

Experimental and ANSYS CFD simulation analysis of hemispherical solar still

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ABSTRACT

Now days, encountering with lack of potable water is one of the major problems in developing as well as under developing countries. There is a lot of saline water in earth hence if saline water is converted into potable water then problem of potable water will be solved. A device, which converts saline water into drinkable water, is called solar still. In every efficient solar still design, water temperature, distillate output, and difference between water temperature and inner glass cover temperatures are very important work on solar still. Many scientists of world applied their work on solar still to increase output. There are many types of solar still design, in such design there is also a design of hemispherical solar still. Hemispherical solar still possess hemispherical head, which can receive solar radiation from anywhere, hence there is no need of applying solar tracking system. Hence, here, two-dimensional three-phase model of hemispherical solar still is made for evaporation as well as condensation process in ANSYS CFD. Simulation results like water temperature, vapor temperature, distillate output compared with actual experimental results of climate conditions of Mehsana (latitude of 23° 59' and longitude of 72° 38') of hemispherical solar still. Water temperature and distillate output were good agreement with actual experimental results. Study shows that ANSYS CFD is very powerful as well as efficient tool for design, comparison purpose of hemispherical solar still.

Keywords: *Hemispherical solar still, ANSYS CFD, distillate output, water temperature*

1. Introduction

The potable water is one of the basic needs for survival of human being. Due to fast increase in population in the world in general and India in particular, the potable water consumption has been increased tremendously. On the other hand available water in rivers, lakes and underground water has been polluted due to industrialization for up gradation of living standards for human being. Hence there is a need to develop self sustained system to purify available water into potable water for keeping healthy human being.

Potable Water is life because plants and animals cannot live without water. Water is needed to ensure food security, feed livestock, and take up industrial production and to conserve the biodiversity and environment. Although, India is not a water poor country, due to growing human population, severe neglect and over-exploitation of this resource, water is becoming a scarce commodity. While this is a growing concern all over the world, India is most vulnerable because of the growing demand and indisciplined lifestyle. This calls for immediate attention by the stakeholders to make sustainable use of the available water resources to ensure better quality of lives. 70% of the earth surface is covered with water, which amounts to 1400 million cubic kilometers (m km^3). However, 97.5% of this water being sea water, it is salty. Fresh water availability is only 35 m km^3 . Out of the total fresh water, 68.7% is frozen in ice caps, 30% is stored underground and only 0.3% water is available on the surface of the earth. Out of the surface water, 87% is stored in lakes, 11% in swamp and 2% in rivers. As all the sweet water is not extractable, only 1% of the total water can be used by human beings. Fig. 1. shows map of city, Mehsana, Gujarat and Fig. 2. Shows picture of water crisis.

Solar still is particularly important for locations where solar intensity is high and there is a scarcity of fresh water classified into direct or passive solar still and indirect or active solar still. The direct solar distillation system collects solar energy to produce potable water. Active solar still is particularly costly compared with passive solar still. [1, 2]. A number of experiments have been made to develop and improve performance of solar still. The efficiency of solar still is directly proportional to inlet water temperature inside the solar still. To increase distillate output of solar still, some researcher [3, 4, 5] suggested coupling a flat plate collector because normal efficiency of solar still is about 30 to 40%. They got good improvement of 40 to 50% in distillate output compared with alone solar still. Solar still distillate output is also depends on latent heat of condensation, which is lost to atmosphere during the condensation process, hence some researcher [6, 7] used latent heat of condensation to increase temperature of feed water or saline water inside the solar still to improve performance. They found 10 to 20 % improvement in solar still. Solar still distillate output also depends on superheated steam produced at lower temperature. Hence, some researchers [8, 9] used vacuum pump or vacuum system incorporated with solar still. They found also improvement in distillate water output from solar still. In this research paper, actual as well as CFD analysis of hemispherical solar still is compared under steady state conditions under climate conditions of Mehsana, Gujarat.

2. Material and methods

2.1 Test site for experiment

New hemispherical solar still was tested under climate conditions of Mehsana (latitude of $23^{\circ} 59'$ and longitude of $72^{\circ} 38'$), Gujarat in a typical summer month, May 2012. Mehsana city is located at center of Gujarat. Tropics of cancer is also passing through this city hence this site is best for meteorological environment of Solar energy. It has two distinct season like hot season and cold season. Hot season is best chosen for experiment due to good solar insolation. Relative humidity exhibits a large diurnal cycle on order of 55% round the year. The monthly average wind speed for Mehsana (latitude of $23^{\circ} 59'$ and longitude of $72^{\circ} 38'$) 2.5 m/s.

2.2. Design of the hemispherical solar still

A schematic diagram of hemispherical solar still is as shown in Fig. 1 and photographs of components as well as complete fabrication of hemispherical solar still is shown in Fig. 2. The hemispherical solar still consists of circular basin and black colored absorber plate which carrying saline water, acrylic hemispherical cover, conical shaped water Distiller called hopper and container, which carries all of above components. Here, basin as well as black colored absorber plate made of mild steel. Mild steel plate has effective area of 0.55 meter square and a thickness of 5 mm. A hole of 30 mm is drilled centrally to carry out saline water from the MS tray. Acrylic hemispherical head is attached at top of the still which has absorptivity as well as transmissivity of 0.85 and 0.7 respectively.

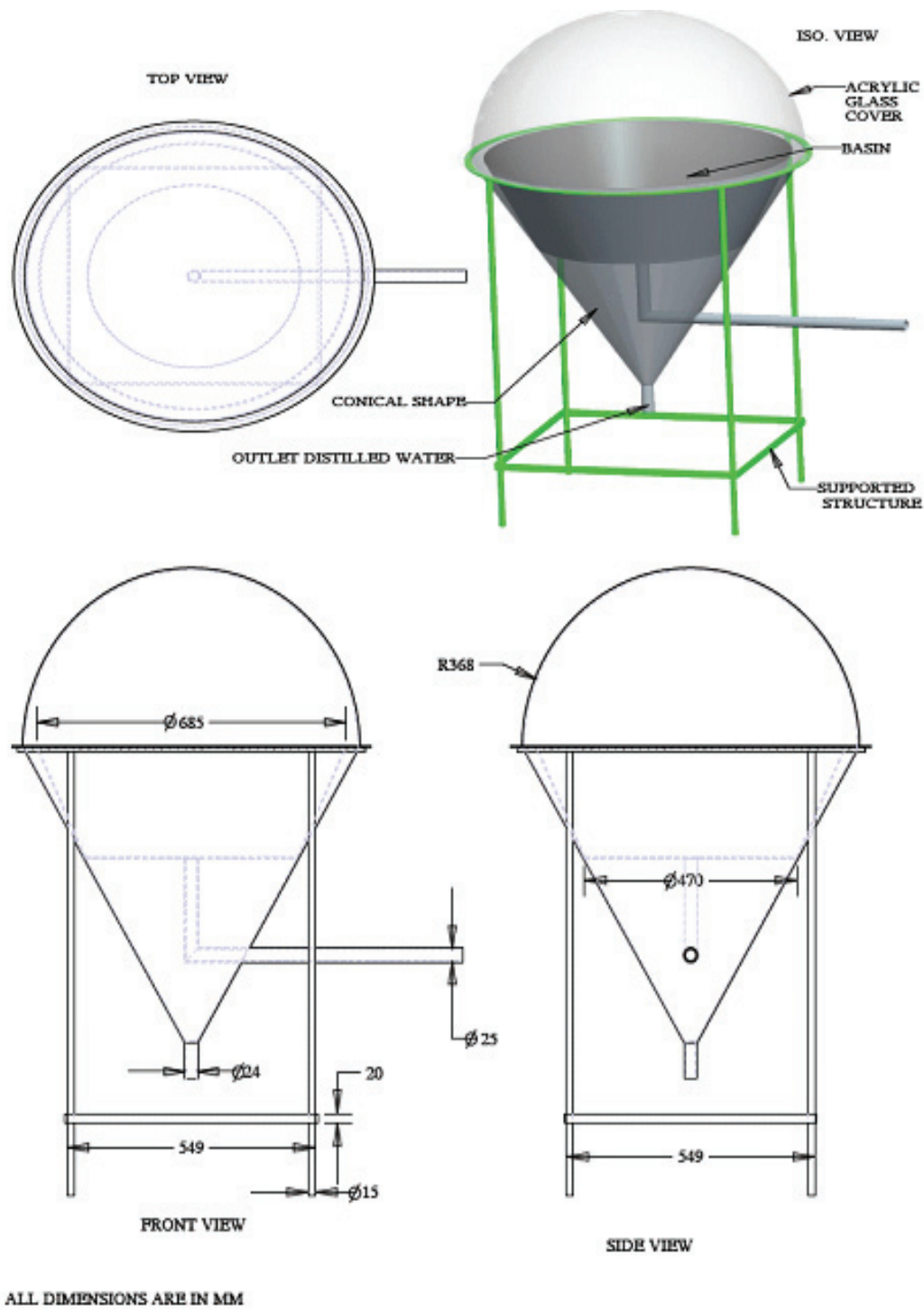


Figure 1 Schematic diagram of hemispherical solar still



To decrease heat transfer losses, 5 mm thick rubber gasket is provided. Here for further sealing as well as pressure between hemispherical cover as well as basin, 4 C clamps have fitted at equal distances. Three K type thermocouples have used to know temperatures like inner glass cover, water temperature as well as ambient temperature. To know insolation of solar still, pyranometer is attached, which has 0.1 meter square lest count.

2.3. Experimental procedure

Experiments have performed at Geetanjali Society, Mehsana (latitude of 23° 59' and longitude of 72° 38') on May, 2012. Before starting experiments all electronic instruments like pyranometer, thermocouples, Anemometer have calibrated properly otherwise there will be chances of errors in experiments. Experiments started around 9:00 am morning to 5:00 pm evening. Different temperatures, wind speed, solar insolation measured at every one hour of interval. Table 1 shows various measured temperatures and yield for hemispherical solar still. Here, 20 cm water depth has taken for measurements.

Table 1 measured temperature, yield, distillate output yield of hemispherical solar still

Sr. No.	Time (Hour)	T _a (°C)	T _w (°C)	T _g (°C)	I(t) W/m ²	M _w (kg)
1	9:00	20	0	0	0	0
2	10:00	24	430	29	370	0.025
3	11:00	27	45	30	460	0.120
4	12:00	28.5	53	32	520	0.210
5	13:00	31	55	34	650	0.235
6	14:00	30	65	37	720	0.290
7	15:00	28	50	32	510	0.150
8	16:00	27	39	30	310	0.090
9	17:00	25	30	37	120	0.040

3. Simulation in ANSYS CFD software

3.1. Flow geometry

Flow geometry is very important parameter for making model in ANSYS CFD. Fig. 3 First 3D model is made in Solid works 2012 software and then import into ANSYS software. Fig. 3 shows 3-D model of hemispherical solar still and Fig. 4 shows unstructured meshes of hemispherical solar still.

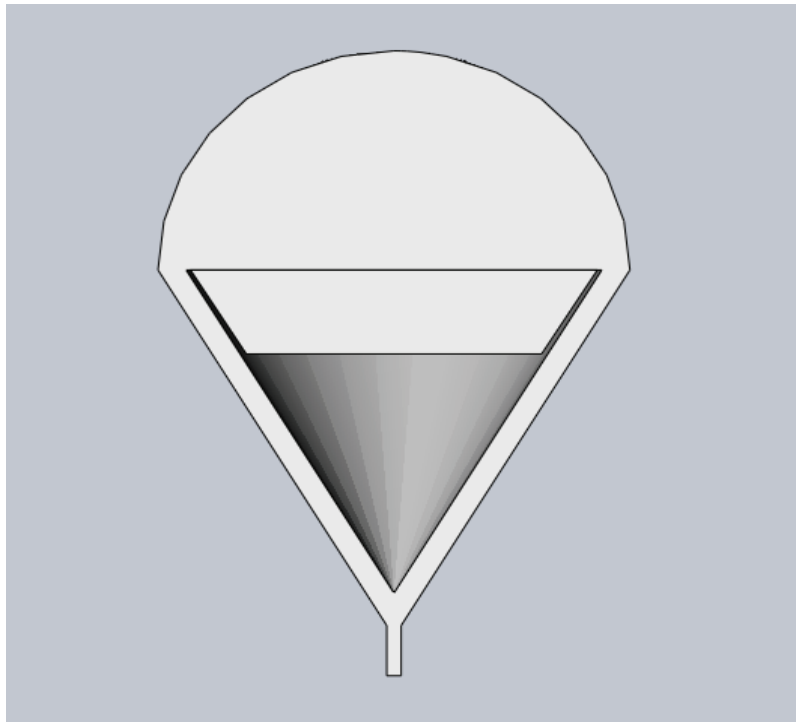


Figure 3 3-D model of hemispherical head solar still in Solid works 2012 software

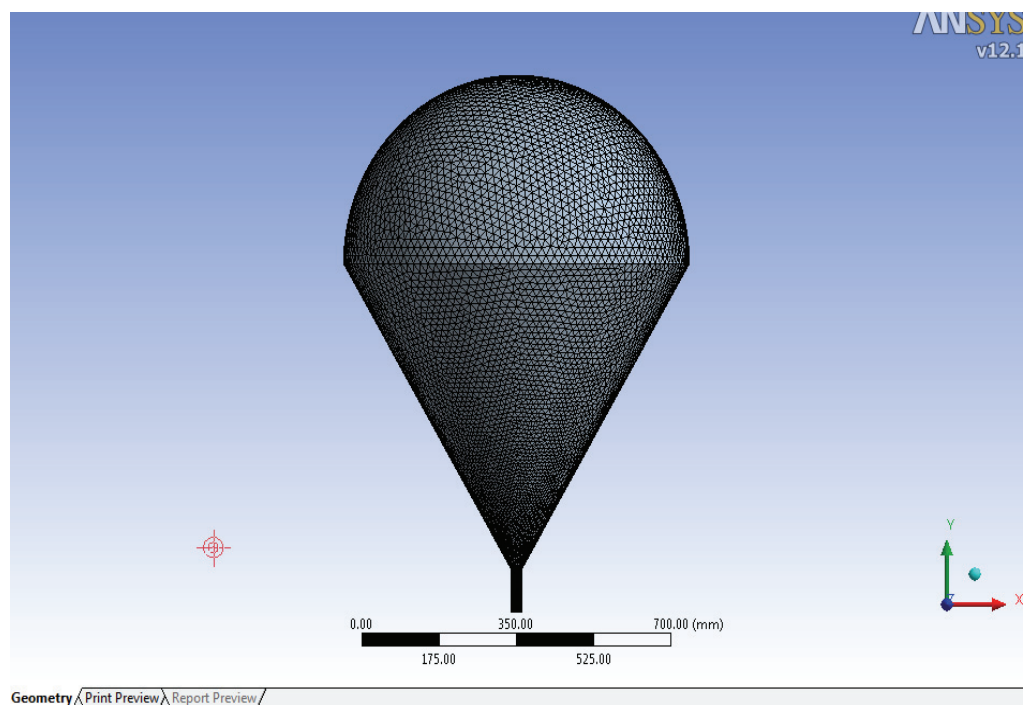


Figure 4 Unstructured mesh of hemispherical solar still

3.2. Initial and boundary conditions

Continuity equation and momentum equation are very important for ANSYS software. Hence, to solve momentum as well as continuity equations, suitable boundary conditions must be specified at all boundaries. Here, total 9 hours Experimental data have used, hence ANSYS CFD simulation run time of 9 hours is required, which is unsteady state condition and it is not possible because of large number of compute time limitations as well as time steps. Hence, for easy calculations, an assumption has taken that, time period of 1 hour is applied to water as well as glass cover of hemispherical solar still, at that time temperature of water and glass cover remains constant. Hence, overall process is required 9 stages consisting of 1 hour time interval in quasi static condition

Here, in every 1 hour of time interval, an average temperature was set as a boundary conditions of hemispherical solar still. Solar insolation is based on absorption coefficient, emissivity of glass, reflectivity of glass etc. Due to evaporation of water, droplets of water formed and for droplet of water, adhesion as well as cohesion, forces also taken accounted to obtain good result.

Here, there is also an assumption taken that when solar insolation is applied to hemispherical solar still and after one hour of simulation, whatever water level decrease inside basin that much water is obtained at distillate output.

Initial water level inside the basin of hemispherical solar still has taken as 2 cm and after end of simulation whatever level is decrease inside basin, same amount of water is entered inside the basin for balancing purpose. Hence, hydrostatic pressure is proportional to water inside the basin of hemispherical solar still.

4. Result & discussion

4.1. Result & discussion of experimental work

Fig. 5 shows the comparison between the hourly variation of Ambient and water temperature. Here, ambient temperature has not much variation compared with water temperature. Water temperature is increasing from morning 9:00 to 2:00 p.m. Fig. 6 shows comparison between hourly variation of solar insolation and water temperature. Fig. 6 shows graph with increasing scale because when hours passes from morning to noon, then sun gives bright sunshine hence, insolation increases and corresponding water temperature also linearly increases. Water temperature is very important parameter because when insolation is higher, the thermal energy of sun will increases water temperature, hence water temperature increases from morning 9:00 am to 2:00 pm noon after then it will get decline due to lower sunshine hours.

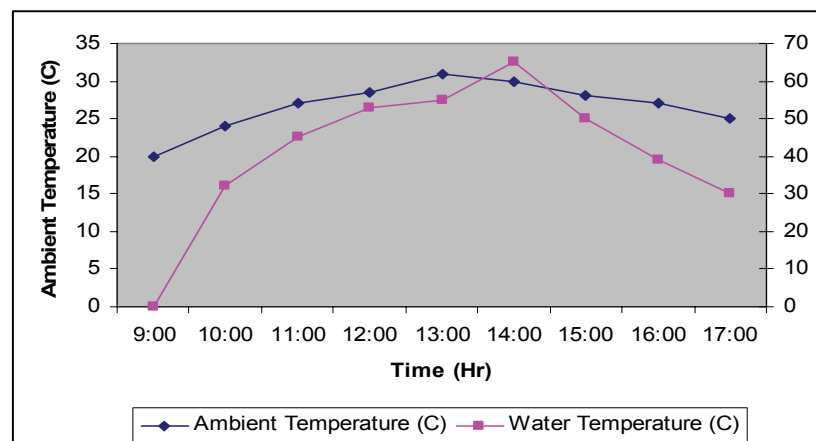


Figure 5 Comparison of Time Vs ambient and water temperature

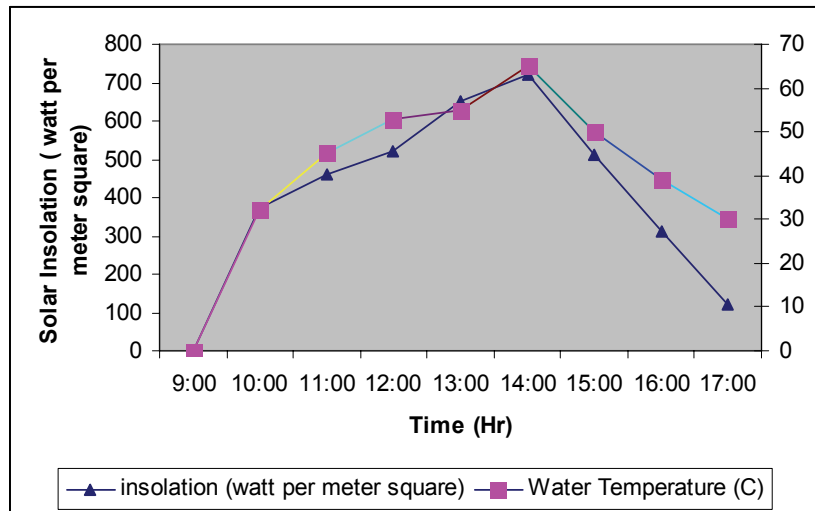


Figure 6 Comparison of Time Vs solar insolation and Water Temperature

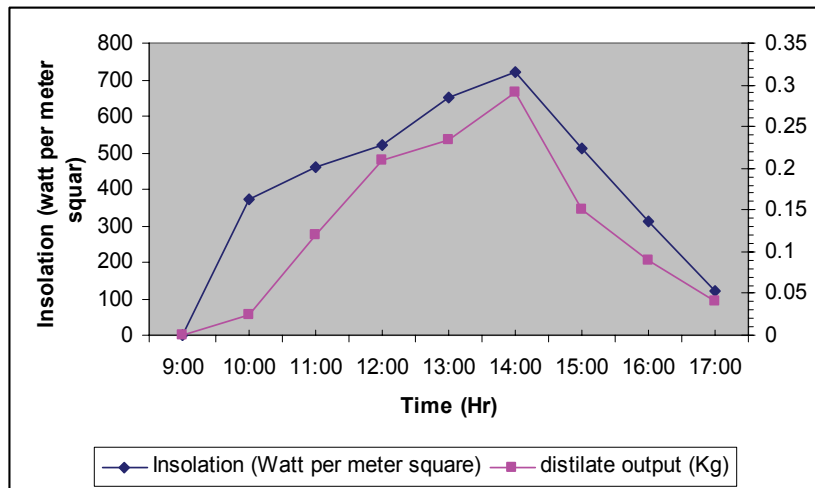


Figure 7 Comparison of Time Vs insolation and Distillate output

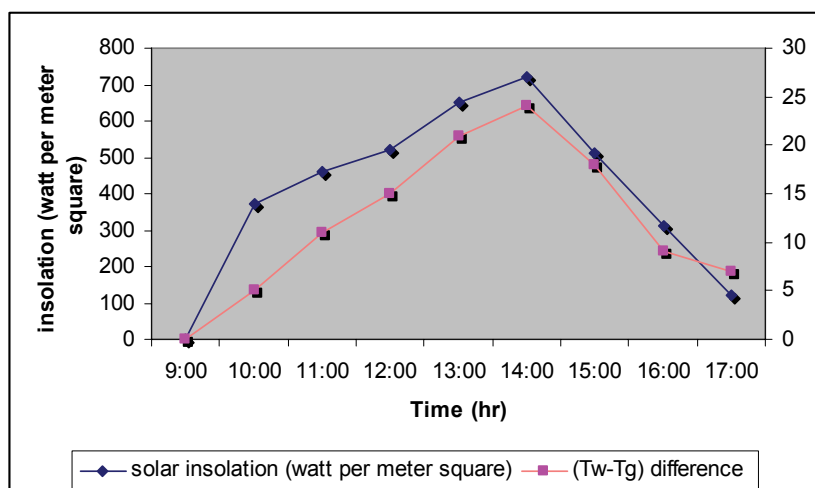


Figure 8 Comparison of Time Vs Solar Insolation and difference of Temperature

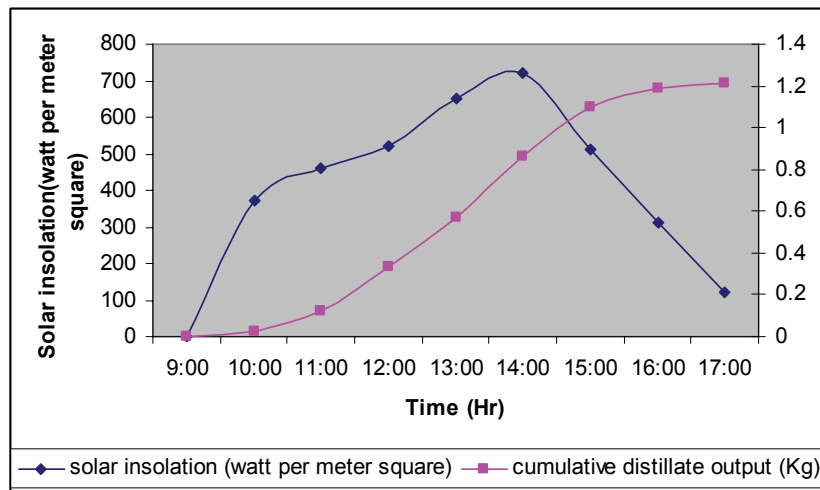


Figure 9 Comparison of Time Vs solar insolation and cumulative distillate output

Fig. 7 shows comparison between hourly variation of insolation and distillate output. When water evaporates, then due to its lower density it will get condensation on inner side glass cover and droplets will be formed. Due to the incline surface of still, all will collect in distillate channel. Fig. 7 shows increasing distillation from morning 9:00 am to 2:00 pm evening. At 9:00 am distillate, output is zero because of starting of project. After 2:00 pm due to lower sunshine hours, evaporation rate is lower and hence distillate output lower.

Many researchers have found that higher temperature difference between water temperature and inner glass cover temperature, higher will be distillate output. Hence, Fig. 8 shows comparison of hourly variation of solar insolation and temperature difference of water and glass cover temperature. Fig. 8 shows that, it will be zero during starting of experiment and then gradually increases from morning to noon 2:00 pm. Hence, maximum water distillate water available at 2:00 pm. And due to lower difference in temperature, after 2:00 pm, distillate output is decreases. Fig. 10 shows hourly variation of solar insolation and cumulative distillate output of hemispherical solar still. It shows that, there is a gradually increases in cumulative output from morning 9:00 am to 5:00 pm evening.

4.2 Result and discussion of ANSYS CFD simulation

The ANSYS CFD analysis was carried out using the commercial package of ANSYS CFX 12 on five 3 GHz CPU processors and two 3.00 GHz PU processors. Computation time per simulation required to reach quasi steady state condition was about 4 to 12 hour according to the computer used for FD simulations. Building model geometry and its meshing were done using ANSYS workbench 12. Unstructured mesh of type tetrahedral was used. It consists of 102324 nodes and 360263 elements. And Sensitivity of simulation results has checked by different grids. CFD prediction results become insignificantly closer to the experiment results, hence or lowering computational effort, the simulations were carried out with 102324 nodes. Hence, objective of this paper is CFD modeling of evaporation and condensation processes that occur in hemispherical solar stills. Water in the system vaporizes by cause of solar energy. Temperature difference between water vapor and lass leads to vapor condensation on the glass surface. Droplets slip down and gather on the downcomer. For fresh water calculation in simulations, amount of accumulated water on down comer were considered as the rate of water production. Fresh water production rate and water temperature from simulation results ere compared with experimental data. Fig. 10 shows steady state condition applied to hemispherical solar still.

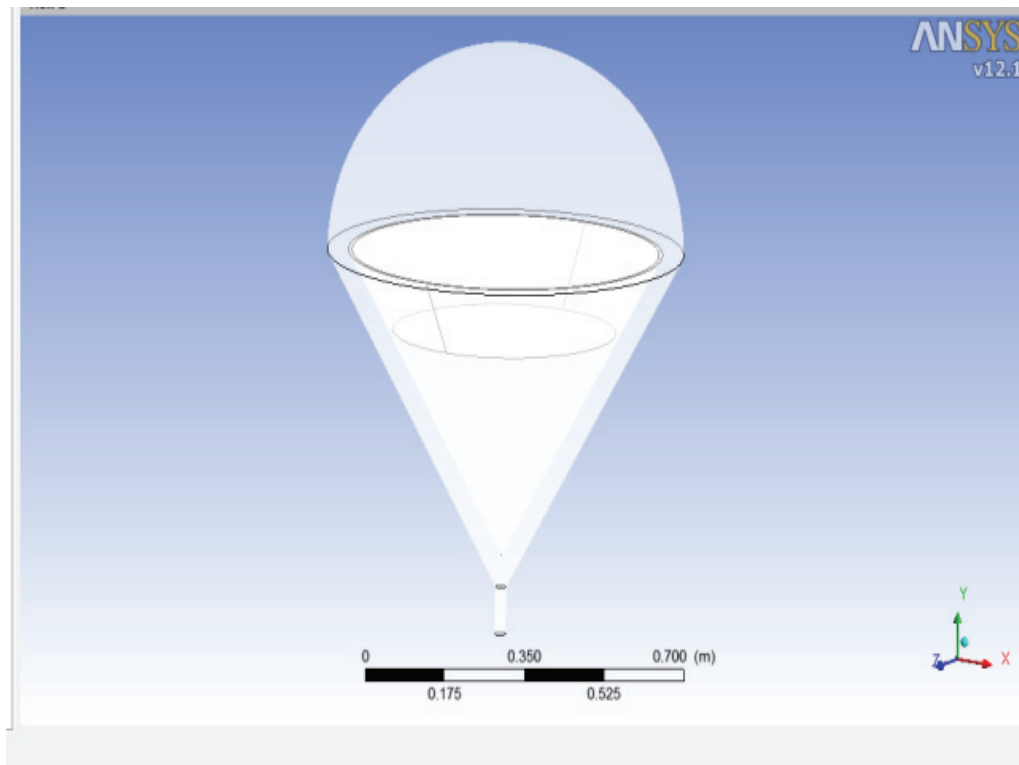


Figure 10 Application of steady state condition applied to hemispherical solar still

After application of steady state condition to model made in ANSYS CFX, next step is to apply water domain, vapor domain as well as heat transfer. Here, first water domain is applied, because it gives idea of water inside basin of hemispherical solar still and then after evaporation, vapor is formed. After water and vapor domain, next step is application of solar insolation. Fig. 11 shows water domain and Fig. 12 shows vapor domain. Here motion of water and vapor remains stationary. Fig. 13 shows solar insolation to hemispherical cover and water.

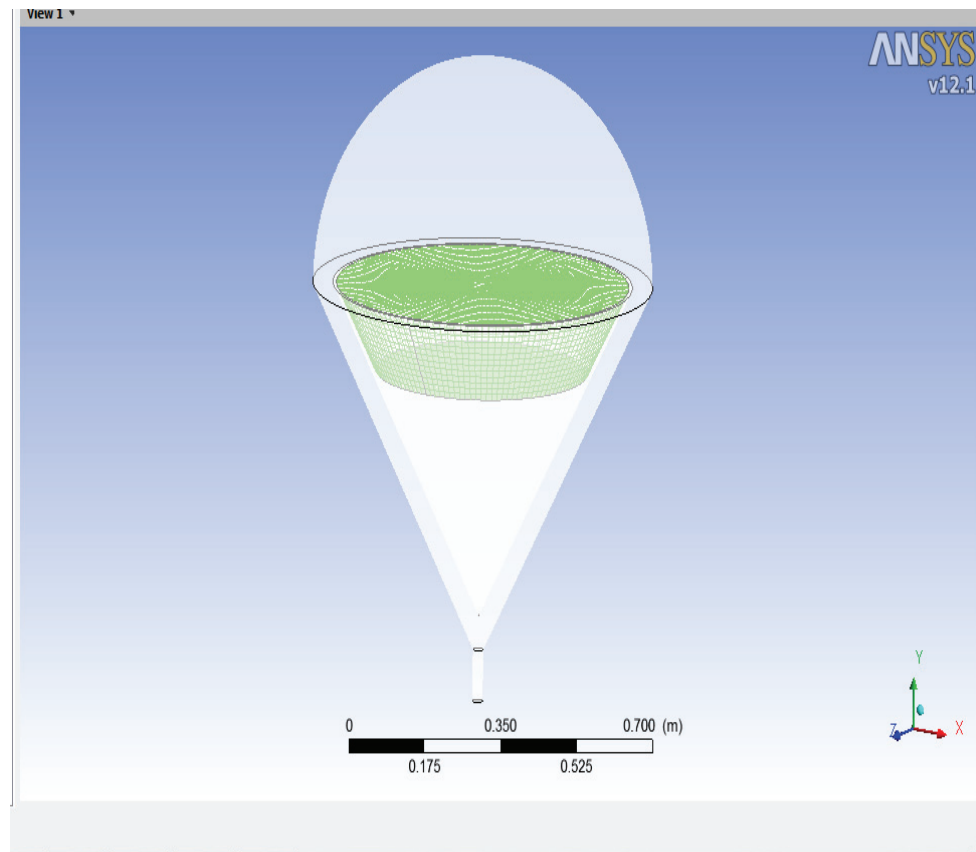


Figure 11 Water domain applied to Hemispherical solar still

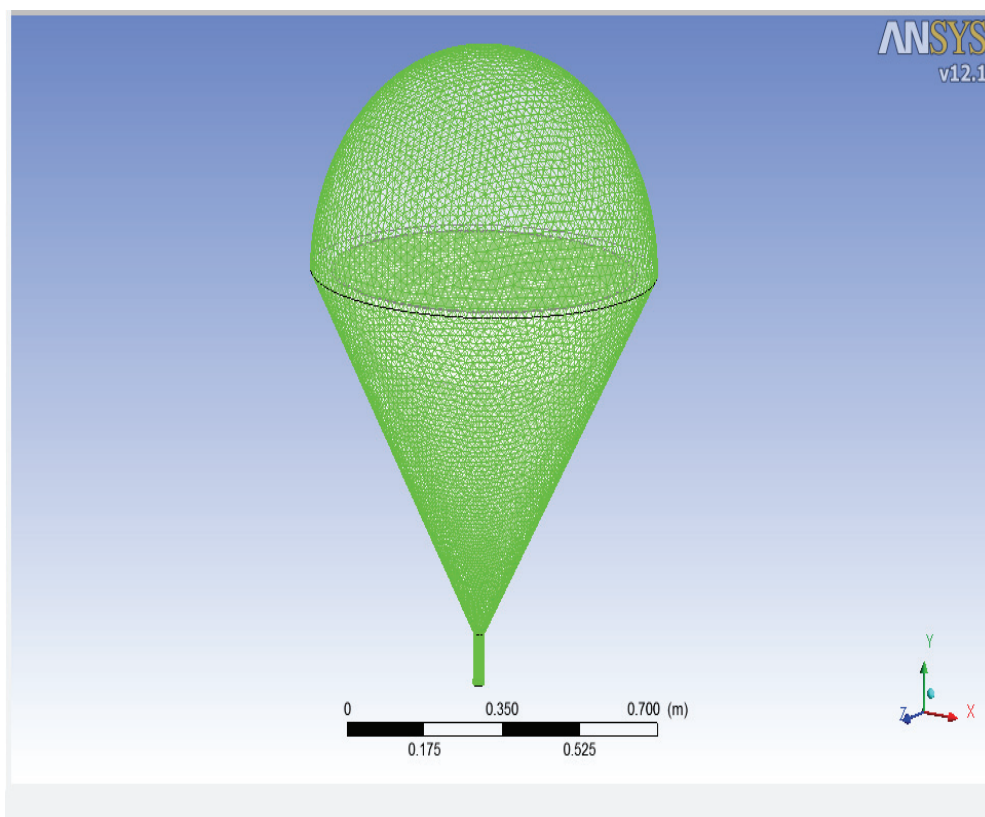


Figure 12 Vapor domain applied to hemispherical solar still

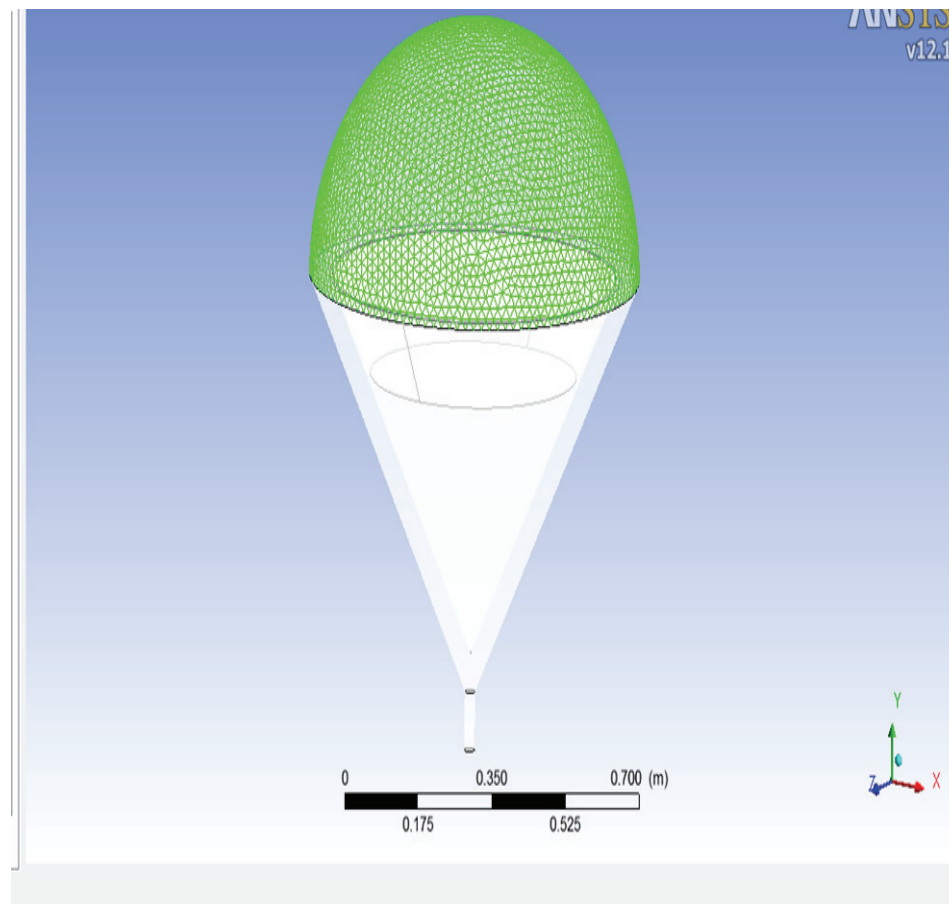


Figure 13 Solar radiation applied to hemispherical solar still

Fig. 14 shows results of simulation runs and the experimental data of 9 hours of time period. In this Fig. it is clearly show that, as process of evaporation and condensation begins at 9:00 am morning, then water particles warm up in the solar still . it starts increasing up to 14:00 pm due to less thermal energy in form of solar insolation, warming of water is less hence it gets declined after 14:00 pm to 17:00 pm. It also shows 12 % distillate water errors while comparing with actual experimental results. Fig. 15 shows comparison of simulation results water temperature and actual experimental water temperature which has measured by K Type thermocouples. It shows good agreement and average error of water temperature is 8 %.

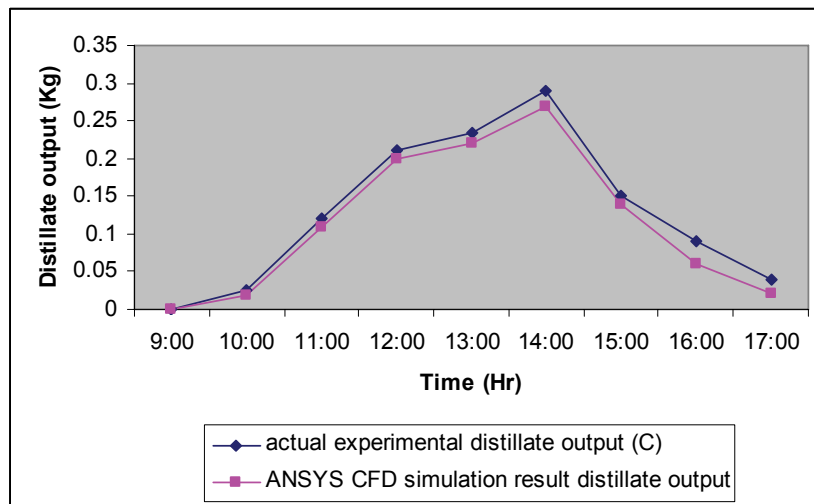


Figure 14 Comparison of distillate output of actual result and ANSYS CFD simulation results

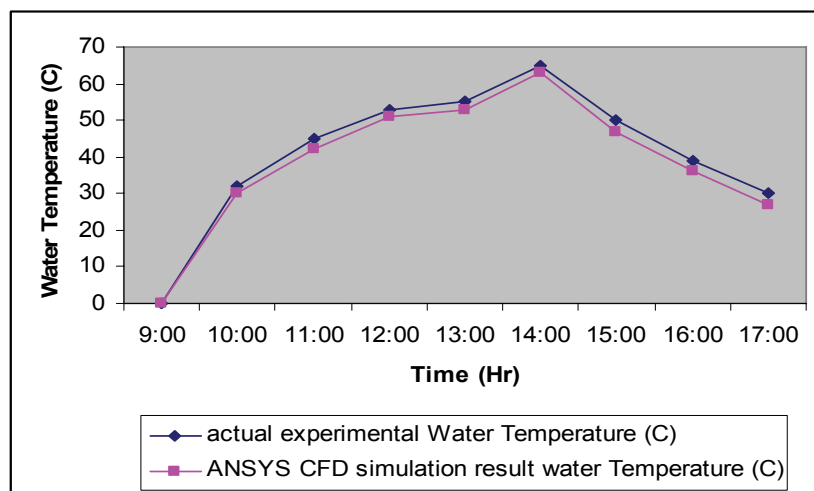


Figure 15 Comparison of actual water temperature and ANSYS CFD simulation results

5. Conclusion

Hemispherical solar still is an innovative solar still which produces potable water from the saline water. From the research and development on hemispherical solar still, following points obtained in conclusion.

Top of the cover of the hemispherical solar still receives solar radiation from all sides hence cost of using solar tracking system is omitted. Higher difference of temperature of water inside basin and inner glass cover, higher distillate output from solar still. There is a very good agreement with experimental results of water temperature, distillate output with ANSYS CFD simulation results. ANSYS CFD is very important tool for comparison of experimental results, with errors in measurements.

6. References

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