iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** XI **Month of publication:** November 2020

DOI: https://doi.org/10.22214/ijraset.2020.32050

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue XI Nov 2020- Available at www.ijraset.com

Numerical Simulation of Single and Double Slope Solar Still for Different Performance Affecting Variables

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Abstract: Two-phase, three dimensional, a single slope and double slope single basin still were simulated using ANSYS FLUENT v19.2. Simulations were made done for evaporation and condensation process at Delhi's climate conditions (27.0238° N, 74.2179° E). Temperature inside the single slope solar still is maximum between 12:00 to 13:00 hrs while the double slope still has a low temperature at the same time, compared to the single still. The maximum and minimum temperature of the water-vapor mixture inside the single slope still were calculated 54.9445°C and 19.4401 °C, whereas, in double slope, the maximum and minimum temperature of the water-vapor mixture inside the still was 52.21 °C and 12.6988°C. The maximum water production rate in single slope solar still is 0.60729 kg/m^{2}hr, while the maximum water production rate in the double slope is 0.54371 kg/m^{2}hr. Condensation depends on the temperature difference between the glass surface and outer environment, more condensation is noticed in the single slope solar still. Inner water temperature is responsible for more evaporation and higher temperature, i.e., more than 4°C approximately is observed in single slope solar still as compared to the double slope.
Keywords: Solar Still; Computational Fluid Dynamics; Water temperature; Solar heat flux; Water Productivity

I. INTRODUCTION

Freshwater is a basic need for the survival of humans beings and other organisms. But, there is a limited supply of fresh water on the surface of the earth. Earth contains 71% water on it and only 2.5% of water is available as potable water, that too as ice and groundwater, leaving possibly 1.04% of freshwater available for human consumption [1]. Also, 7.6 billion of the world population depends upon this mere percentage of water to drink, cook, irrigate crops, and feed livestock. The issue is that the percentage of freshwater reduces day by day due to pollution and indiscriminate uses. Due to inadequate availability of water, the health issues are prevailing among humans and other living beings. Globally, at least two billion people use a drinking water source contaminated with feces. Contaminated water can transmit diseases such as diarrhea, cholera, dysentery, typhoid, and polio. Consumption of this contaminated water is estimated to cause 485000 diarrhoeal deaths each year [2].

There are so many technologies involved in the treatment of contaminated water using different methods by using membrane process (reverse osmosis and non-filtration) and thermal process (multi-stage flash distillation, multi-effect distillation, and electro-dialysis). But solar desalination is the best method for removing impurities from water to provide potable water. It is an eco-friendly, low-cost method and also provides drinkable water in remote areas. Solar distillation uses the evaporation and condensation process in which solar radiation incidents on the glass surface and then transmits and absorbed by an absorber surface, increasing the basin's temperature and converting water into vapor.

Many research works are being carried out to enhance the different parameters of a single and double solar still with experiments and simulation on different software. There is much software for modeling as MATLAB, ANSYS, COMSOL, FORTRAN, TRNSYS, CATIA, etc. The experimental work consumes more time for setup and experimentation, but simulation takes less time to give results. Setoodeh et al. [3] developed a three-dimensional, two-phase model for the evaporation and condensation process using a computational fluid dynamics simulation tool to simulate single slope solar still for calculating water temperature and production and also analyzed heat transfer coefficient. The simulation work was done using ANSYS 11. As a result, it was predicted that computational fluid dynamics is a powerful tool for design, parameter analysis, and removing difficulties in solar still construction. Singh et al. [4] studied experiment and simulation work to enhance productivity with varying depth of water and checked for its thermal efficiency. The modeling was done using ANSYS v14.0 for the climate condition of Jaipur. Solar still has more productivity at low water depth. Panchal et al. [5] worked on the experimental and computational fluid dynamics model of the single-slope solar still. The Geometry was created using ANSYS Workbench 10 and unstructured tetrahedron mesh was used to predict the results. The simulation results of distillate output, water temperature, and heat transfer coefficients are predicted using ANSYS CFX 10.

Maheshwari et al. [6] researched a single basin double slope solar still using ANSYS CFX 14.0 to check the overall production. The overall production is maximum in March and November. Gokilavani et al. [7] did experimental and modeling work of single slope solar still. The geometry of the model was created using ANSYS Workbench 14.5 and then simulated in ANSYS CFX. The experimental work was compared with the simulated study and verified the water temperature distribution over the glass surface for 27/Nov/2013 and 28/Nov/2013.

The result shows the maximum temperature achieved inside the glass on 27/Nov/2013 is higher as compared to 28/Nov/2013. Mahendren et al. [8] did a simulation work for double slope solar still to enhance its efficiency for getting better productivity. The mathematical model and coding were done by using the MATLAB program to calculate the various heat fluxes in the still, determine the hourly output of the still, and find the still's efficiency. Complete numerical analysis was done and various characteristics graphs were plotted in MATLAB. Simulink toolbox was used to show simulation. ASCII text files, which are M-files, were used to calculate convective, evaporative, and radiative heat transfer rates. Nayak et al [9] did thermal modeling and experiment on double slope solar still.

Modified double slope solar still was designed by applying a transparent acrylic sheet and the north wall of the solar still was imposed by an opaque fiber-reinforced plastic. The geometry of the model was created with the help of CATIA V5R18 software. The simulation result and experimental result was almost closer to each other.

The experiment was conducted for Allahabad (25.23°N, 79.09° E) to check the productivity of solar still. The result shows the modified double slope solar still has 16 kg of purified water from 25 kg of brackish water, which was formed twice than conventional solar still.

Tripathi and Tiwari [10] developed a simulation model for thermal analysis of single-slope solar still by taking a parameter of the solar fraction. The geometry of the model was created in AUTOCAD 2000. The simulation work was done for weather conditions of New Delhi (27.0238° N, 74.2179° E). A MATLAB program was used to calculate convective and evaporative heat transfer coefficients and also estimated solar fraction. The following formula for the solar fraction (Fn) for a particular wall still was used in modeling.

$$F_n = \frac{solar\ radiation\ on\ the\ wall\ of\ the\ still\ for\ a\ given\ time}{solar\ radiation\ on\ the\ wall\ and\ the\ floor\ of\ the\ still\ for\ the\ same\ time}$$

Chaibi [11] presented a simulation model of double slope solar still integrated with a greenhouse roof to check the influence of solar irradiation, optical material properties, and process parameters on freshwater. A numerical simulation was performed for the climate condition of Tunisia.

For the calculation of solar irradiation, simulation code TRNSYS (Transient System Simulation) was used, which helps in hourly calculations of radiation values for an inclined glass surface. And for solving heat transfer equations, An engineering equation solver (EES) was used in the model.

The effect of solar radiation and visual material properties are considered in the system. Solar radiation proportionally affects the efficiency of the rooftop- incorporated framework. The thermal and optical performance could be improved by maximization of the solar energy yield. Ali Saeed et al. [12] performed a numerical investigation using Nano-Phase Change Material (NPCM) to optimize the performance of Single Slope Solar still. Nanoparticles (Al_2O_3) spread in paraffin Wax (PCM) beneath the basin of solar still. The numerical solution was done using COMSOL 5.3 software. Results were compared with previous outcomes and showed significant agreement.

The addition of 1 kg of PCM constitutes the optimum amount of improvement. Thus, using 3 Vol.% concentration of Al_2O_3 Nano-Particles dispersed in 1 kg of Paraffin Wax(PCM) gives the perspective of improvement in the traditional single slope solar still productivity by about 20% daily. Ileri et al. [13] performed an experimental work for solar stills to analyze the glass cover thickness's effect on the productivity yield. In these solar stills, three glasses are of 3mm, 5mm, and 6 mm thickness while the fourth cover was made up of plastic.

Thermal modeling was developed for solar still and for getting the solution of the thermal equations, a programming software FORTRAN-77 was used. A numerical simulation was performed for Ankara's climate condition (40°N,33° E). The simulation results were compared with the experimental data.

The Newton-Raphson method was used for solving the mathematical model to find the roots of radiative heat transfer coefficients for glass and water temperature. Efficiency for 3 mm thickness glass was found to be 26.22 % more, as compared to 5mm and 6 mm. Hamadou et al. [14] worked on single slope solar still having a copper heating plate above heat transfer fluid to enhance the thermal effect. A MATLAB program was developed based on the command ode 15s to solve nonlinear differential explicit equations in matrix form.

This work was enabled to optimize the inlet temperature, wind speed, heat transfer fluid, seawater rate, basin depth, and relative humidity but this technique was used only for the rate and yield of distilled water. The simulation results showed that wind speed has a major effect on distilled water production than relative humidity.

Kumar and Kumar [15] did simulation works to check the temperature difference in single and double slope solar still for the climate condition of New Delhi.

The geometry of both stills was created in ANSYS workbench and then simulated using ANSYS V19.0. As a result, it was observed single slope solar still has a higher temperature compared to double slope solar still. Zerrouki et al. [16] did a numerical simulation of capillary film solar still coupled with conventional solar still to obtain daily distillate production for Algeria's climate condition.

Mathematical modeling was done by using FORTRAN-90 to solve the non-linear equation of both systems using Ranga-Kutta-Fehlberg integration method.

As a result, capillary film solar still coupled with conventional solar still has more distillate yield than simple conventional solar still. Maalem et al. [17] used COMSOL multiphysics to simulate trapezoidal single slope solar still to check the temperature, velocity, and concentration field. Energy balance equations were solved by using the finite element method. The result shows that simulation work has good agreement with experimental work.

Thakur et al. [18] performed modeling work using computational fluid dynamics tools and experimental work for single slope solar still to check production at different depths. The geometry was created and then imported for meshing in ANSYS meshing with a minimum grid size of 4 mm and 10 mm to achieve better results. The meshing geometry has several nodes 632088 and the total number of elements 553048. The computational work was done for optimizing the different water depths of solar still i.e., 0.01, 0.02, and 0.03 m meshing type of hex-dominant was used. Result obtained through computational fluid dynamics work has a good agreement with the experimental data. The optimum depth for good productivity was 0.01m. Bhaisare et al. [19] developed a computational fluid dynamics model of double slope single basin solar still for the Gorewada water purification plant, Nagpur. The geometry was created in ANSYS workbench and then imported to ANSYS meshing.

The simulation result was obtained by using ANSYS 16.0v. Maximum heat flux decreased concerning time, i.e., from 9.1054e+005 to 2.0565e+005 in 1 sec and predicted maximum temperature remains constant and minimum temperature varies with time. Badusha and Arjunan [20] developed a two-phase three-dimensional model with the help of ANSYS. Still was made for evaporation and condensing process in solar still by using computational fluid dynamics techniques. There was good agreement between the simulation result and the experimental result with certain errors. The result predicted by ANSYS CFX shows that it is a potent tool for design, parameter analysis, and difficulty removal in solar still construction. Aybar and Assefi [21] performed an investigation for single-slope solar still to determine the effects of water depth in the basin and angle of inclination of the glass cover over the basin. The solar still is modeled mathematically using the 4^{th} order Runge Kutta (RK) method in FORTRAN. Optimum depth is found to be the least depth of water and the best inclination angle is the Latitude of the place of installation of the setup. The productivity of the system under local climatic conditions was found at 5.3 kg/m^2day. The written code results are compared with the experimental outcomes and the relative error is well within the permissible limits of 3.37%. The literature review shows no research work available to compare the water temperature, pressure, solar heat flux, and productivity of freshwater of single and double slope solar still and no further work available for New Delhi. Researchers have less attention doing simulation in ANSYS Fluent. This present study aims to create a three-dimensional computational fluid dynamics model of single slope and double slope to check the evaporation and condensation processes within solar stills at Delhi's climate conditions (27.0238° N, 74.2179° E). Both models were developed using ANSYS Workbench and simulation works were done with ANSYS FLUENT v19.2. All variables inside both solar still were estimated and examined at each stage. The results were compared with each other to check the differences. Water production of the single and double slope of both systems was also examined for the entire day of June 21, 2020.

II. METHODOLOGY

Two different two-phase 3D models were designed in the volume of fluid of the multiphase phase model. Both stills were also developed using evaporation and condensation processes at transient conditions, which means only surface evaporation of liquid occurred and their interface was considered for modeling. The performance of solar stills based on productivity as well as internal heat and mass transfer coefficient were studied. The internal heat and mass transfer coefficient in solar still based on convection, radiation, and evaporation. Hence, the convective heat transfer coefficient, radiative heat transfer coefficient, and evaporative heat transfer coefficient are for the heat transfer. An RNG k-ε turbulence model was applied with standard wall functions for both phases. The time and volume- average continuity, energy, and mass transfer equations were numerically solved in this work for each phase.

A. Governing Equations

Under steady-state conditions, model equations are dependent on continuity, momentum, energy, and mass transfer conservation concepts.

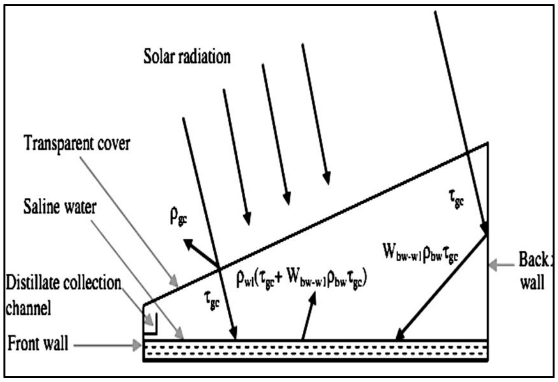

Fig 1. The single slope solar basin [4]

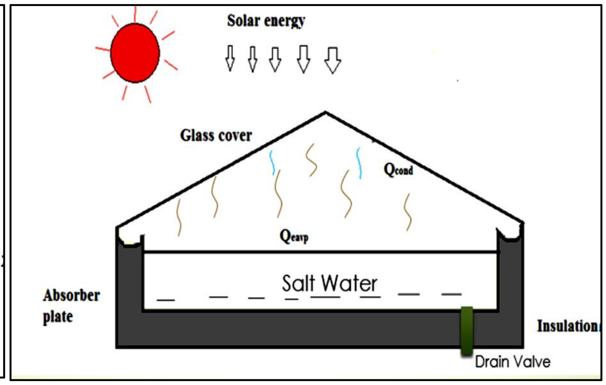

Fig 2. Double slope solar basin [6]

1) Energy Equations

The following assumption of energy balance equations have been made to write energy equation [4,5]:

1. There is no temperature gradient across the basin water and glass cover of solar still.
2. There is no leakage in solar still.
3. The water level is kept constant inside the basin.
4. The heat capacity of the glass surface and absorber, insulated material is neglected.

The energy equation of the mixture is given as:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(a_k\rho_k E_k) + \nabla\cdot\sum_{k=1}^{n}\{a_k\bar{v}_k(\rho_k E_k + p)\} = \nabla\cdot\left(k_{eff}\nabla T\right) + S_E \quad (1)$$

where k_{eff} is the effective conductivity $(a_k(k_k + k_t)$,

$a_k =$ the absorptivity

2) Continuity Equation

The continuity equation of the mixture is [4].

$$\frac{\partial}{dt}(\rho_m) + \nabla.(\rho_m\overline{v_m}) = 0 \quad (2)$$

where $\overline{v_m} = \frac{\sum_{k=1}^{n} a_k\rho_k\overline{v_k}}{\rho_m}$

$\overline{v_m}$ = the mass averaged velocity

ρ_m = Density of mixture

3) Momentum Equation

The momentum equation of all phases is achieved by combining each momentum equation [4]:

$$\frac{d}{dt}(\rho_m\bar{v}_m) + \nabla(\rho_m\bar{v}_m\bar{v}_m) = -\nabla p + \nabla[\mu_m(\nabla\bar{v}_m + \nabla v_m^T)] + \rho_m\bar{g} + \bar{F} + \nabla(\sum_{k=1}^{n} a_k\,\rho_k\bar{v}_{dr,k}\cdot\bar{v}_{dr,k})$$
(3)

ρ_m = Density of mixture

$\bar{F}$ = The gravitational body force and external body forces

μ_m= molecular viscosity of the mixture

4) Volume Conservation Equation

It is a constraint that shows the unity of volume fractions by adding [4].

$$r_G + r_L = 1 \quad (4)$$

r_G = volume fraction of gas.

r_L = volume fraction of liquid.

5) Mass Transfer Equation

The enthalpy sources in a system for different phases are [4].

$H_p = -m_p i_q j(h_p^i)$ (5)

$Hq = m_{p^i q} j\left(h_p^i + h_p^{f^i} - h_q^{f^j}\right)$ (6)

$h_p^{f^i}$ = formation enthalpy of species i of phase p.

$h_q^{f^j}$ = formation enthalpy of species i of phase q.

h_p^i = enthalpy of species i of phase p.

H_p = total enthalpy of phase p

Hq = total enthalpy of phase q.

6) Pressure Constraint

The gas phase and liquid phase share the same pressure field [3]

$P_G = P_L = P$ (7)

Pg = Partial saturated vapor pressure at the gas temperature

7) Heat Transfer Equation

The two-resistance model was expressed for interphase heat transfer has been used. The heat transfer coefficient across the interface and the gas phase was modeled using the zero-equation model and the liquid phase has been expressed by [3]:

$h_{total} = h_{r\omega} + h_{cw} + h_{e\omega}$ (8)

$h_{Cw} = 0.8840(Tw - Tg + \frac{(P_\omega - p_g)(T_W + 273)}{268 \cdot 9 \times 10^3 - P_W})^{1/3}$

where, $P_w = exp\left(25.317 - \frac{5144}{T_W + 273}\right)$

where $Pg = \exp\left(25317 - \frac{5144}{Tg + 273}\right)$

$h_{e\omega} = 16.273 \times 10^{-3} h_{Cw} \cdot \frac{P_\omega - P_g}{T_W - T_g}$ (9)

And,

$h_{rw} = \varepsilon_{eff} \sigma[(TW + 273)^2 + (Tg + 273)^2 (Tw + Tg + 546)]$

where, $\varepsilon_{eff} = \frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_\omega} - 1$

8) Water Production

Defined contact mass flux was used for mass transfer models. Some assumption of water production was used by Eq. (3). The rate of freshwater production is equivalent to the rate of vaporization of the water. So, the rate of vaporization of the water shows water production. Hence, the mass flux equation between the two different phases are:

$\dot{m}_{ew} = \frac{\dot{q}_{ew} \cdot A_W \cdot t}{h_{fg}}$ (10)

where,

$$h_{fg} = 2 \cdot 4935 \times 10^6 [1 - 9.4779 \times 10^{-4} T + 1.3132 \times 10^{-7} T^2 - 4.7974 \times 10^{-9} T^3]$$

$\dot{q}_{ew} = h_{ew}(T_w - T_g)$

$\dot{m}_{ew}$ = distillate output

9) Solar Irradiance

$$\delta = 23 \cdot 45 \sin(360 * (n + 284) / 365)$$

$$\omega = (solar\ time - 12{:}00) \times 15$$

where,

$$Solar\ time = Standard\ time \pm 4(L_{st} - L_{L_0 ca}) + E$$

$Ig = I_b + I_d$ (11)

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where, $I_b = I_{bn} \cos\theta_z$ and, $Ig = I_{bn} \cos\theta_z + I_d$
δ = sun declination angle
n = day of the year, starting from 1st January
ω = Hour angle, degree.
Ig = Hourly global irradiance
I_b = Hourly diffuse radiation
I_d = Hourly diffuse radiation
I_{bn} = Beam radiation on the surface normal to the direction of the sun rays.

B. *Computational Fluid Dynamics Model of Modeling*

Computational Fluid Dynamics (Computational Fluid Dynamics) is a valuable tool that has been used to analyze and investigate the fluid flow pattern of moisturized air and temperature variation near the walls. For visualizing the flow filed, any location computational fluid dynamics can prepare the design, get the controlling step, and guide. In the study, computational fluid dynamics is utilized to create geometry, and the simulation result is obtained by using ANSYS 19.2v.

1) *Geometry Creation:* ANSYS is a beneficial engineering simulation software that is mostly used to solve engineering problems and make them more optimized. Figure 3 and Figure 4 show the 3D geometry of single slope and double slope solar still, which were modeled using Ansys Design modeler in Ansys 19.2.

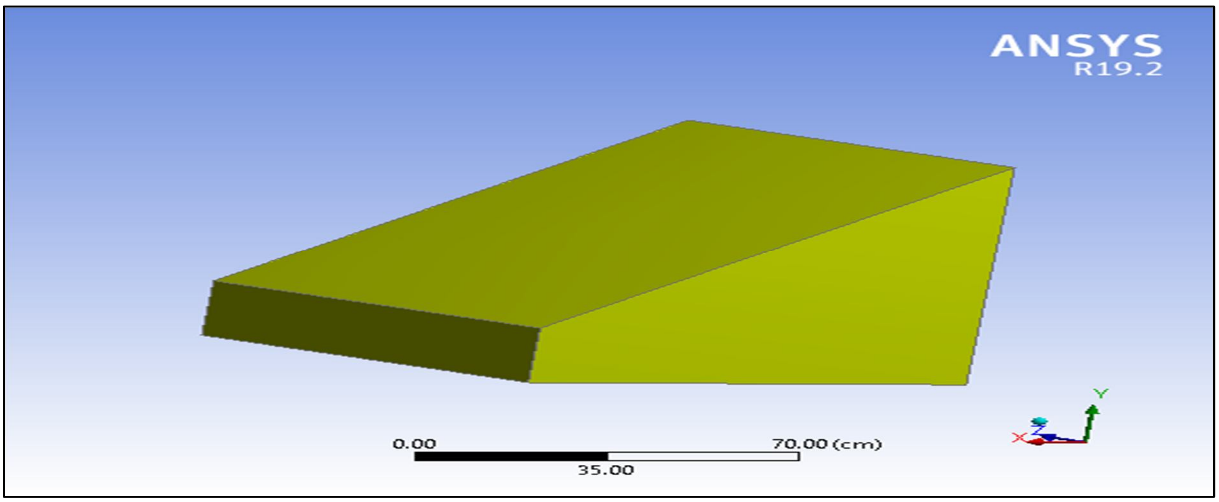

Fig. 3. Single Slope Single Solar Still.

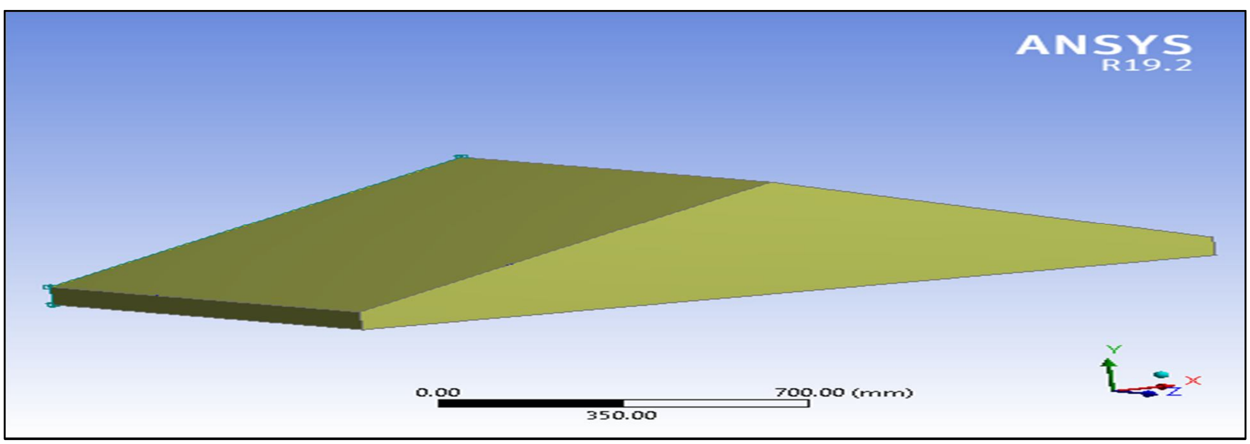

Fig. 4. Double Slope Single Solar Still.

Both stills consist of absorber parts, sidewalls on both sides, front wall, back wall, and collector (single collector in single slope and double collector in double slope) are modeled as per the dimensions.

2) *Meshing:* The physical model of both systems meshed by using ANSYS 19.2 workbench Meshing. The stills' results were checked at the different number of meshing elements as 40560, 54500, and 62430 for a single slope and 45320, 586200, and 64130 for a double slope. But, the results are predicted much closer at 54500 elements of single while 586200 elements. Figure 5 shows an unstructured mesh of single slope solar still, consisting of 545000 elements and 566610 nodes at a growth rate of 1.2 and element size 10mm using 3D hexahedral meshing.

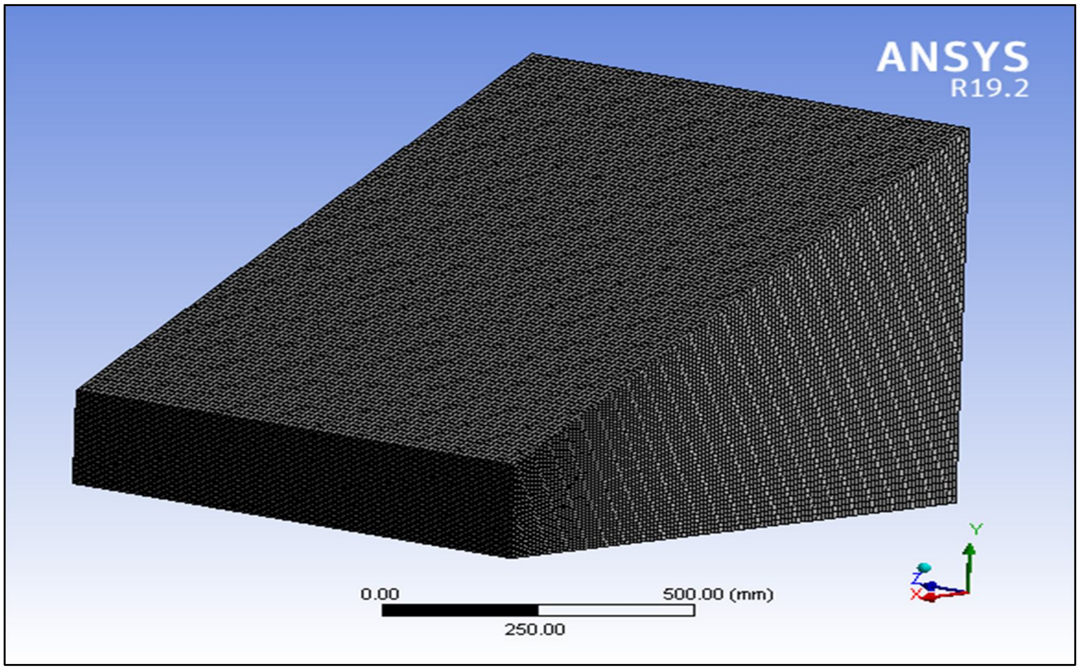

Fig. 5. The unstructured mesh of single slope.

Figure 6 shows an unstructured mesh of slope solar still, consisting of 586200 elements and 612464 nodes at a growth rate of 1.2 and element size 10 mm using 3D hexahedral meshing.

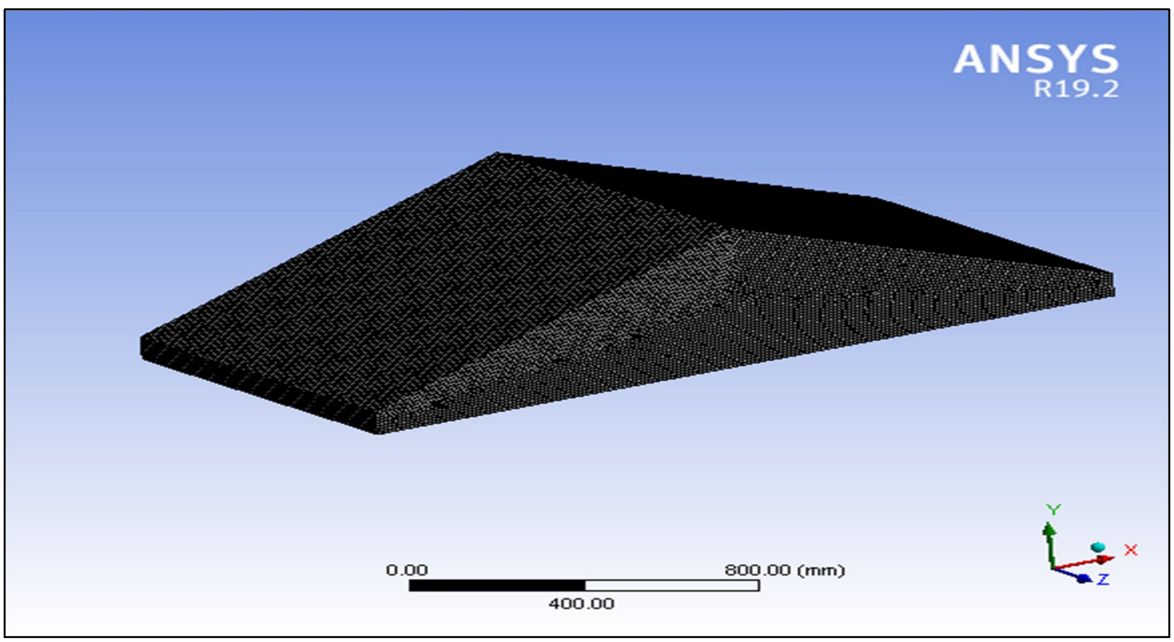

Fig. 6. The unstructured mesh of double slope still.

3) *Boundary and Initial Conditions:* Meshing files of both solar stills are imported to ANSYS FLUENT. A two-phase model of both solar still was developed in the volume of fluid (VOF) framework for liquid (water) and a mixture of air and water vapor system at the transient condition with gravitational acceleration. Solar insolation incident on solar stills is the important factor inside stills, based on the absorptivity and transmissivity of the glass cover. First, it is incident upon glass cover and then absorbed by an absorber, which increases the water temperature. In the fluent, physics and boundary conditions are specified to solve the continuity equation, momentum equation, and energy equation at all the boundaries. The RNG k-ε viscous model was used, which predicts the spreading rate of flow and better water production performance. In the model, the near-wall condition was treated using 'standard wall function". Adhesion forces are taken for producing droplets inside the solar stills. No-slip wall boundary conditions were specified for both gas phase and liquid phase. Initial water level at the initiation of the stills' first stage was 2 cm, so water and air volume fraction were considered as 0.13 and 0.87. Computational fluid dynamics simulation had run time of 5 hours for single slope solar still and 6.30 hours for double slope solar still.

Table 1: Boundary conditions for the simulation process of single slope and double slope

Domain	Domain type	Location	Boundary type	Boundary details
Solid	Cell	Absorber plate	Wall	Stationary wall with heat flux
		Glass cover	Wall	Fixed wall Temperature
		Sidewalls	Wall	Adiabatic
		Front and back wall	Wall	Adiabatic

III. RESULT AND DISCUSSION

In this study, simulation results were calculated at fair weather conditions, and each stage of both stills using ANSYS FLUENT v19.2. In Simulation results, the temperature distribution, velocity, water volume fraction, solar heat flux, and water production of both solar stills are examined and predicted the temperature and water production of both stills for the entire day.

A. Simulation Results

ANSYS FLUENT v19.2 was used to carry out the results using 3 GHz CPU processors as parallel run with double precision. Fluent uses a second-order upwind solution method to transform the governing equations into a numerically solvable algebraic equation.

1) *Temperature Distribution:* Computational fluid dynamics predict both solar stills' water temperature and are compared with each other at every stage. In the volume rendering of Figures 7 and 8, the blue color shows the minimum temperature while the red color shows the maximum value of temperature. The maximum and minimum temperature predicted inside single slope solar still, are 327.9445 K and 292.4511 K, whereas in double slope solar stills maximum temperature is 323.6474 K and the minimum temperature is 294.0343K. There is an approximately 8.36% error in their maximum temperatures and an 8.139% error in minimum temperatures.

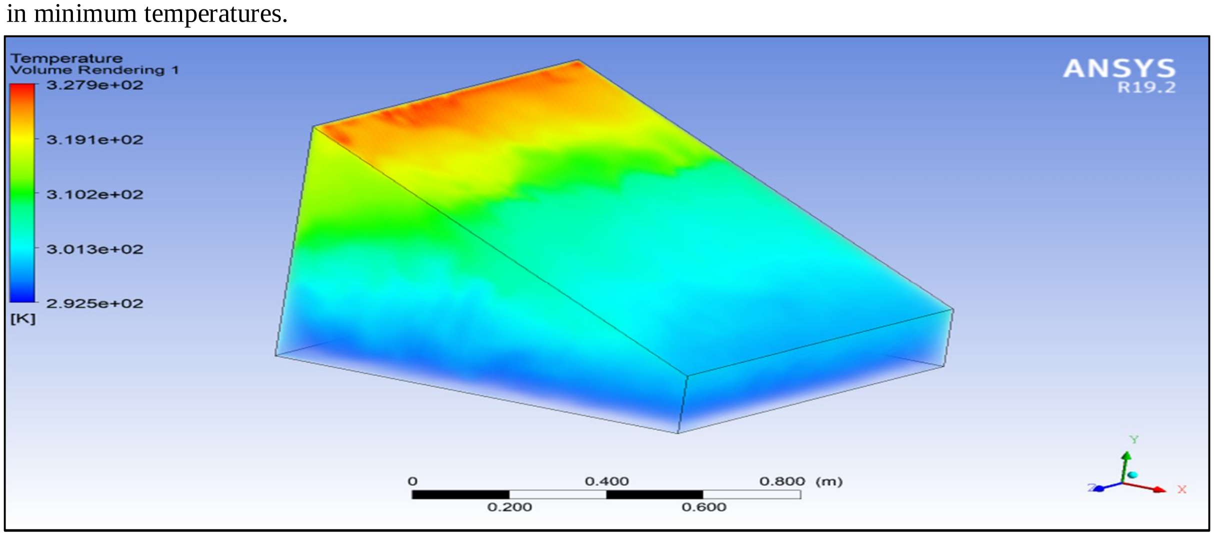

Fig. 7. Temperature Distribution inside Single slope

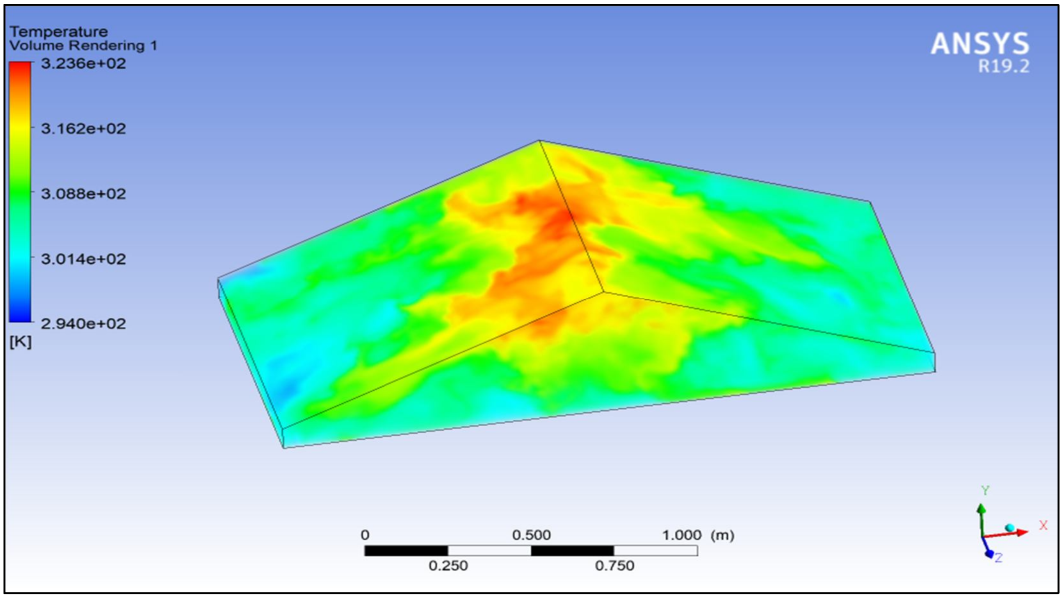

Fig. 8. Temperature Distribution inside double slope still

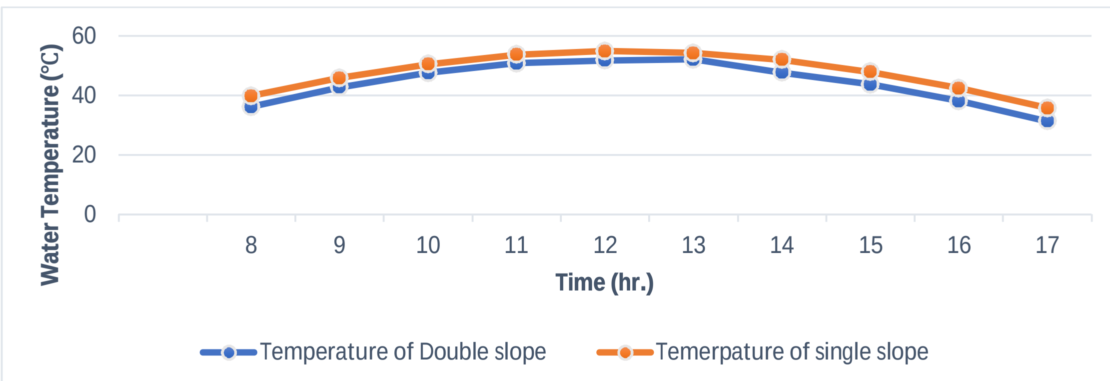

Fig. 9. The water temperature of both single and double slope solar still

The temperature of both solar stills is predicted from 08:00 to 17:00 hr. Figure 9 shows the temperatures of both solar stills at different hours. The average water temperature error from 08:00 to 17:00 hr was predicted at 7.932%, respectively. The maximum temperature was attained at double slope solar still at 12:00 noon while in single slope solar still at 13:00 hr.

Table 2: Simulation results for hourly variation of water and glass temperature, Solar intensity, and yield of single slope solar still

Time (hr)	Water Temperature (°C)	Glass Temperature (°C)	Solar Intensity (W/m^2)	m_{ew} (kg/m^2.hr)
08:00	39.9545	38.281	421.27	0.265
09:00	45.9567	43.8938	585.559	0.184
10:00	50.5961	48.9845	720.719	0.1595
11:00	53.7344	52.7698	798.367	0.16782
12:00	54.9445	53.562	845.284	0.315
13:00	54.2991	52.879	828.131	0.41762
14:00	52.0504	50.763	770.578	0.60729
15:00	47.988	46.8934	671.823	0.5812
16:00	42.4538	40.342	503.072	0.45152
17:00	35.7752	31.5839	325.553	0.364826

Table 3: Simulation results for hourly variation of water and glass temperature, Solar intensity, and yield of Double slope solar still.

Time (hr)	Water Temperature (°C)	Glass Temperature (°C)	Solar Intensity (W/m^2)	m_{ew} (kg/m^2.hr)
08:00	36.2	33.561	408.742	0.20769
09:00	42.7615	41.6523	525.954	0.1527
10:00	47.6474	46.0343	680.782	0.13972
11:00	50.8486	48.0921	735.548	0.14873
12:00	51.8289	49.6988	810.132	0.2856
13:00	52.21	51.0652	790.095	0.39812
14:00	47.7914	45.0947	710.885	0.54371
15:00	43.7765	41.9073	598.516	0.50238
16:00	38.22	36.930	430.827	0.42621
17:00	31.3583	26.9563	289.362	0.3048201

2) *Water Volume Fraction:* As the water temperature increases, the inside area of both the stills starts warming up and water start changing into vapors. Figure 9 shows the condensed water droplets on the glass of a single slope, while Fig. 10 shows a side view of single slope solar still. The presence of water can be only seen on glass and near the base of still in both solar stills. The maximum and minimum volume fraction of water was obtained 0.0183968 and 1.8773×10^{-6}.

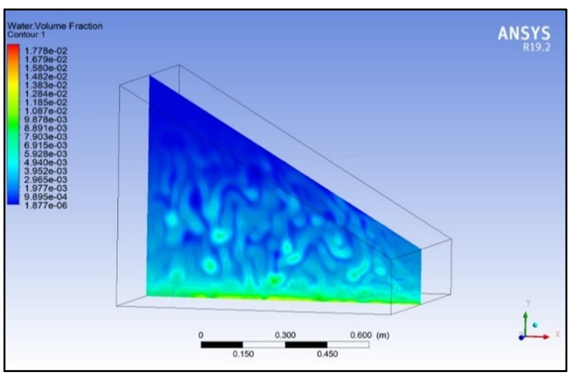

Fig. 10. Water volume Fraction contour inside single slope

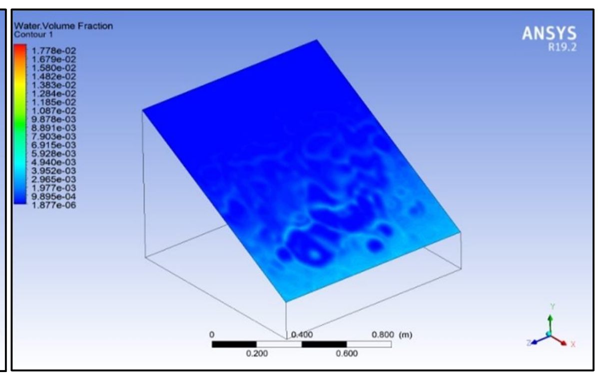

Fig. 10. Water volume Fraction contour on the glass of single slope solar still

The blue color shows less amount of the volume fraction of water, while the red color shows more water volume. The volume fraction of droplets is increasing downward on the glass. The maximum water volume fraction on the glass is observed 0.0309681 and a minimum of 3.22 × 10^{-5}. It is predicted that the water volume fraction of glass of double slope is higher compared to glass of single slope.

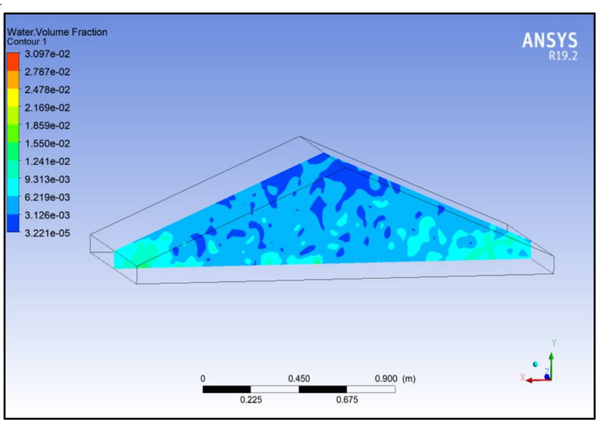

Fig. 11. Water volume Fraction contour inside double slope

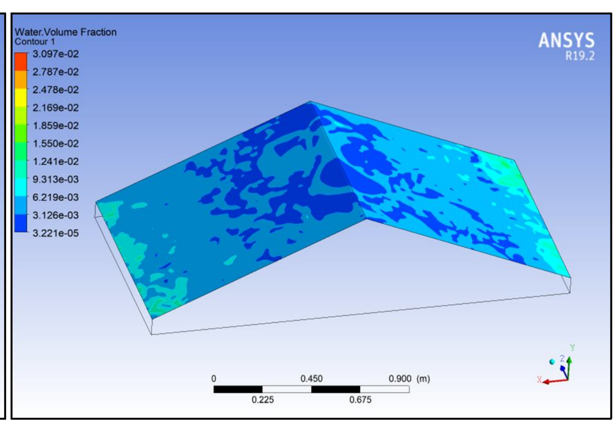

Fig. 12. Water volume Fraction contour on the glass of single slope solar still

3) *Velocity Vector:* The vapor phase velocity vector of single slope solar still on a plane is shown in Figures 13 and 14. First, the water changed into vapors and started to move upward due to the buoyancy effect. The vapor phase follows a circular path from the bottom to the glass surface. Vapor condensate on the glass and changes into water droplets, which move downward on the glass surface. This process takes place in both solar stills, which shows the heat transfer mechanism. There is a difference in vapor velocity in both solar stills, which more near the bottom in single slope solar still while in double slope solar still. The maximum velocity of vapor in the single slope was observed 2.192 m/sec, while in double slope solar still, it is only 0.70289 m/sec—this difference of vapor velocity influences on water production.

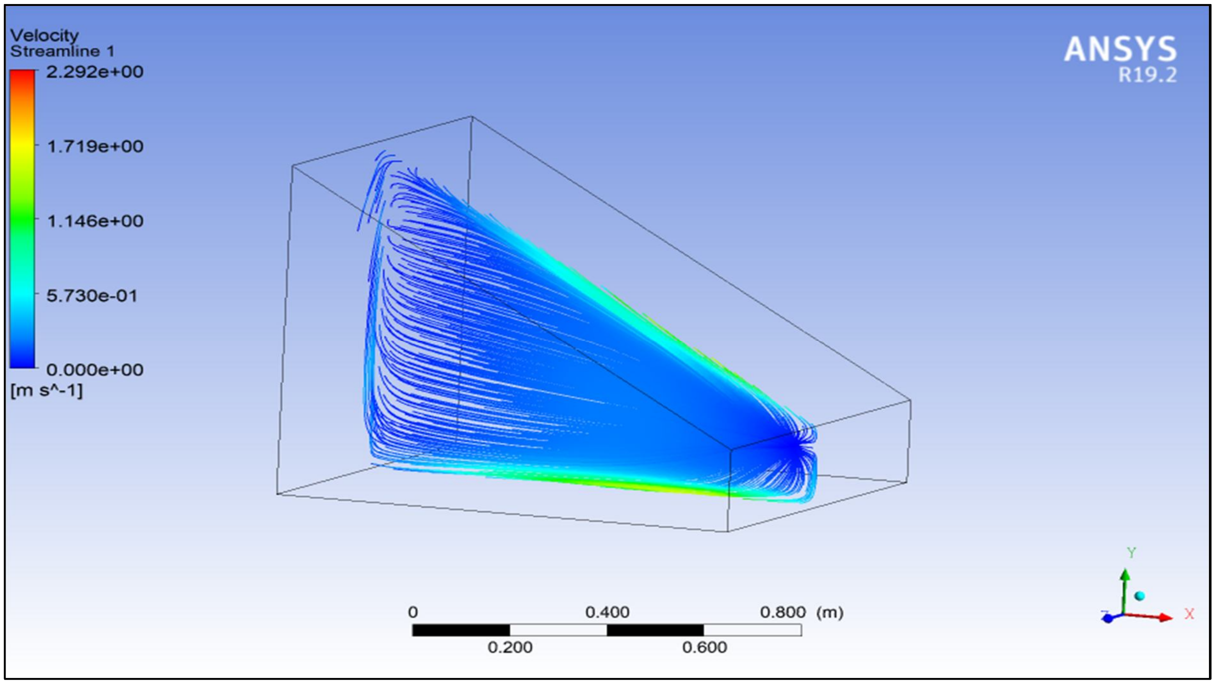

Fig. 13. Vapor phase velocity vector of single slope solar still

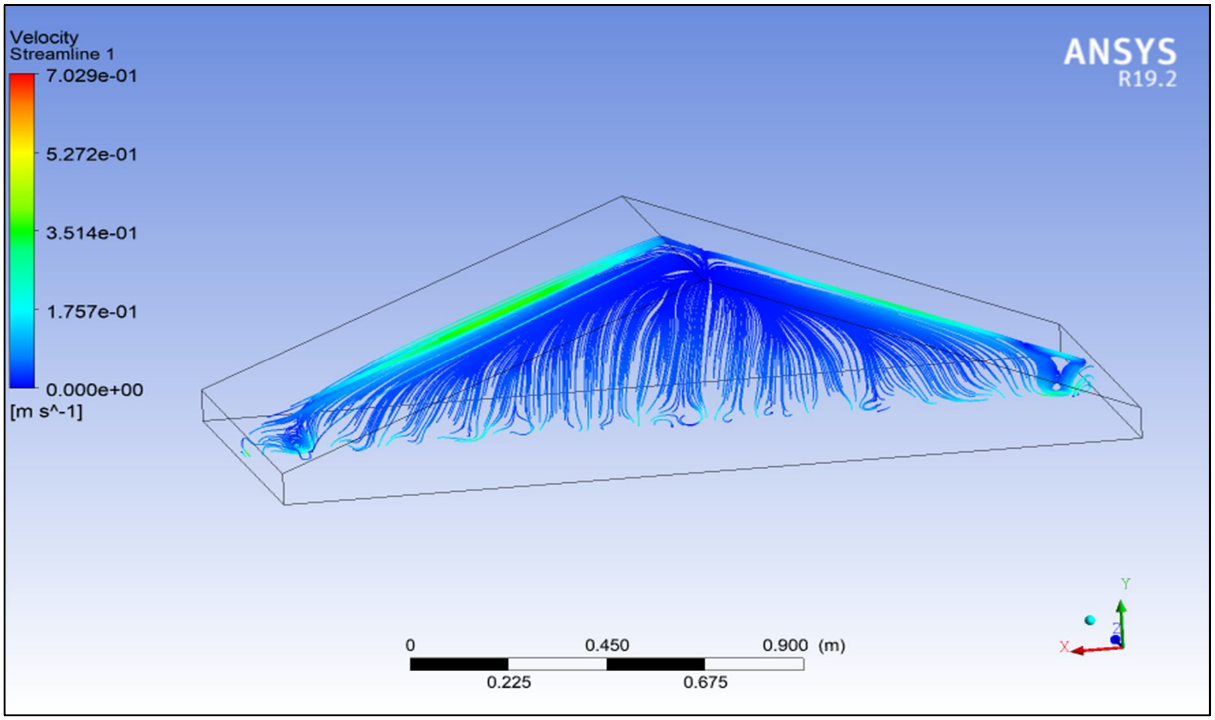

Fig. 14. Vapor phase velocity vector of single slope solar still

4) *Solar Intensity:* When Solar energy incidents on the glass surface increase the inside temperature of the solar still and converts water into vapor. Fig. 15 shows the hourly variation of the solar intensity of both stills. The result predicted a single slope gets a higher intensity of solar energy than double slope solar still. There is approximately an error of 8.1846 % in the solar intensity of both stills. The maximum solar intensity absorbed by the single slope is 845.284 W/m^2 while in double slope is 810.132 W/m^2. The average solar intensity of the single-slope solar still is 647.0356 W/m^2. While in the double slope, the average solar intensity was 598.0843 W/m^2.

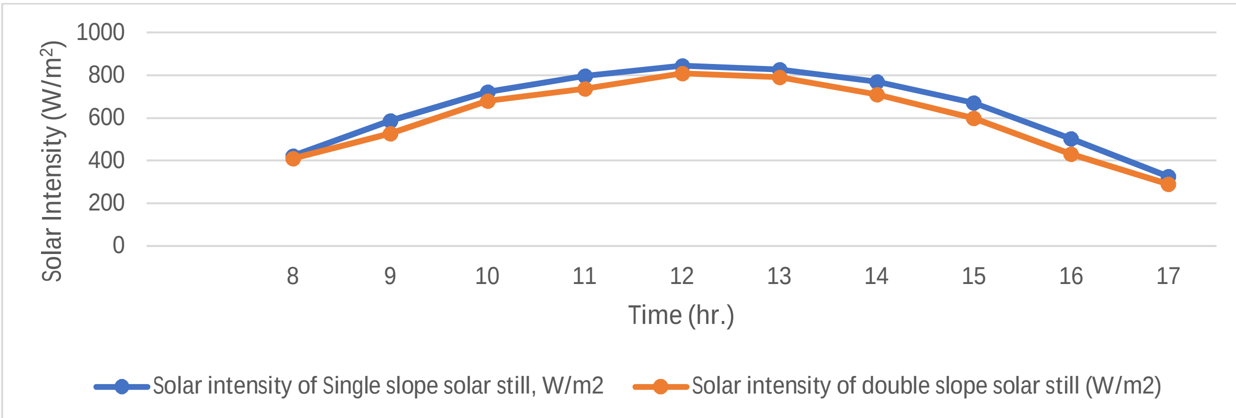

Fig. 15. Hourly variation of solar intensity of single and double slope solar still

5) *Water Production:* Fig. 16 shows the hourly variation of the mass yield of both stills. The simulation process was started at 08:00 hr and came to an end at 17:00 hr. As time passes, the inside area of both still warm-up and still space become saturated. The rate of production of freshwater increases from 11:00 to 14:00 hr in both still. Then, it starts to decrease. The maximum production of freshwater in single is predicted to be 0.60729 kg/m^2 hr at 14:00 hr while the double slope is of 0.54371 kg/m^2 hr. There is an approximately 11.69% difference in water production in both stills.

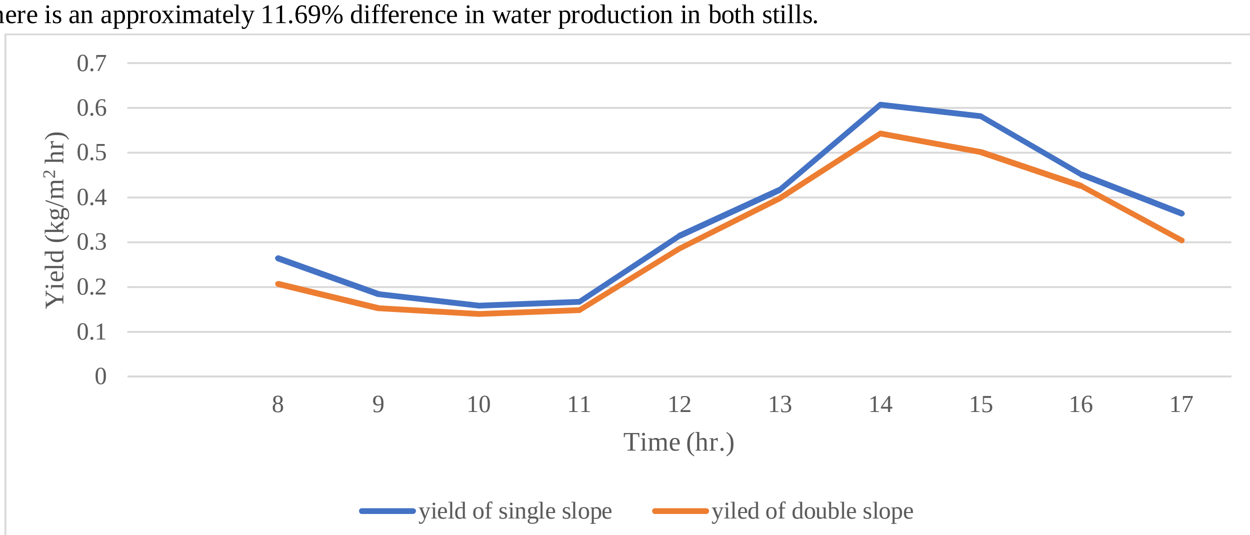

Fig. 16. Hourly variation mass yield of single and double slope solar still.

IV. CONCLUSIONS

The study aims to develop a computational fluid dynamics model of single slope and double slope solar still. Two different two-phase three-dimensional models using computational fluid dynamics have been developed. In both stills, evaporation and condensation processes occur. The models were conducted for water-mixture (air and water vapor) systems with the aim of ANSYS FLUENT V19.2 software. The computational fluid dynamics simulation was conducted for transient conditions using these models. Both systems' simulation data were obtained in 5 hours and 6.30 hr with 10 steps of 15 minutes period. In both systems, water absorbs solar radiation and evaporates and the vapor condenses on the glass. The main conclusions of the study are:

A. The maximum temperature of air and water vapor mixture inside the single slope is 54.9445℃ and the minimum temperature is 19.4401 ℃ The maximum temperature of the mixture inside the double slope is 52.21 ℃ and the minimum temperature is 12.6988℃. There is an approximately 8.36 % error in their maximum temperatures and an 8.139 % error in minimum temperatures.
B. The maximum volume fraction is 0.0183968 and a minimum of 1.8773×10^{-6} in the single slope, while the maximum volume fraction inside the double slope is 0.0309681 and a minimum of 3.22×10^{-5}.
C. The maximum velocity of vapor in the single slope was observed 2.192 m/sec while in double slope solar still, it is only 0.70289 m/sec.
D. The maximum production of freshwater in single is predicted to be 0.60729 kg/m^2 hr at 14:00 hr while the double slope is of 0.54371 kg/m^2 hr. There is an approximately 11.69% difference in water production in both stills.

Computational fluid dynamics results show that computational fluid dynamics is a powerful tool for design, parameter analysis, and difficulties removal in solar still construction. In the future, further work can be done by changing different design parameters of solar still.

V. ACKNOWLEDGMENT

The authors are highly thankful to the Centre for Energy and Environment and Department of Mechanical Engineering, Delhi Technology University, Delhi (India) for their assistance and facilities in compiling this review manuscript

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