3.0 Results and Discussion

Transient simulation of the solar still was carried out for the location coordinates (12.885290°N 77.572602°E) in Bengaluru a city in the state of Karnataka. Initially, it was simulated for 12 hours. (7:00 am to 6:00 pm) IST wherein, 10 litres of saline water was given as input for the desalination unit and freshwater output of 2 litres was obtained, which would be much more in the case of

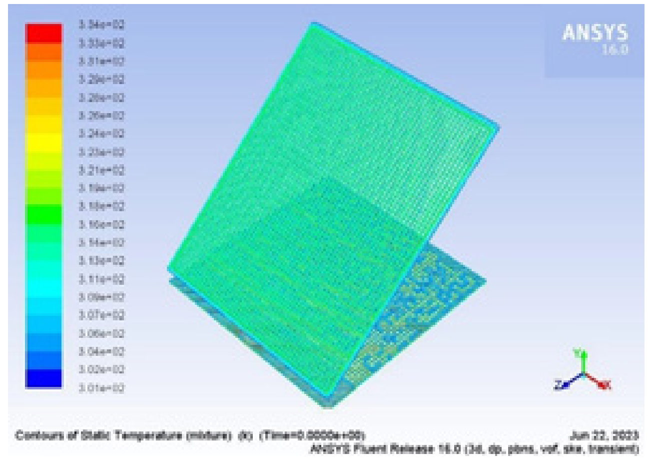

Figure 7. Static temperature (glass).

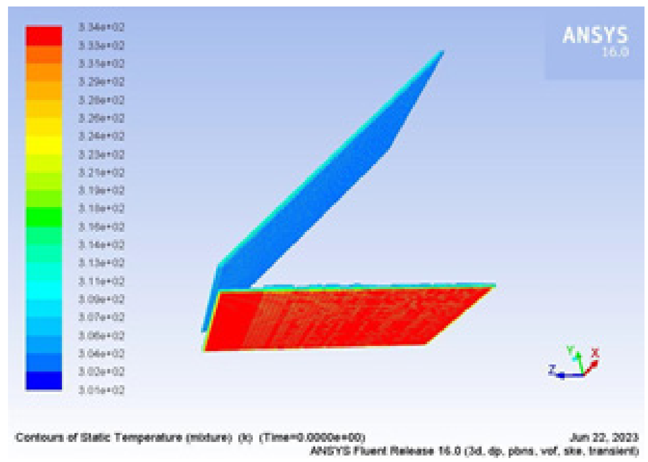

Figure 8. Static temperature (absorber plate).

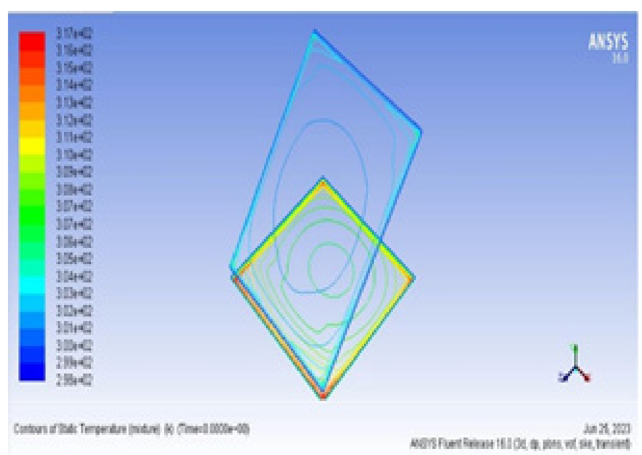

Figure 9. Contour of water volume fraction at the distillate channel.

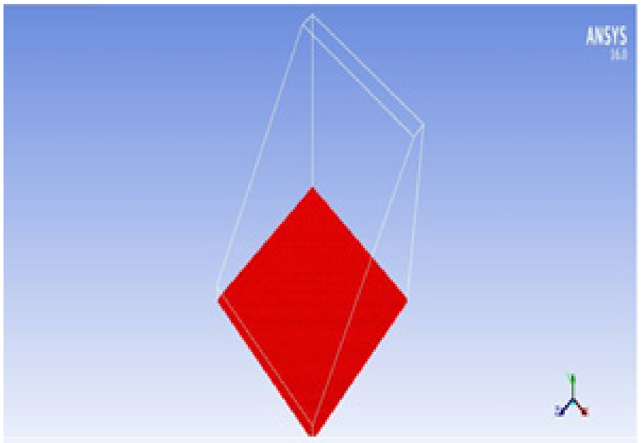

Figure 10. Water depth (1cm height).

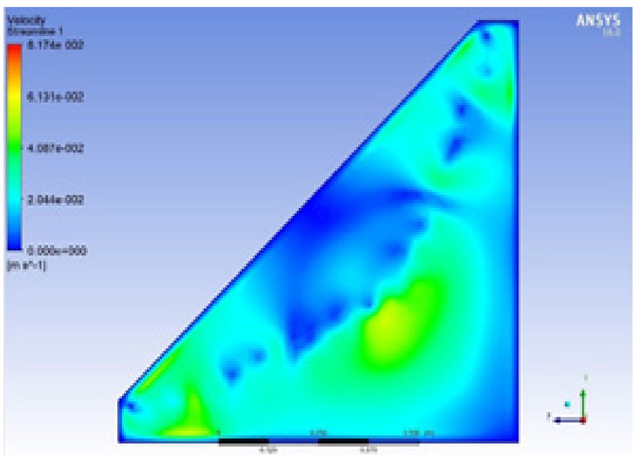

Figure 11. Velocity contour.

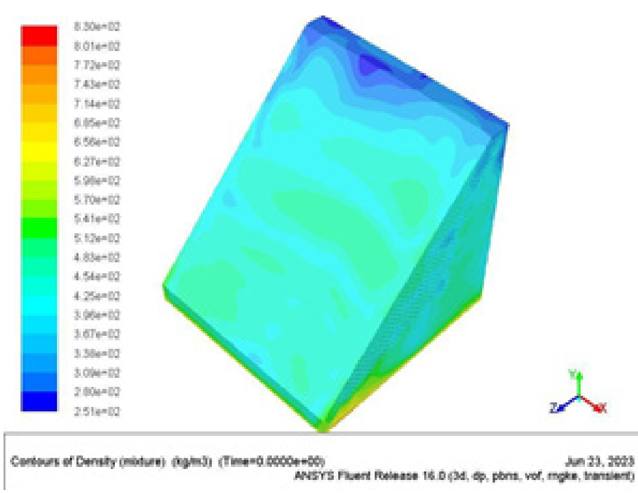

Figure 12. Density contour (isometric view).

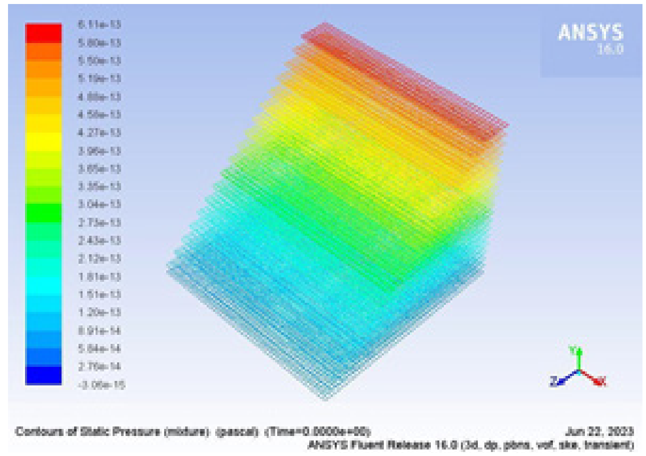

Figure 13. Pressure contour.

Arab regions and other areas where the temperatures are certainly high specifically in coastal areas and where the temperatures are usually high. The outlines of the interior temperature of the solar still show that within the solar still, the temperature of the water begins to rise as the solar radiation falls in the container. After some time water gets heated up and evaporation takes place. Based on the results obtained from the simulation from Figures 7 and 8 the observation was made that there was higher heat generation in the lower that is generally due to the copper material that is being used.

The temperature inside the solar still increases as the intensity of solar radiation increases. Interior temperature still increases at a very rapid rate at the time frame of 2:00 pm IST to 3:30 pm. Here, the interior temperature still follows the pattern of solar radiation falling over the glass cover. It is clear from the outlines of the interior temperature of the still that is temperature of the walls is nearly steady in the still. This is because, after one hour of operation, the hot vapours have acquired nearly all the space in the still outlines of glass temperature and are also shown at various time intervals. Since the exposure of mesh was defined in a way that the still always facing due south. The effect of the movement of the sun with time of the day can be fluently seen on the temperature profile of the glass cover. The glass had a peak temperature of 380K in the peak hours of the sunshine.

Figure 9 shows temperature outlines inside the solar still drawn at the X- Y reference planes passing through the Centre of the still and equal to its side walls also.

Figure 10 shows the water depth i.e., the depth for which the experiment is conducted (for 1cm) the water height is indicated with red, cyan colour.

Figure 11 shows the velocity contour wherein there is a change of velocity concerning time maximum velocity concerning the mixture being 0.0817m/s and then minimum 0.001m/s.

Density contour is as shown in Figures 12, there is variation in density as the fluid gets evaporated and maximum density is observed in the absorber plate and the minimum density is observed on the plate surface. Density variation is only observed when there is a clear shift between phase change from liquid to vapour, i.e., from conversion of saline water to potable drinking water.

Figure 13 shows the pressure contour and then there is a variation of pressure in the fluids mixture as it goes on evaporating and then maximum pressure is found at the top of the wall surface

4.0 Conclusions

The technique of producing freshwater using solar stills gains much attention because of its technological and commercial benefits, including its low cost of development, manufacturing, and technology. The single slope solar still model was successfully simulated for temperatures at various points within the solar still, and the simulated values are also in line with the experimental values. The temperature of the glass in the solar still followed a similar trend to solar radiation. It has increased with solar heat flux intensity, reaching a peak value of around 337K at 12:00 hours. And then started decreasing due to the decreasing intensity of heat flux. The rate of distillate water output is 2 litres/m^2. It has been shown that simulated and experimental data for distillate yield found the same with a 3-5% error. Solar still yields thermal efficiency of 24% for the water depth of 1cm for the inflow of brackish water of volume 10 litres. The efficiency of the single slope solar still depends on certain crucial factors, one of them being inclination. The solar still showed better thermal efficiency at an inclination of 38° when compared with 22°, 28°, 32° and 44°.

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