INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 2, Issue 6, 2011 pp.985-998
Journal homepage: www.IJEE.IEEFoundation.org

Modelling and verification of single slope solar still using ANSYS-CFX

Hitesh N Panchal[1], P. K. Shah[2]

[1] Research Scholar, Kadi Sarvavishwavidyalaya University, Gandhinagar, India.
[2] Principal, Silver Oak College of Engineering & Technology, Ahmedabad, India.

Abstract
Solar distillation method is an easy, small scale and cost effective technique for providing safe water. It requires an energy input as heat and the solar radiation can be source of energy. Solar still is a device which uses process of solar distillation. Here, a two phase, three dimensional model was made for evaporation as well as condensation process in solar still by using ANSYS CFX method to simulate the present model. Simulation results of solar still compared with actual experiment data of single basin solar still at climate conditions of Mehsana (23°12’ N, 72°30’). There is a good agreement with experimental results and simulation results of distillate output, water temperature and heat transfer coefficients. Overall study shows the ANSYS CFX is a powerful tool for diagnostic as well as analysis of solar still.

Keywords: ANSYS CFX; Heat transfer coefficient; Water temperature.

1. Introduction

A solar still operates sing the basic principles of evaporation and condensation. The impure saline water into solar still and sun’s ray penetrate a glass surface causing the water to heat up through the greenhouse effect and consequently, evaporate. When the water evaporated inside the solar still, it leaves all contaminants and microbes behind the basin. The evaporated and now purified water condenses on the underside of the glass and runs into a collection through and then into an enclosed container. In this method the salts and microbes that were present in the original feed water to solar still, are left behind. Additional water fed into solar still flushes out concentrated waste from the basin of solar still to avoid excessive salt deposition in the basin. [1]. Jadav Madhav V [2] used Black granite as basin material inside single slope solar still and compared with iron steel basin of solar still. He proved that, average productivity of black granite basin solar still is 3.784 L/m2.day and iron steel basin is 2.358 L/m2.day, means 38% more. Basin water temperature of increased about 87 C compared with Iron steel basin still water of 79 degree Celsius. M. Sakthivel.et.al [3] conducted experiment on regenerative solar still with and without jute cloth. Jute cloth is a medium to provide large evaporation surface and provide and provide latent heat of condensation. They proved that, cumulative still yield in regenerative solar still with jute cloth increases approximately 20% and efficiency increased by 8% with low cost modification as the jute cloth is very cheap and easily available. Omar badran [4] used active solar single slope solar still using different operational parameters like different insulation thickness, solar intensity, effective absorptivity & Transmissivity theoretically and compared with experimental data to choose best factor enhancing solar still productivity. He proved from study that active solar stills can be of the options for enhancing productivity of still. Kalidasa Murugavel et.al [5] made a double basin solar still from mild steel plates and used layer of water as well as different heat storage materials like quartzite rock, red brick pieces, cement concrete pieces, washed stones and iron scrapes. He found that, still with ¾ size quartzite rock was effective basin material to increase distillate output among other sensible heat storing materials. F.F. Tabrizi, A.Z. Sharak [6], used inbuilt sandy heat reservoir experimentally under climate conditions of Iran. He proved that, integrated sandy heat reservoir increases significantly productivity of solar still during nights as well as cloudy days conditions, and it does not require any pumping element as well as operators for night mode usage. K. Kalidasa Murugavel et.al[7] used double slope basin solar still tested with mild steel plates with minimum mass of water and different wick materials like light cotton cloth, sponge sheet, waste cotton pieces, coir mate pieces in basin also use aluminum fin arranged in different configuration. He found that from experiment that, light black cotton cloth is effective wick material compared with other wick materials as well as aluminum fin covered with cotton cloth and arranged in length wise was more effective. R.dev et.al [8] used new approach to obtain characteristic equation of a double slope passive solar still based on experimental observations from composite climate conditions of New delhi. He concluded that, non linear characteristic curves have more accurate for analyzing performance, thermal testing and further modification depending on various parameters associated with design. Climate and operational conditions. R.dev et.al.[9] made a inverted absorber solar still having curved reflector to heat it from top and bottom with single slope solar still. He used instantaneous gain and loss efficiencies by experimental data for climate conditions of Muscat, Oman. He also compared similar operating and climate conditions with single slope solar still and also he found annually cost of distillate output of Inverted absorber solar still and single slope solar still were 0.95 & 0.54 Rs .A.J.N. Khalifa[10] studied literature on relation between cover tilt angle and productivity of simple solar stills in various seasons for relation between optimum tilt angle and latitude angle and concluded that, cove tilt angle should be larger in winter and smaller in summer, increasing tilt angle would increase productivity and maximum productivity achieved by using cover tilt angle close to the latitude of place. S.abdullah et.al.[11] made four identical solar stills used various absorbing materials used in single slope solar still like uncoated and coated porous medium called metallic wiry sponges and remaining two used black volcanic rocks and without any medium in climate conditions of Jordan. From experiment, he found that, uncoated sponge has highest water collection during day time followed by black rocks and coated wiry sponges

Objective of this paper is ANSYS CFX modeling of evaporation and condensation processes that occurs in solar stills. Water in the system vaporizes by the solar insolation. Temperature difference between water vapor and glass leads to vapor condensation in glass cover. Droplets slip down and gather on the distillate channel. For fresh water calculation in simulations, amount of accumulated water on distillate channel is considered as rate of water production inside solar still. Fresh water production rate and water temperature from simulation results compared with actual results. And also comparison made with simulation result and experimental results of water temperature, glass cover temperature, evaporative heat transfer coefficient and convective heat transfer coefficient.

2. Mathematical modeling

Performance of solar still based on productivity, efficiency as well as internal heat and mass transfer coefficient. Hence performance directly proportional to internal heat transfer coefficient and distillate output from solar still. Internal heat and mass transfer coefficient in the solar still based on three parameters called convection, radiation and evaporation, hence there are three heat transfer coefficient called convective heat transfer coefficient, radiative heat transfer coefficient and evaporative heat transfer coefficient.

2.1 Convective heat transfer

Action of buoyancy force due to density difference of humid air due to temperature difference is the major reason behind the convective heat transfer coefficient in solar still. The convective heat transfer coefficient of water surface to condensing glass cover is given by:

$$q_{cw} = h_{cw}(T_w - T_g) \tag{1}$$

Heat transfer coefficient h_{cw} can be calculate by following equation

$$h_{cw} = \frac{0.884[(T_w - T_g) + (P_w - P_g)(T_w + 273)}{(268.9\times 10^3 - P_w)^{\frac{1}{3}}} \tag{2}$$

2.2 Radiative heat transfer

Solar energy is responsible for the formation of pure water from the solar still. Radiative heat transfer is also responsible through solar energy. Rate of radiative heat transfer from water surface to condensing cover is given by:

$$q_{rw} = h_{rw}(T_w - T_g) \tag{3}$$

Radiative heat transfer coefficient h_{rw} is given by:

$$h_{rw} = \varepsilon_{effect}\sigma[(T_w + 273)^2 + (T_g + 273)^2] \tag{4}$$

Here,

$$\sigma = 5.669\times 10^{-8} W/m^2K^4 \tag{5}$$

$$\varepsilon_{effect} = (\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1)^{-1} \tag{6a}$$

$$\varepsilon_g = \varepsilon_w = 0.9 \tag{6b}$$

2.3 Evaporative heat transfer

When solar energy is incident inside the solar still, water evaporates and converted into steam. Hence, evaporative heat transfer is given by following equation

$$q_{ew} = h_{ew}(T_w - T_g) \tag{7}$$

Evaporative heat transfer coefficient is given by

$$h_{ew} = 16.27\times 10^{-3} \times h_{cw} \times \frac{(P_w - P_g)}{(T_w - T_g)} \tag{8}$$

Total heat transfer coefficient from water surface to condensing cover is given by following equation

$$h_{1w} = h_{cw} + h_{rw} + h_{ew} \tag{9}$$

2.4 Energy balance

When solar energy is incident inside the basin water, heat transfer mechanism starts. Figure 1. Shows the energy flow in single slope single basin solar still. Energy balance equation can be written with following assumption

1. There is no vapor leakage in solar still
2. It is an air tight basin, hence no heat loss.
3. Heat capacity of cover and absorbing material, insulation is negligible.
4. There is no temperature gradient across the basin water and glass cover of solar still.

5. Water level inside the basin maintained at constant level.
6. Only film type condensation is occurs in place of drop type condensation.

- Energy balance for glass cover

$$\alpha_g^{'} I(t) + (q_{rw} + q_{cw} + q_{ew}) = q_{rg} + q_{eg} \quad (10)$$

- Energy balance for basin water

$$\alpha^{'}{}_b I(t) + q_w = (MC)_w \frac{T_w}{dt} + q_{rw} + q_{ew} + q_{cw} \quad (11)$$

- Energy balance for basin

$$\alpha_b^{'} I(t) = q_w + (q_{cb} + q_s (\frac{A_{ss}}{A_s}) \quad (12)$$

- Heat transfer coefficients

$$h_{1g} = 5.7 + 3.8V \quad (13)$$

- Hourly yield of solar still is given by:

$$m_w = \frac{q_{ew}}{L} \times 3600 \quad (14)$$

- Efficiency of solar still is given by

$$\eta = \frac{q_{ew}}{I(t)} \quad (15)$$

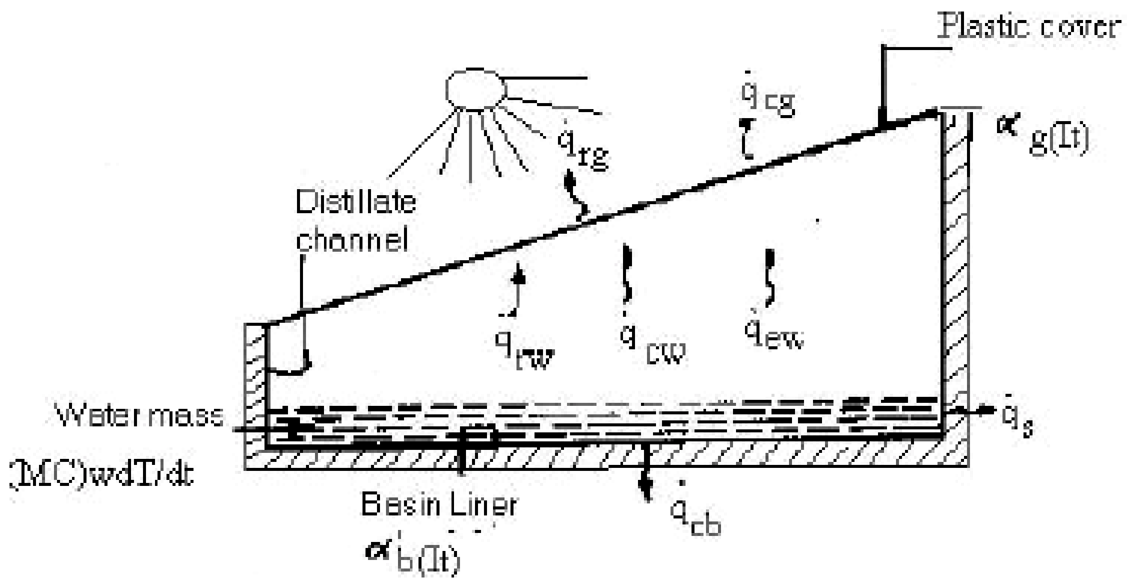

Figure 1. Energy flow in Single basin single slope solar still

3. Experimental set up

Figure 2 shows experimental set up of single slope solar still. Experimental set up consists of condensing cover of 30 degree fabricated to accommodate 0.20 m water depth maximum. The bottom surface of the still was painted black for greater absorptivity. As we know that, output from the still gets maximum when it consists of least water depth. To avoid spilling of water into distillate channel and to prevent the contact of distillate channel with flasks cover as well as with water level, height of lower vertical side of still was kept as 0.30 m, whereas the height of higher vertical side was kept 0.85 m. The effective basin area of 1 meter x 1 meter made of GRP of 4 m thickness. Condensing cover made of toughed glass of 4 mm is fixed to the top of vertical walls of the stills using a rubber gasket on both sides of glass and clamp fixed iron frames made of angles. A plastic pipe is connected to thin channel to drain the distillate water to an external measuring jar. Whole set up of solar still is installed on stand.

Figure 2. Experimental set up of solar still

4. Flow geometry

ANSYS is engineering simulation software, which is widely used in engineering problems. Figure 3 shows 3 dimensional model of solar still based on data available in experimental set up of solar still by ANSYS 10. Figure 4 shows meshing structure of solar still.

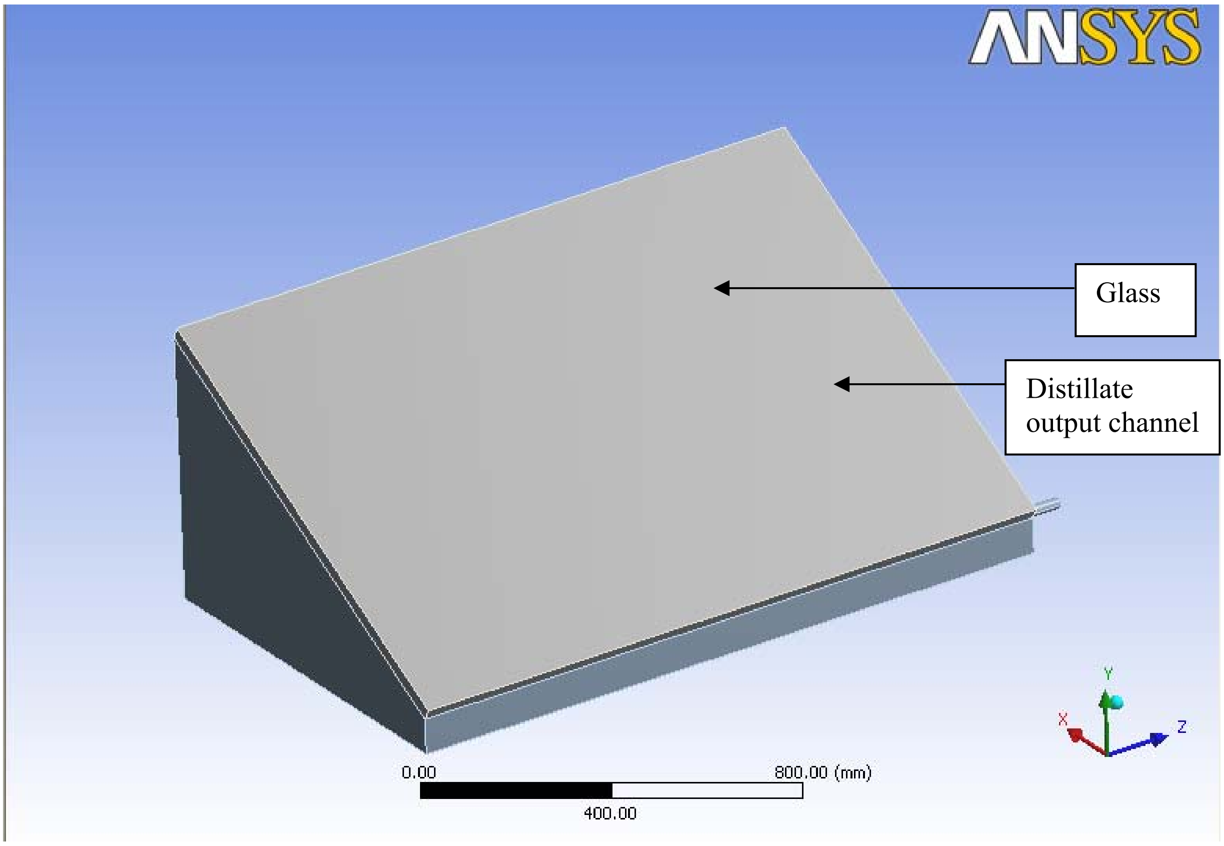

Figure 3. Model geometry of solar still made in ANSYS Workbench

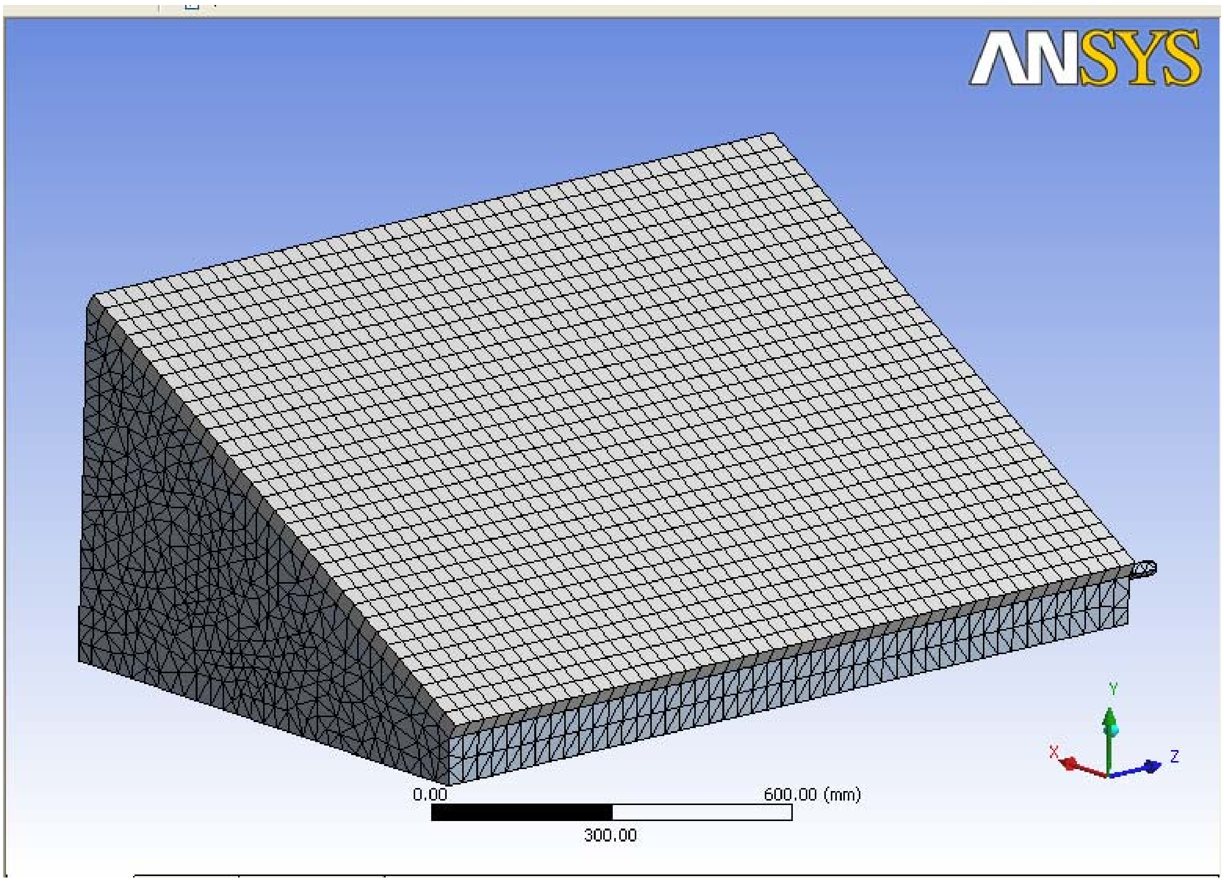

Figure 4. Meshing of model of Solar still in ANSYS

4.1 Boundary & initial conditions

Continuity equation, momentum equation and boundary conditions must be specified at all the boundaries in model of solar still in ANSYS. The recorded experimental data are for 8 hours (morning 9 to evening 5). Here Ansys CFX run time of 8 hours that is required for modeling of solar still which is in an unsteady state process. Hence, to overcome this problem, it assumes that steady state condition is reached after time period of 1 hour and received water; glass temperatures inside basin are constant.

Here distillate output temperature is assumed equal to glass cover temperature. Solar insolation is based on absorption factor and emissivity of glass. For producing droplets inside the solar still, it assumes that adhesion forces are taken into account in simulation. Side walls were assumed as adiabatic wall; hence no heat losses occur in solar still to ambient. A no-slip wall boundary condition was specified for the liquid phase and free slip boundary conditions was used for gas phase. Figure 5 shows the non slip boundary conditions of solar still model. It assumes that, distillate water collected in distillate channel equal to evaporation takes place inside the solar still. For effective simulation, adiabatic condition is required, which prevents the heat transfer losses. Hence, there is a good agreement is required between walls as well as glass, hence between them, no leakage should be occur, hence condition is require in simulation in ANSYS, hence Figure 6 shows adiabatic condition between glass and walls. It is shown by Green colour.

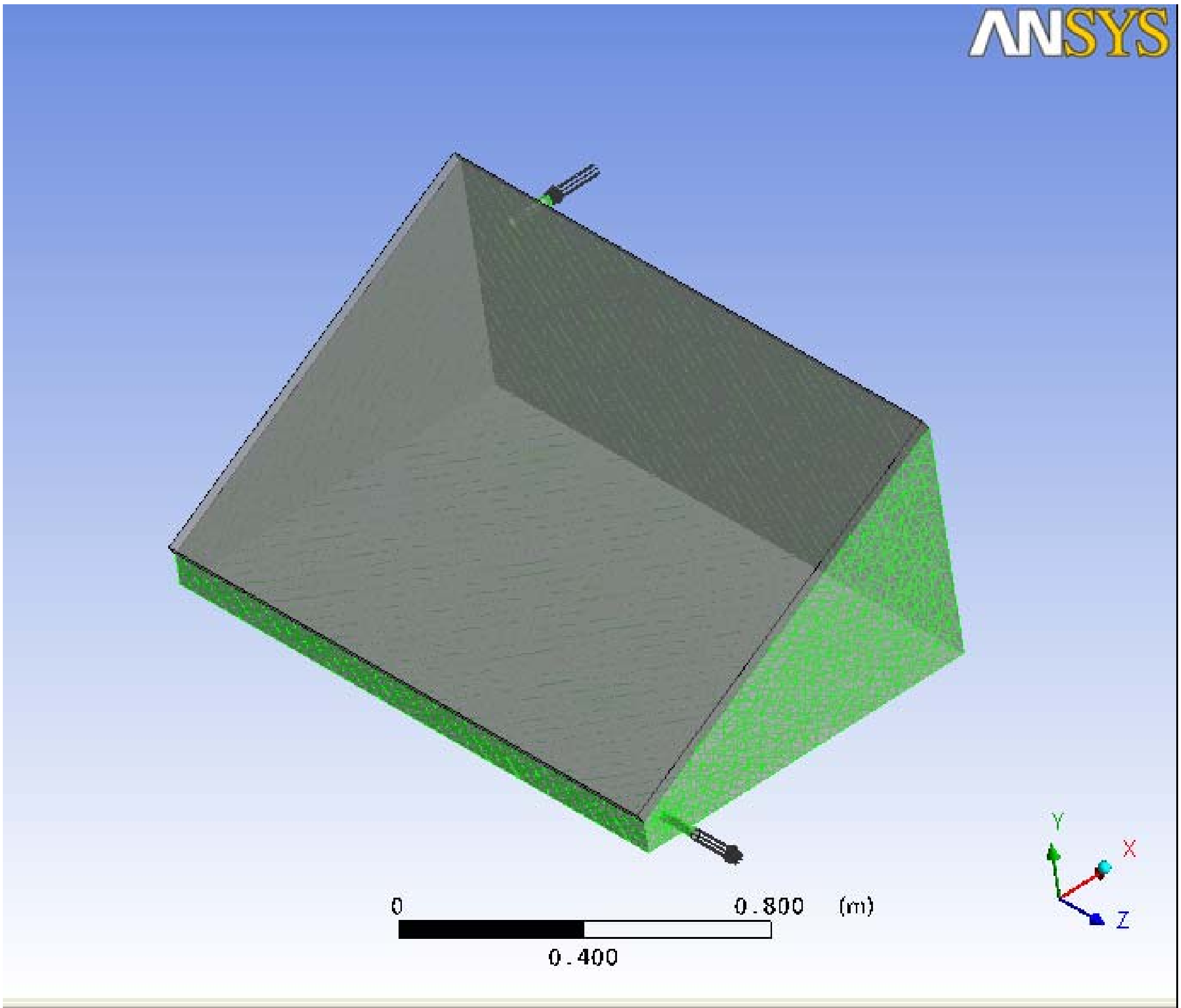

Figure 5. No slip wall boundary condition of solar still

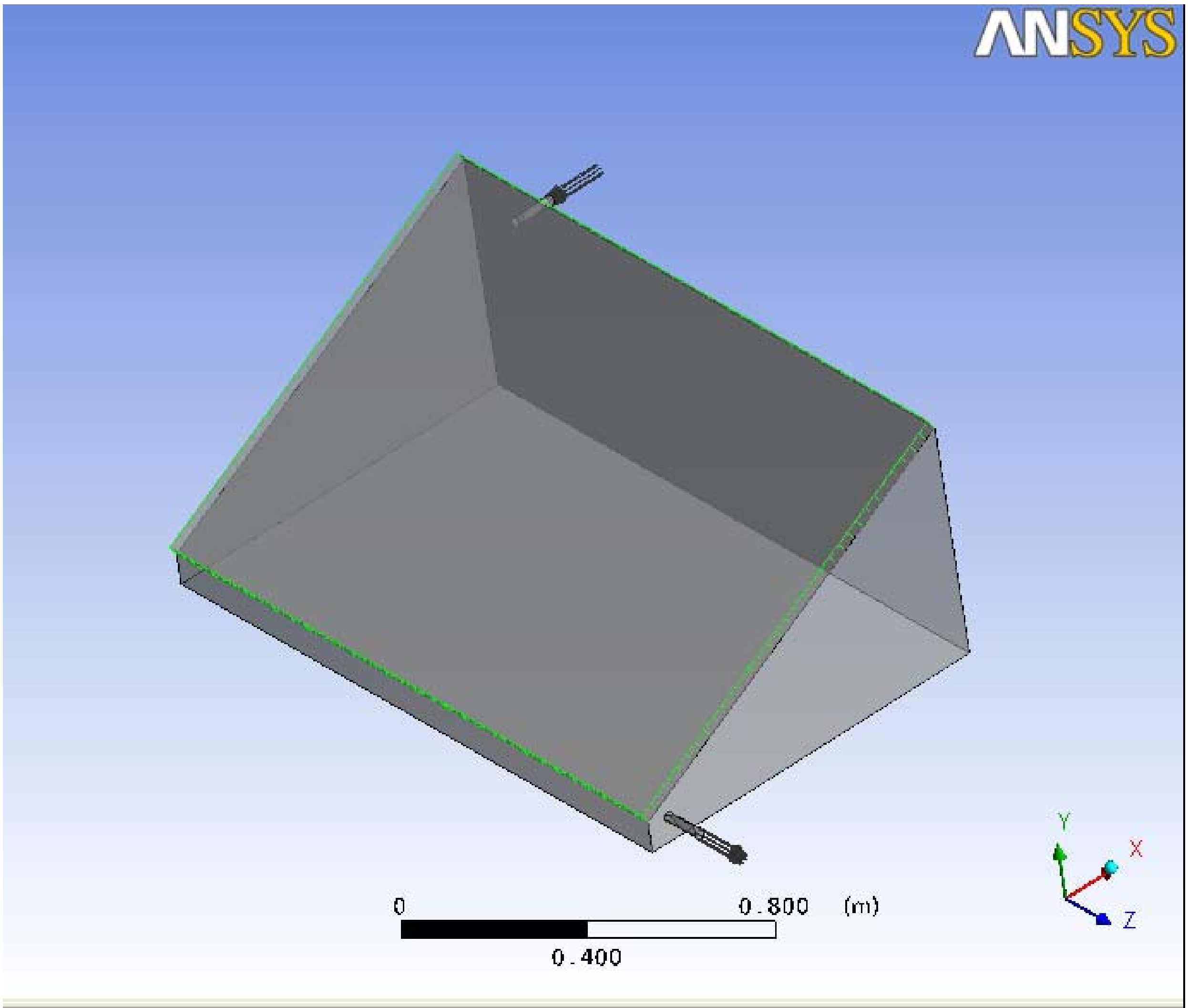

Figure 6. Adiabatic condition between glass and wall

Initial water level inside the solar still is assumed as 0.30 meter for simulation purpose. Water and volume fraction were considered as 0.13 and 0.87 respectively. Initial temperature of water and gas velocity was used according to experimental data in each hour. Most important factor inside solar still is application of solar insolation, incident in solar still. First it will incident on glass cover, due to absorptivity and transmissivity of glass cover, it will absorb by absorber plate and increase temperature of water. Figure 7 shows application of heat flux (solar insolation) in watt per meter square.

5. Simulation results

Building model geometry and its meshing were done using ANSYS Workbench 10. Unstructed mesh of type tetrahedron was used. The sensitivity of the simulation result is very important for optimum analysis, and it can be checked by grid size, hence by checking the results of 32311 47126 64512 and 84121 cells, with increasing numbers of grids, hence simulation result become close to experimental results.

Figure 8 Shows result of simulation runs and experimental data in a 8 hours time period. In this figure, it is noted that, as the process begins at 9 am by passing time, water starts warming up due to increase in solar insolation and formation of vapor as well as distillate water production starts and increases upto 3 pm. After, it decreases gradually due to decrease in solar insolation in sky.

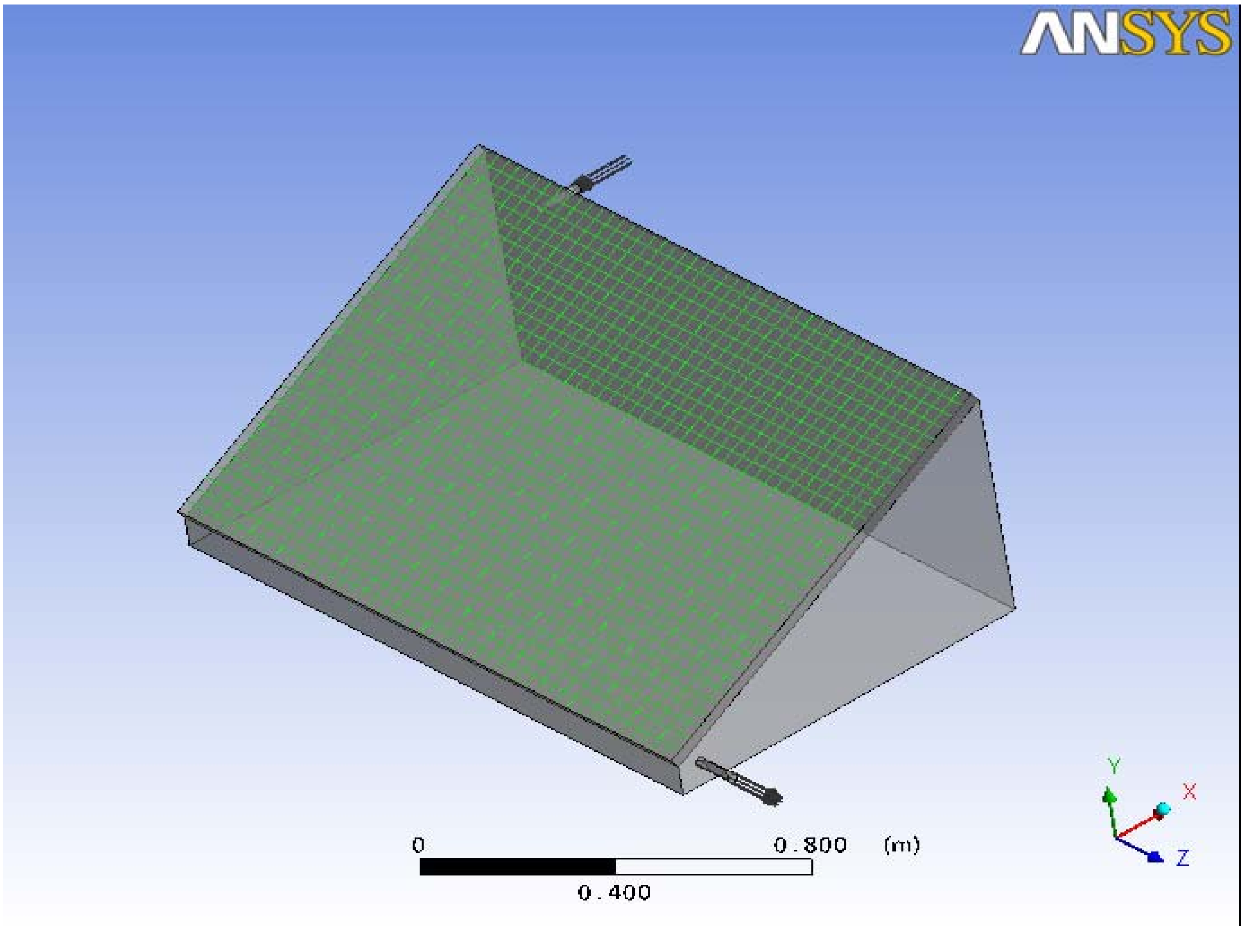

Figure 7. Application of Incident solar insolation applied to glass cover

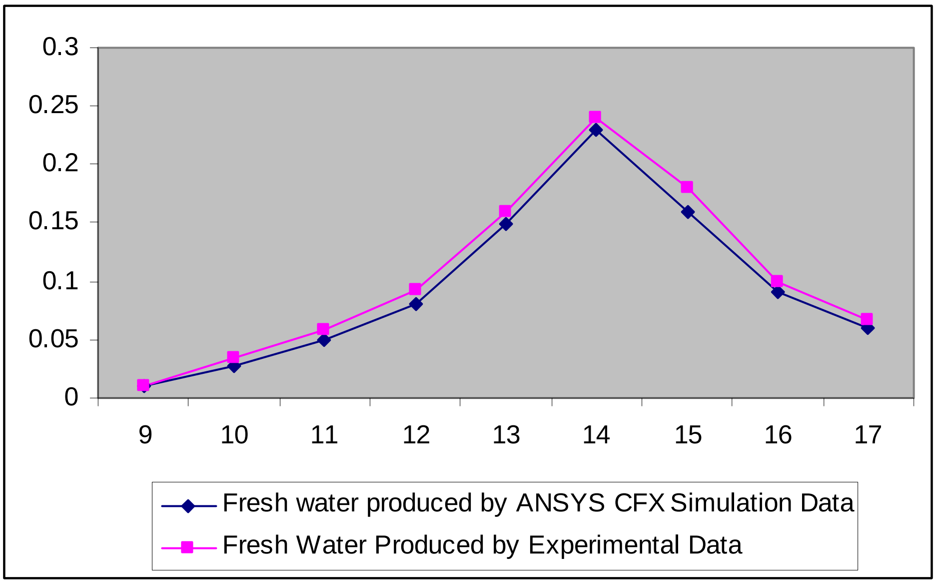

Figure 8. Rate of water production from experimental data and simulation results

Water temperatures predicted by ANSYS CFX simulation are compared with experimental data is as shown in Figure 8. It shows that, water temperature increases upto 3 pm, due to good availability of heat energy in solar insolation, and after 3 pm, decreases gradually. Here there is some difference between available experimental result and simulation result, Difference between available experimental result and simulation result is called " Error", hence From Figure 8 and Figure 9, it shows that the average errors for production rate and water temperature are 6.0% as well as 10.25% respectively.

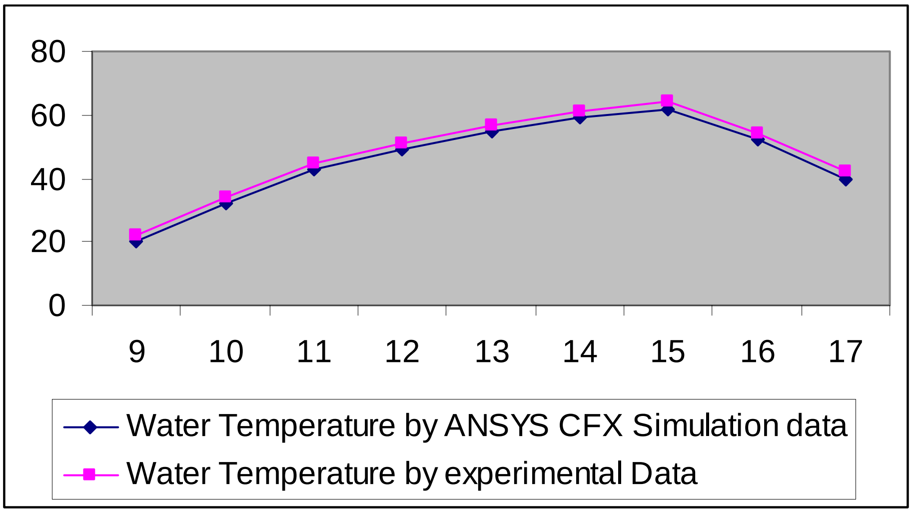

Figure 9. Water temperature predicted by ANSYS CFD Simulation and experimental data

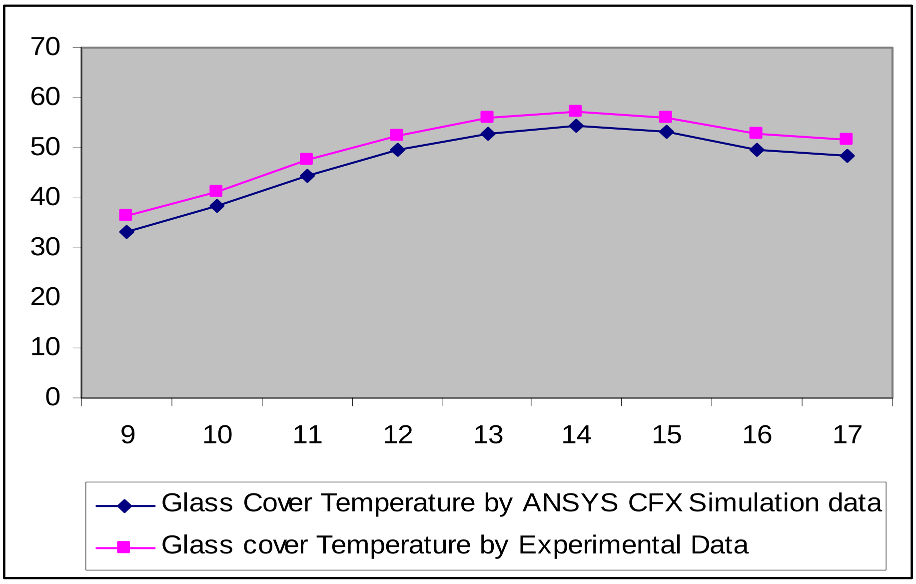

Figure 10. Glass cover Temperature predicted by ANSYS CFX Simulation result and experimental data

In solar still, after evaporation, condensation process starts, and condensation produced by inner glass cover, and difference of temperature of water and glass cover defines performance of solar still. Experiments shows that, higher temperature difference of water and glass cover temperature, higher distillate output and reverse cause the decrease in distillate output from solar still (Figure 10).

Figure 11 shows simulation result of various temperatures measured by probe put in solar still model called temperature contour. In solar still, temperature plays vital role for optimum analysis of solar still, hence temperature variation is very crucial and it is shown by showing colours in model. Figure 12 shows side view of temperature contour.

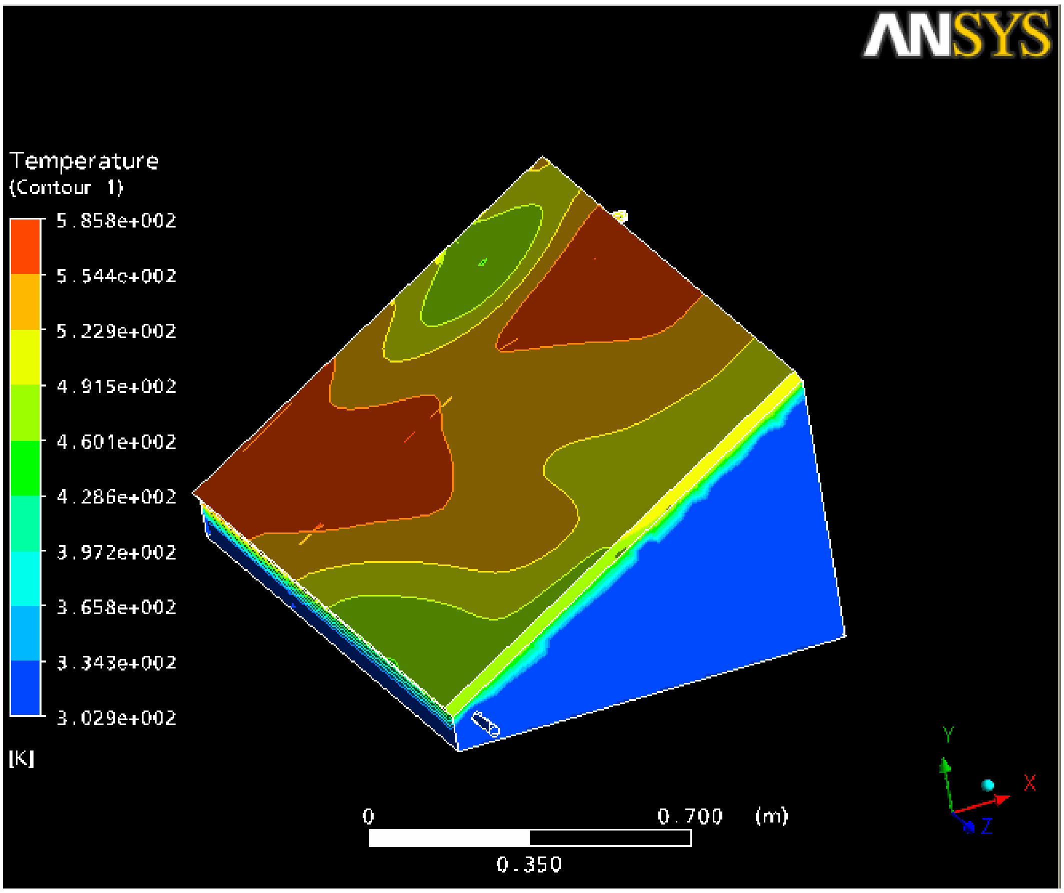

Figure 11. Temperature contour various points in solar still

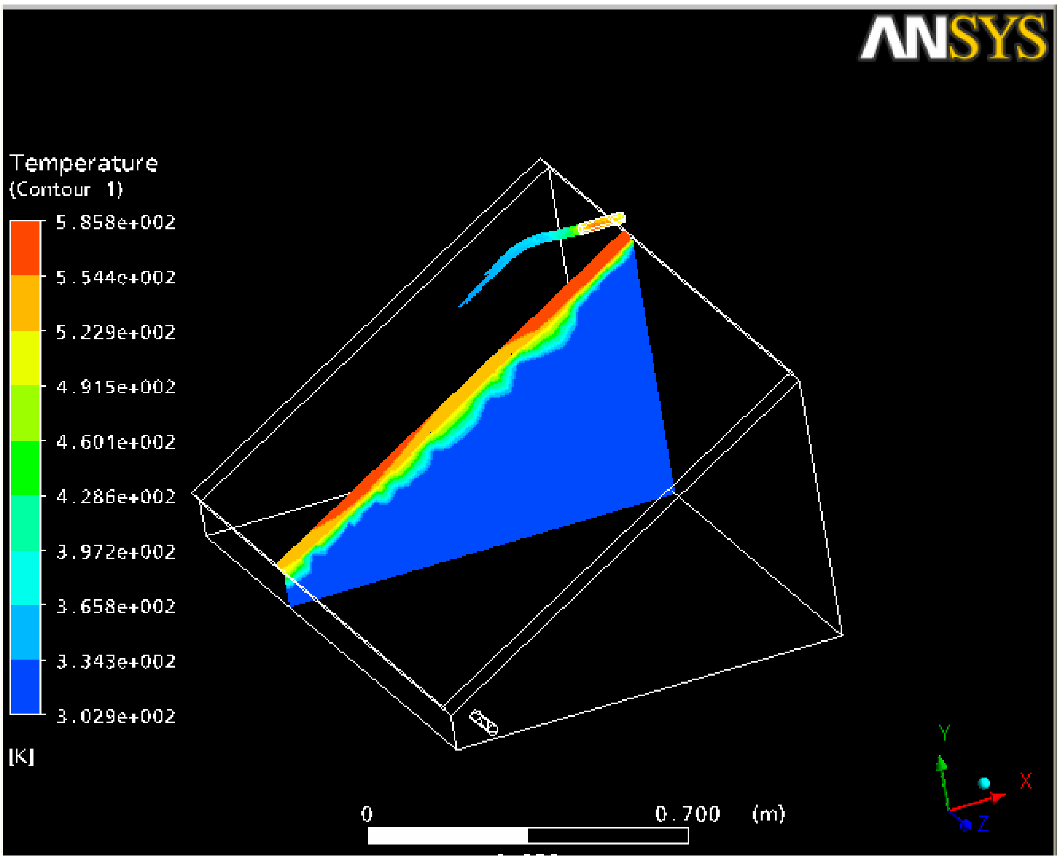

Figure 12. Side view of Temperature contour of solar still

As we know that, heat transfer is only phenomena require for producing distillate output from solar still. It is due to buoyancy force and it is produced by density difference in the gas phase. Density difference also occurs because of temperature difference in the mixture. Therefore gas phase gets a motion in solar still and heat transfer takes place due to natural convection process. Figure 13 and Figure 14 shows the variation of evaporative as well as convective heat transfer coefficient from experimental result and ANSYS CFX simulation results.

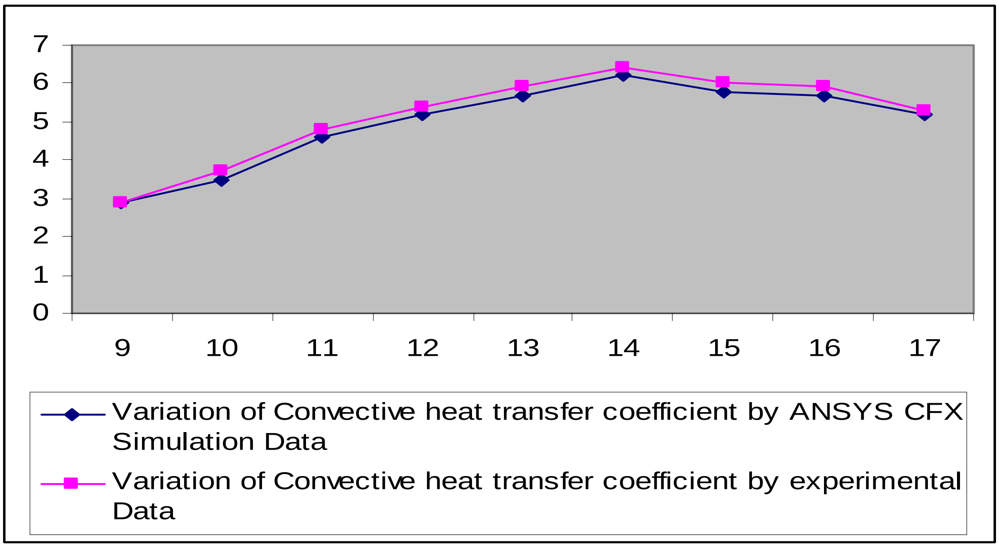

Figure 13. Side view of temperature contour of solar still

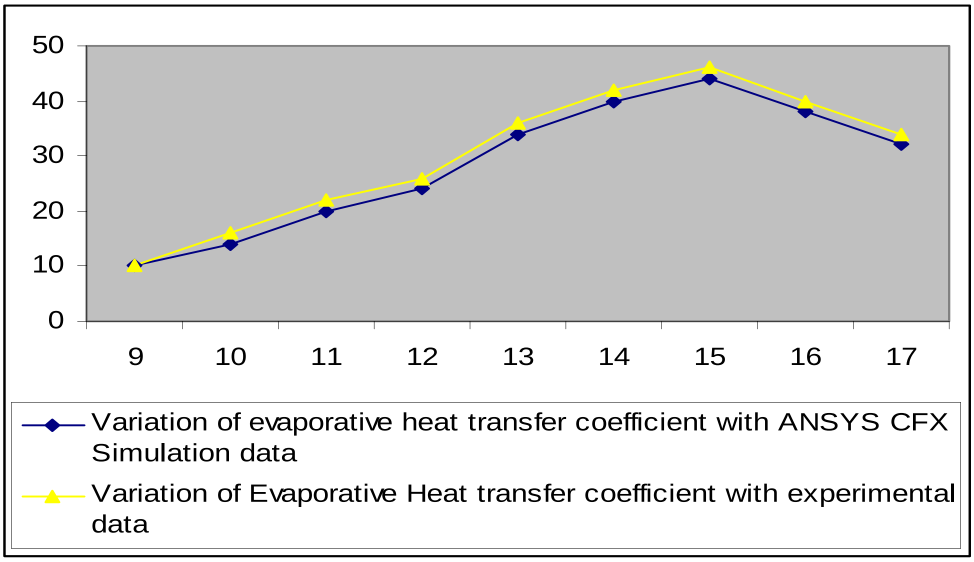

Figure 14. Side view of temperature contour of solar still

6. Conclusion

Here, evaporation and condensation processes are occurring in solar stills were simulated by ANSYS CFX. A two phase, three dimensional model were developed and simulation continue upto 8 hours continuously as 8 steps of 1 hour period. There are good correlations or agreements between simulated results as well as experimental results of Distilled water rate, Water temperature, glass cover temperature, convective heat transfer coefficient and evaporative heat transfer coefficient. Predicted results by ANSYS CFX show that, it is very powerful tool for design, parameter analysis and difficulty removal in solar still construction.

Nomenclature

A_c	Area of cover, m^2
As	Area of basin liner, m^2
Ass	Area of solar still sides, m^2
hcw	Convective heat transfer coefficient from water to cover, W/ m^2 /C
hw	Convective heat transfer coefficient from basin liner to water, W/ m^2 /C
hcb	Convective heat transfer coefficient from bottom insulation to ambient, W/ m^2 /C
hrb	Radiative heat transfer coefficient from bottom insulation to ambient, W/ m^2 /C
hrw	Radiative heat transfer coefficient from water to cover, m^2 /C
hew	Evaporative heat transfer coefficient from water to cover, m^2 /C
*h*1*w*	Total heat transfer coefficient from water to cover, m^2 /C
*h*1*g*	Total heat transfer coefficient from cover to atmosphere, m^2 /C
I(*t*)	Total solar radiation W /m^2
Ki	Thermal conductivity of insulating material, W/m/C
L	Latent heat of vaporization J/kg
Li	Thickness of insulation m
(*MC*)*w*	Heat capacity of water mass in basin, J/m^2 /C
Mew	Distillate output from still L/m^2/day
Pg	Partial pressure at cover temperature N/m2
Pw	Partial pressure at basin water temperature N/m^2
qcw	Convective heat transfer from water to cover W/m^2
qrw	Radiative heat transfer from water to cover W/ m^2
qew	Evaporative heat transfer from water to cover W/ m^2
*q*loss	Overall heat loss from water surface to ambient through top and bottom W/ m^2
qcb	Heat transfer from base to ambient by conduction W/m2
qs	Side heat loss to ambient by conduction W/ m^2
qcg	Convective heat loss from cover to ambient W/ m^2
qrg	Radiative heat loss from cover to ambient W/ m^2
Ta	Ambient temperature C
Tg	Cover temperature C
Tw	Basin water temperature C

Greek

α’g	Solar flux absorbed by cover
α’w	Solar flux absorbed by basin water
α’b	Solar flux absorbed by basin
geff	Effective emissivity, dimensionless
gg	Emissivity of cover, dimensionless
gw	Emissivity of water , dimensionless
σ	Stefan-Boltzmann constant
ηi	Instantaneous efficiency, %

References

[1] G N Tiwari, A K Tiwari, “ Solar distillation practice for water Desalination Systems”, Anamaya publication, pp. 1-10.

[2] Jadav Madhav, “ Performance of black granite basin solar still”, International Journal of Tech Science, Vol.2 (2), 2011, pp. 161-168.

[3] M. shakthiwel, S. Shanmugasundaram, T. Alwarsamy, “ An experimental study on a regenerative solar still with energy storage medium-Jute Cloth”, Desalination 264(2010) pp. 24-31.

[4] Omar Badran, “ Theoretical analysis of solar distillation using Active solar still”, International Journal of thermal & environment engineering, Vol.3 No.2, 2011, pp 113-120.

[5] K. Kalidasa Murugavel, S Sivakumar, J Riaz Ahmed, Kn K S K Chockalingam, K Srithar, “ Single basin double slope solar still with minimum basin depth and energy storing materials”, Applied Energy, 87 (2010) 514-523.

[6] Farshad Farshchi Tabrizi, Ashkan Zolfaghari Sharak, “ Experimental study of integrated basin solar still with sandy heat reservoir,”, Desalination 253 (2010) 195-199.

[7] K. Kalidasa Murugavel, K Shrithar, " Performance study on basin type double slope solar still with different wick materials and minimum mass of water", International Journal of renewable energy, Vol. 36, 2011 pp. 612-620.
[8] Rahul dev, G N Tiwari, " Characteristic equation of the inverted absorber solar still", Desalination 269 (2011) 67-77.
[9] Rahul dev, H N Singh, G N Tiwari, " Characteristic equation of double slope passive solar still", Desalination 267(2011) 261 – 266.
[10] Abdul Jabbar N Khalifa, " On the effect of cover tilt angle of the simple solar still on its productivity in different seasons and latitudes", Energy conversion and management, 52 (2011) 431-436.
[11] Salah Abdallah, Mazen M. Abu-Khader, Omar Badran, " Effect of various absorbing materials on the thermal performance of solar stills", Desalination 242 (2009) 128-137.

Hitesh N Panchal, received Bachelor and Master from Govt. Engg. College, Modasa and L D College of Engineering, Gujarat in 2004 and 2006 respectively. His Ph.D. is pursuing in Solar Thermal Engineering from KSV University, Gandhinagar, Gujarat under guidance of Dr. P. K. Shah. He is an Assistant Professor in the Department of Mechanical Engineering, L C Institute of Technology, Mehsana He has Presented 14 Research Papers in International Conferences and 22 Research Papers in National Conferences. He has Published 13 Research Papers in Reputed International Journals having a good impact factor. He is also a reviewer of 7 International Journals having high repute. His areas of interests are Internal Combustion Engine, Automobile Engineering, and Solar Thermal Engineering Etc. He is a member of ISTE, ISME, SOPTER, SESI etc.
E-mail address: engineerhitesh2000@gmail.com

P. K. Shah did his Graduation and Post-Graduation in Mechanical Engineering from Gujarat University. He obtained his Ph. D. in Solar Heat Transfer from North Gujarat Uni. He has teaching experience of 39 years in various Engineering Colleges in Gujarat. He is a popular teacher among the students. He has written number of technical research papers and has presented them in National and International Conferences. He has published 20 Research Papers in reputed International and National Journals. He has written many scientific and general articles in various magazines. He also has written a text book on Thermodynamics for Engineering students. The subjects of his interest are Heat and mass Transfer and Energy Sources. Presently, he is working as Principal in Silver Oak College of Engineering and Technology, Ahmedabad.
E-mail address: pravinkshah@gmail.com