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Effect of Steps Height and Glass Cover Angle on Heat Transfer Performance for Solar Distillation: Numerical Study

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ABSTRACT

Productivity and heat transfer in the stepped solar still by varying the glass cover angle and steps height were numerically investigated. In order to obtain the productivity and heat transfer coefficient, mass, momentum, energy, and diffusion equations were applied for simulating the distillation process. Further, the numerical simulation validated by existed experimental data. Simulation results indicated the highest freshwater production in comparison with experimental set up condition, which is at the step height 4cm and glass cover angle 60.23°, belongs to the step height of 5.5cm with 1400 mL/m^{2}h, namely 91٪ increase and much less for the step height of 1cm with 350 mL/m^{2}h, namely 52٪ decrease. Most increase in Nusselt number obtained for the angle of 55° with Nu=12.03 with 29٪ increase and much less for the angle of 65° with Nu=8.16 with 12٪ decrease. In addition, most and less variation of the heat transfer coefficient obtained for the step height of 5.5cm with h_c=4.04 W/m^2 K, with 39٪ increase and for the step height of 1cm with h_c=2.18 W/m^2 K, with 24٪ decrease, respectively.

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NOMENCLATURE

C	concentration [k mol / m^3]
C_p	specific heat [kJ/kg K]
D	molecular diffusion coefficient [m^2/s]
g	gravity [m/s^2]
H	mean distance between water and glass [m]
h	heat transfer coefficient [W/m^2 K]
k	thermal conductivity [W/m K]
L	length [m]
$\dot{m}$	productivity [mL/m^2 h]
Nu	Nusselt number
P	absolute pressure [Pa]
Ra	Rayleigh number
T	temperature [K]
u	x axis velocity [m/s]
v	y axis velocity [m/s]
x	direction
x′	parallel direction with glass
Y	mass fraction of water in wet air
y	direction

Greek Symbols	
β	thermal expansion factor[1/K]
β^*	species expansion factor [m^3/k mol]
ΔT	difference between water and glass[K]
φ	relative humidity
ω	humidity ratio
μ	dynamic viscosity [kg/m s]
ρ	density [kg/m^3]

Subscripts	
a	air
c	convection
g	glass
i	diffusive species index
l	left
m	mean temperature
n	normal direction
r	right
sat	saturation
w	water

1. INTRODUCTION

There are two potential in the solar irradiation, i.e. its light and heat. The sunlight can be converted into electrical power by means of photovoltaic (PV) modules [1-5]. Moreover, its thermal energy can be also used to produce electricity by solar thermal power plants [6, 7]. Besides, the thermal energy of sun also can be utilized

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directly for thermal objectives, e.g. in solar chimney [8, 9], air heating [10, 11], solar dryers [12, 13], solar water heaters [14-16]. Another interesting applications of the solar heat is solar desalination, which is studied in this study. Providing potable water which is a serious challenge these days; although oceans and seas cover about 70 percent of earth, however, most are salty and not suitable for consumption, not only for drinking even for farming. Scientist and engineers proposed various method for purification of water, most common method is reverse osmosis. Some of the methods have advantages and disadvantages which were discussed by researchers and could be found in the literatures [17-19]. Since most water treatment methods use considerable amount of energy and subsequently electricity, therefore using renewable energy such as solar energy, seems more reasonable and promising. Many experimental and numerical researches were reported in this field. Most recent work to be continued these days and some of the related ones will be reviewed here. de Paula and Ismail [20] numerically investigated on heat and mass transfer on an inclined solar still. Their results indicated that for high Rayleigh numbers an increase in cavity inclination causes the Nusselt and Sherwood numbers and the condensation rate to increase. Kabeel et al. [21] reported a comprehensive review article about tubular solar still and the advanced design techniques in tubular solar still which aimed to improve the yield of stills. Gazar et al. [22] showed that the fractional model has more accuracy compare with the classical model and hybrid nanofluid rises daily productivity by 27.2% in summer and 21.7%, in winter compare to the still without the nanofluid. Hedayati et al. [23] studied on the exergy performance evaluation of basin type double slope solar equipped with PV/T collector. The PV/T collector improves the freshwater production during the sunshining hours of the day by preheating the saline water and utilization of phase change material (PCM) makes it possible to produce freshwater at the night. Khalilmoghadam et al. [24] investigated on a system of energy recovery using PCM and pulsating heat pipe. Their result showed an increase in productivity also decreases cost per liter of water. Sivaram et al. [25] studied on the effect of external condenser on the stepped solar still to improve productivity. Their results have shown an increase in the overall efficiency of still by 10.6% in summer and 12.2% in winter. Higher performance was observed in winter than summer when the passive external condenser was added with the stepped evaporator and found inverse for the stepped solar still without condenser. Bouzaid et al. [26] numerically analyzed the thermal performances for a cascade solar desalination still with baffles on basins. The performance of the still investigated and compared with the ordinary model; the results indicated that the design allows an increase in the production. Rahbar and Esfahani [27] estimated productivity of single slope solar still numerically and their results compared with experimental data. Rahman et al. [28] studied numerically triangular solar collector based on double diffusion natural convection model and achieved local and average heat and mass transfer coefficient using dimensionless numbers. El-samadony et al. [29] investigated on influence of glass cover inclination angle on radiation heat transfer rate within the stepped solar still and presented a theoretical analysis of the radiation heat transfer rate inside the stepped solar still. In addition, radiation shape factor between the hot saline water and glass cover for the stepped solar still computed. It was found that the influence of the radiation shape factor on the thermal performance predictions is significant. Most experimental works indicated minimum depth of water in the basin lead to more efficiency of solar still. Stepped solar stills by providing maximum cross section and minimum depth and less chamber volume in comparison with one basin solar still with one or double slope are more desirable for more productivity. Gawande et al. [30] studied on the shape of absorber surface and performance of the stepped type solar still by utilizing convex, concave absorber instead of flat absorber and indicated increase in the productivity of 57% and 29%, respectively. The effect of tilt angle on the productivity of a solar still was experimentally studied by Cherraye et al. [31]. The experiments were performed in arid climate of Ouargala city, Algeria. Different angles of 10° to 45° were tested. As results, it was reported that the inclination angles of 20° for summer and spring, and 30° for autumn and winter, were the optimum values. Ashtiani and Hormozi [32] studied the stepped solar still based on entropy generation, their results indicated that the number and height of the stepped were effective parameters for irreversibility and entropy generation. The effect of different environmental parameters and operational parameters on the system productivity were discussed, e.g., the decrease in humidity increases the productivity, the wind velocity significantly reduces the (T_i–T_o) difference temperature, which adversely affects the productivity of the system, and the cloud coverage affects the solar radiation intensity.

Present study aims to demonstrate numerical simulation with some modifications on the reported theoretical study. The reported theoretical study was mostly based on the experimental measurement. Hence, obtaining experimental data requires lots of time and expensive setup in terms of cost and operation. Obviously changing in the experimental setup is another problem for optimizing of solar still performance, contrary the numerical method has not any of this hardship. However, in the presented method only temperature is the main input value that one needs and the rest such as mass fraction of water vapor in air can be obtained from psychrometric chart or using some reported correlation. To the best of the authors knowledge numerical study on the stepped solar still for estimating the productivity, heat transfer coefficient and Nusselt number have not yet fully been investigated. In this research, after comparing the proposed numerical simulation with the reported experimental and theoretical study, the geometry optimization by varying the glass cover angle and steps height were reported. Therefore, this study soughts various and possible scheme to increase the productivity of freshwater in the stepped solar still by changing the geomety and seeking the thermal behavior and consequently productivity to achieve maximum and optimal production.

2. MODELING

Consider solar still is in equilibrium condition with an ambient and since there is, no external force such as pump and blower use in the passive solar, only natural convection occurs in the solar still cavity. Two-dimensional steady state governing equations on the moist air inside cavity, mass, momentum, and energy conservations are [33, 34]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) +\beta_T g(T-T_0)+\beta_C g(C-C_0) \tag{3}$$

which β_T and β_C are: $\beta_T=-\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p$, $\beta_C=-\frac{1}{\rho}\left(\frac{\partial\rho}{\partial C}\right)_p$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

$$u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}=D_{w-a}\left(\frac{\partial^2 C_i}{\partial x^2}+\frac{\partial^2 C_i}{\partial y^2}\right) \tag{5}$$

Equation (5) can be rewritten as Equation (6):

$$\frac{\partial}{\partial x}(\rho u Y_i)+\frac{\partial}{\partial y}(\rho v Y_i)=-\left(\frac{\partial}{\partial x}(J_i)_x+\frac{\partial}{\partial y}(J_i)_y\right) \tag{6}$$

Y_i is mass fraction of water vapor in wet air $(Y_i=\frac{\rho_i}{\rho})$ and the relation between density and concentration is $(C_i=\frac{\rho_i}{M_i})$ and $\vec{j}_i$ defines by Equation (7):

$$\vec{J}_i=-\rho D_{w-a}\left(\hat{i}\frac{\partial}{\partial x}Y_i+\hat{j}\frac{\partial}{\partial y}Y_i\right) \tag{7}$$

Equations can be solved simultaneously for velocity, temperature, and concentration of water vapor. The boundary condition for velocity, temperature, and concentration are:

For cover glass:

$$u=v=0, T=T_g, Y_i=Y_g\big|_{T=T_g,\varphi=100\%} \tag{8}$$

For steps basin:

$$u=v=0, T=T_w, Y_i=Y_w\big|_{T=T_w,\varphi=100\%} \tag{9}$$

For other walls:

$$u=v=\frac{\partial T}{\partial x}=\frac{\partial Y_i}{\partial x}=0 \tag{10}$$

Note that for the concentration value in boundaries, Psychrometric chart was used in φ=100٪ and then the mass fraction in specific temperature defined as follows:

$$Y_i=\frac{\omega}{1+\omega} \tag{11}$$

which ω is the specific humidity and one can use:

$$\omega=0.622\frac{\varphi P_{sat}}{P-\varphi P_{sat}} \tag{12}$$

Numerically solving above equations and using temperature and concentration profile, one can obtain the productivity of solar still and Nusselt number as follows [27,35]:

$$\dot{m}=\frac{-3600\times\rho\times D_{w-a}}{L_g}\int_0^{L_g}\frac{\partial Y_i}{\partial y}\bigg|_g dx' \tag{13}$$

$$\overline{Nu}=\frac{-H}{L_g(T_w-T_g)}\int_0^{L_g}\frac{\partial T}{\partial n}\bigg|_g dx' \tag{14}$$

The convective heat transfer coefficient could be calculated using definition as [36]:

$$h_c=\frac{Nu\times k}{H} \tag{15}$$

3. DESIGN GEOMETRY AND SIMULATION PROCEDURE

Two-dimensional geometry of solar still which was used by Kabeel et al. [37] has been used for comparing the trend which is shown in Figure 1.

Step 1 has 10cm length and steps 2, 3, 4, each one has 12.5cm. Also, the offset height of each step increases 4.5cm. Front side length is 4.4cm and back side is 15cm. All walls are considered in the adiabatic condition except the top cover (glass) and steps (water surface). In this simulation, the air is assumed completely humid φ=100% and the properties are shown in Table 1. Moreover, the maximum solar radiation of 1050 W/m^2 was assumed

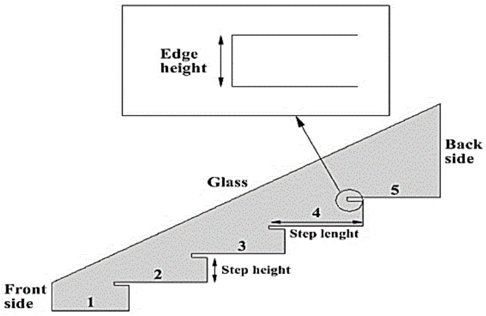


Figure 1. Sketch of stepped solar still geometry

and can be found in literature [37]. In this study, back side, H_l=15cm, front side, H_r=4.4cm, step1 length 10 cm, step 2, 3, 4, 5 length 12.5cm, step height 4cm, edge height 0.5 cm, and depth 200 cm were taken and temperatures variation were shown in Table 2.

4. SOLUTION PROCEDURE AND MESH INDEPENDENCY

Since this is an internal flow case, Rayleigh number can be determined as:

$$Ra = \frac{\rho^2 g\beta c_p H^3 \Delta T}{k\mu},\ H = \frac{(H_l + H_r)}{2} \quad (16)$$

where H_l and H_r are the length of front and back side, respectively. By substitute the physical parameters in the above equation the Rayleigh number obtained to be less than 10^8; therefore, the flow regime is laminar in this study. SIMPLE algorithm was used for pressure-velocity coupling. Besides, PRESTO scheme was suitable and used for pressure interpolations due to the natural convection vortices in the solar still. The momentum, energy, and species equations were discretize using second-order upwind scheme [38]. The discretized and linearized equations were solved by iterative method and the convergency criterion was 10^{-7} for all equations except for continuity equation, which was 10^{-4}. After convergency hourly productivity per unit area, Nusselt number, and convective heat transfer coefficient were determined. Figure 2 shows the implemented meshing which was tetrahedral and structured. Table 3 shows effect of mesh elements and nodes on the Nu, productivity, and heat transfer coefficient and in Figures 3 and 4 the simulation results by changing in the number of mesh are shown.

Further the simulation results compared with the reported experimental data and theoretical analysis [36] are shown in Figure 5 and Table 4. As shown in figure and table, the maximum productivity errors between this simulation and for the reported experiment is 30% and for the theoretical method is 13%. Therefore, this simulation indicates similar trend, however the reported study uses mostly experimental data.

4. PARAMETRIC STUDIES

Simulations were obtained as stated in Table 2 for 12:00 p.m. Velocity profile inside the solar still chamber is

TABLE 1. Properties of humid air [35]

Quantity	Expression, T (°C)
Specific heat, C_p	$999.2+0.1434xT_m+1.101x10^{-4}xT_m^2-6.758x10^{-8}xT_m^3$
Density, ρ	$353.44/(T_m+273.15)$
Thermal conductivity, k	$0.0244+0.7673x10^{-4}xT_m$
Viscosity, υ	$1.718x10^{-5}+4.62x10^{-8}xT_m$
Expansion factor, β	$1/(T_m+273)$
Species expansion coefficient, β_c	$[M_a/M_v-1]/\rho=0.513$
Diffusion coefficient, D_{a-w}	$0.26x10^{-4}$ x (101.325/P) x $(T/298)^{3/2}$

TABLE 2. Thermal condition and geometry parameters used [37]

Case	1	2	3	4
Time	12 pm	13 pm	14 pm	15 pm
T_w(°C)	76	74	74.5	67
T_g(°C)	46	44	43	41

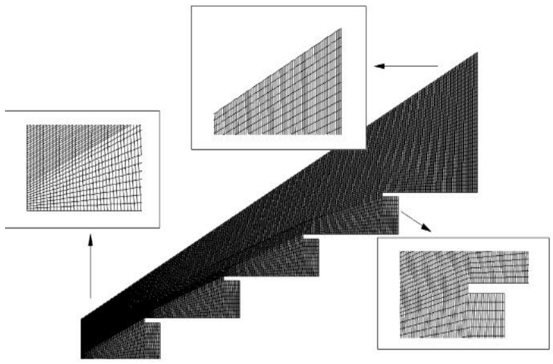


Figure 2. Meshing

TABLE 3. Number of mesh elements

Number of mesh elements	88783	131752	193388	253538	340983	365955
Number of mesh nodes	89910	133132	195036	255415	343160	368205
Nusselt number	10.5	10.1	9.9	9.74	9.83	9.81
Productivity [mL/m²hour]	805	795	790	760	735	732
Heat transfer coefficient [W/ m² K]	3	2.94	2.87	2.85	2.81	2.8

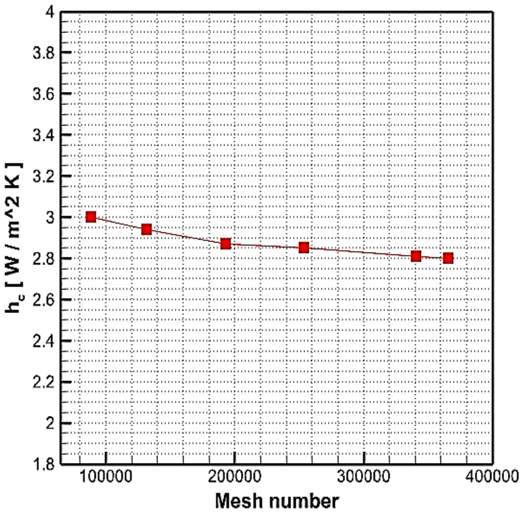


Figure 3. Heat transfer coefficient between water surface and glass vs mesh number

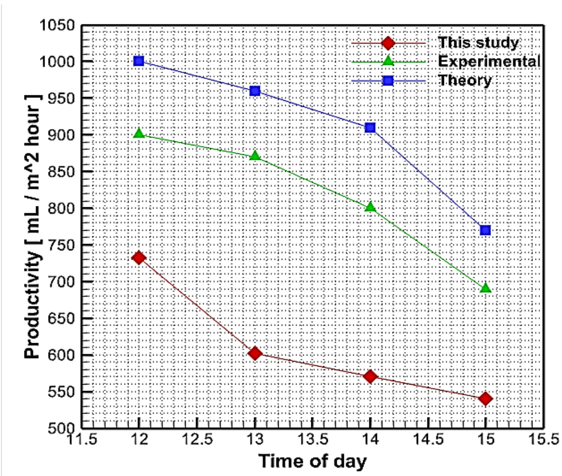


Figure 4. Nusselt and productivity vs mesh number

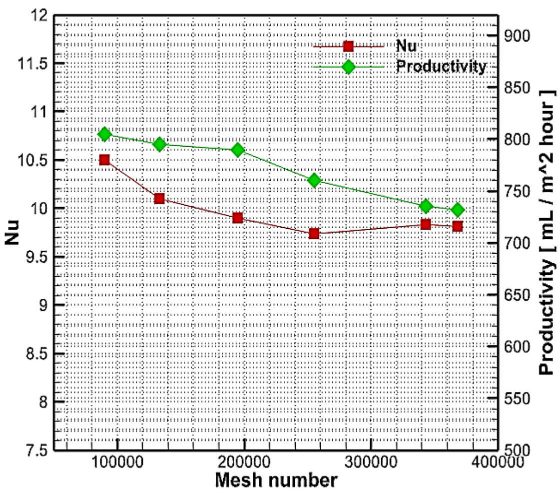


Figure 5. Productivity this simulation with experimental and theoretical reported model [37]

TABLE 4. Comparison of productivity for this simulation with the reported experiment and modeling [37]

Time	12 pm	13 pm	14 pm	15 pm
Productivity of experiment [37] (mL/h.m^2)	900	870	800	690
Productivity of modeling [37] (mL/h.m^2)	1000	960	910	770
Error with exp. (%)	11	10	14	12
Productivity of this simulation (mL/h.m^2)	732	602	570	540
Error with exp. (%)	19	31	29	22

shown in Figure 6. Since the temperature of steps is more than glass temperature as expected, a natural heat transfer convection occurs inside solar still.

Figure 7 shows the temperature profile and circulation of the fluid inside the solar still. All big vortexes in the figure are counter clockwise and physically satisfy the thermal condition in the solar still because the glass cover has lower temperature than mean temperature of the humid air.

Figure 8 depicts the water vapor fraction contour. As one knows from thermodynamic point of view that the air with higher temperature has capability for mixing with much more amount of water vapor and for this reason the mass fraction of water near the steps are more than glass surface.

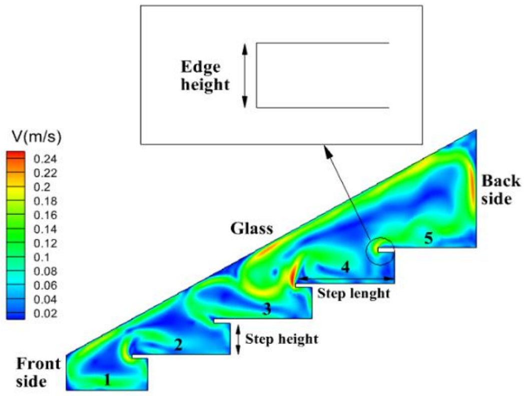


Figure 6. Velocity profiles inside the stepped solar still

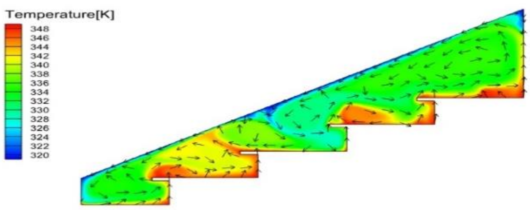


Figure 7. Temperature profile inside the solar step

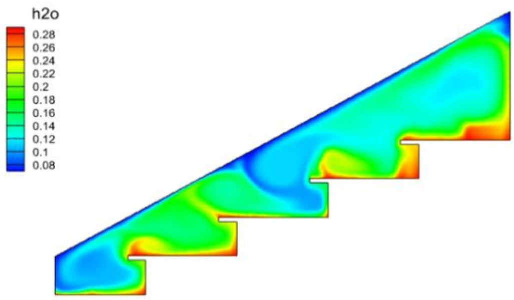
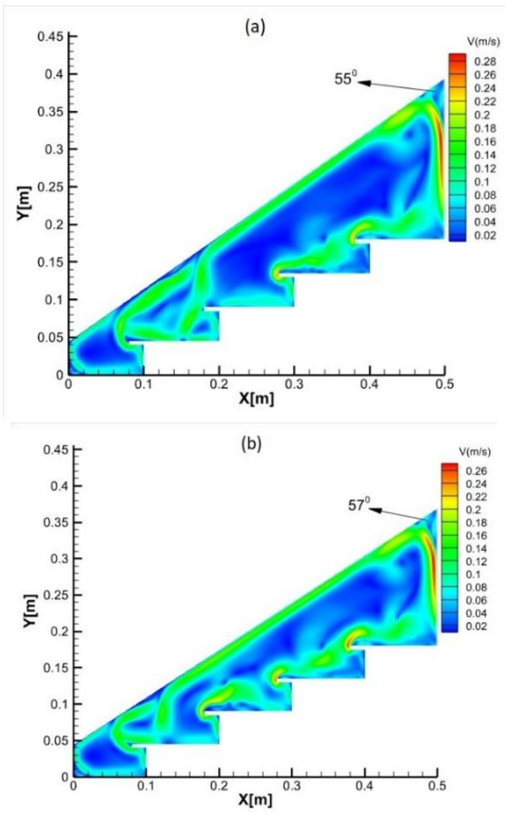
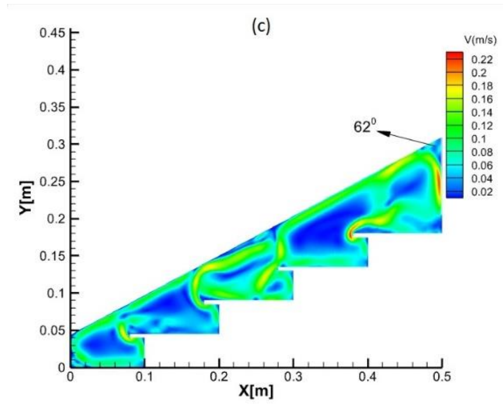


Figure 8. Water vapor mass fraction profile inside the solar still

5. EFFECT OF VARIATION OF GLASS COVER ANGLE

In Figure 4 the experimental model glass cover angle was reported 60.23°; therefore, simulations were extended and preformed for different angles, i.e. 55°, 57°,62°, and 65°. It can be seen from Figure 9 that velocity profiles vary significantly by changing the angles. since the natural convection is the most important phenomenon in the passive solar stills, variation in the productivity, Nusselt number, and heat transfer can be expected to be significant. Figure 10 shows the productivity and Nusselt number in terms of glass angle. Increase in the productivity and decrease in the Nusselt number were observed and their quantitative values are given in Table 5.





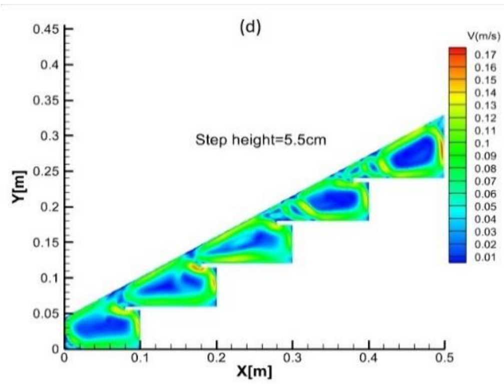


Figure 9. Velocity profile in solar still for different angles

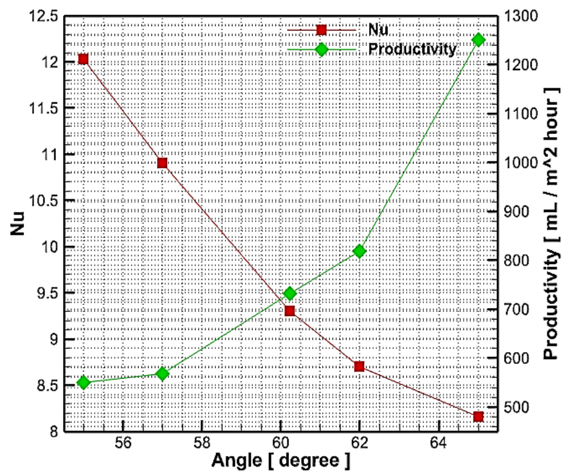


Figure 10. Nu & productivity vs angle of head

TABLE 5. Nusselt number and productivity vs variation of angle of the head

Angle of the head in degree	Nu	Productivity (mL/m^2 h)
55	12.03	550
57	10.9	568
60.23 (Exp. model [37])	9.3	732
62	8.7	818
65	8.16	1250

Figure 11 shows the heat transfer coefficient and mean distance between steps and glass versus angle of the head. As shown in the Nusselt number in the figure with decreasing trend, heat transfer coefficient increases by increasing angle of the head.

Similarly, Table 6 indicates values of the heat transfer coefficient and mean distance between steps and glass beside their variations versus angle of the head changes. As can be seen by decreasing the angle value, the mean distance between steps and glass (H) increases and heat transfer coefficient decreases and vice versa.

Another fluid flow property which variation of that offer meaningful relation with productivity and heat transfer, is vorticity of fluid flow. Figure 12 shows vorticity versus variation of angle of the head or the glass cover angle. Productivity, convective heat transfer coefficient and vorticity all have incremental trend by increasing angle, also one can notice from figure, which the bigger angle of the glass cover causes smaller chamber of solar still and then more vortex to be able to form. In general, by increasing the glass cover angle of solar still, the chamber became smaller and more vortexes appeared and these vortexes lead to enhance the heat transfer and productivity.

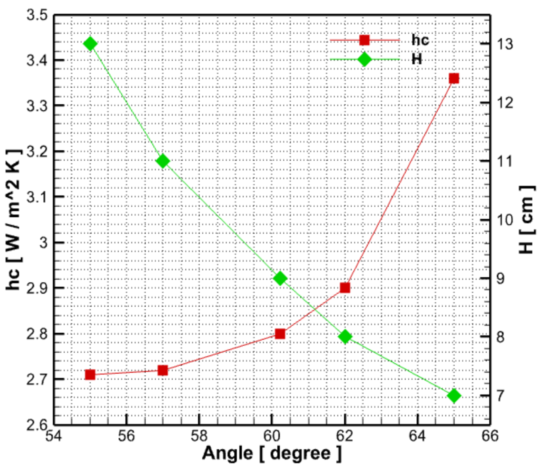


Figure 11. Heat transfer coefficient and mean distance between steps and glass (H)

TABLE 6. Heat transfer coefficient and mean distance between steps and glass (H) versus angle of the head

Angle of the head in degree	Heat transfer coefficient [W/m^2 k]	H(cm)
55	2.71	13
57	2.72	11
60.23 (Exp. Model [37])	2.8	9
62	2.9	8
65	3.36	7

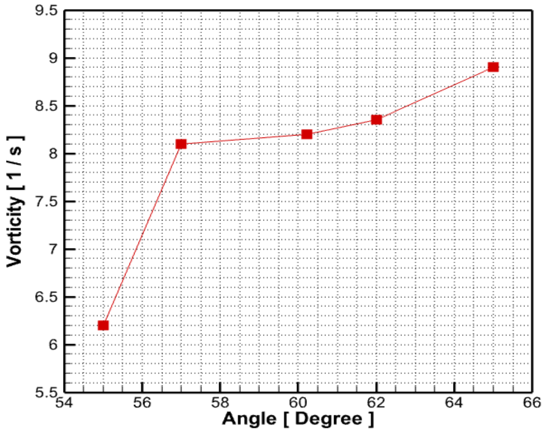
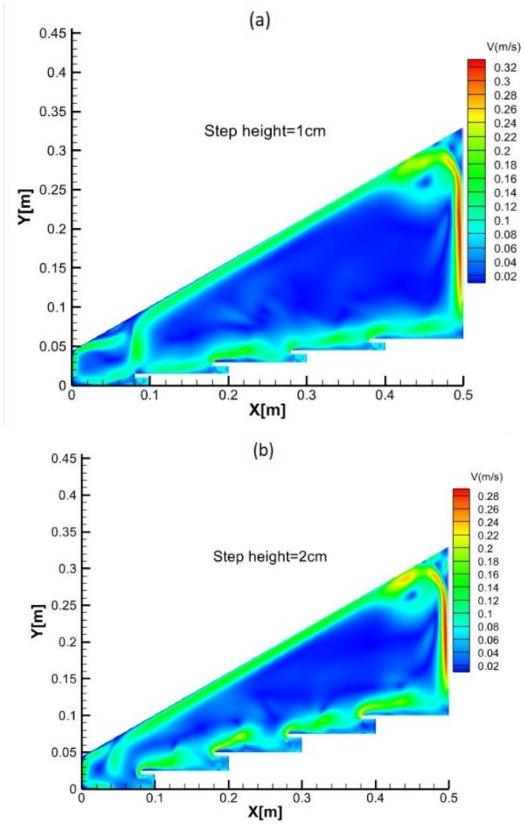


Figure 12. Vorticity vs angle of the head of solar still

6. EFFECT OF HEIGHT OF STEPS

Figure 13 shows for steps height of 1 to 5.5cm and compares to experimental model [37], which is 4cm. With increasing the step height, the cavity of solar still becomes smaller and as expected smaller chamber gives better heat transfer and also more productivity. As seen in figure, the velocity profiles are very different with respect to either experimental model (Figure 6) and each other.



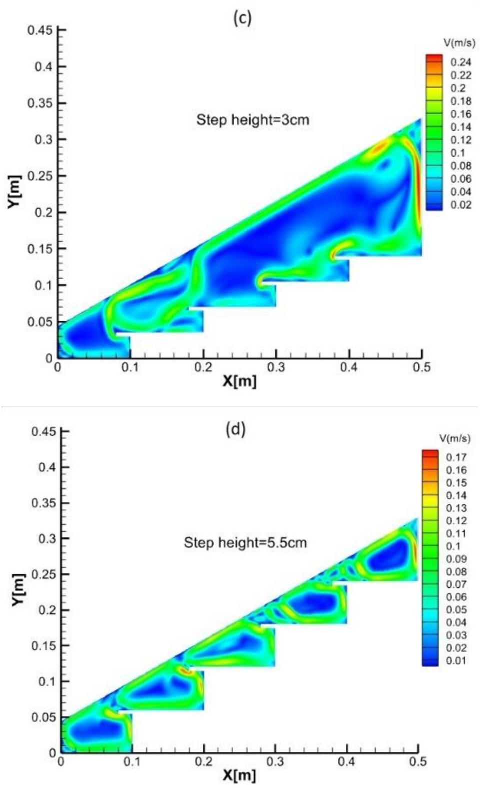


Figure 13. Velocity profile in solar still for various step height of (a) 1 cm, (b) 2 cm, (c) 3 cm and (d) 5.5 cm

Figure 14 shows the Nusselt number and Productivity for the above cases. As seen in figure, by increasing the steps height, the productivity increases and the Nusselt number decreases. This behavior caused by creation of vortexes and decrease mean distance between the steps and glass simultaneously. Table 7 illustrates the quantitate values and variation of them. Further, the convection heat transfer coefficient and the mean distance between steps and glass (H) plotted versus the steps height and are shown in Figure 15.

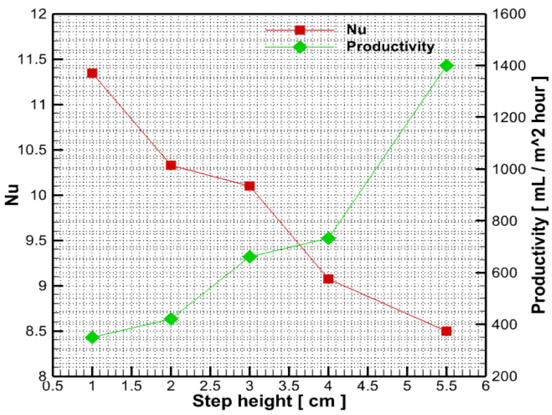


Figure 14. Nusselt and productivity vs steps height of solar still

TABLE 7. Nusselt number and productivity for various step height

Step height (cm)	Nusselt number	Productivity ($mL/m^2 h$)
1	11.34	350
2	10.33	420
3	10.1	660
4 (Exp. model [37])	9.07	732
5.5	8.5	1400

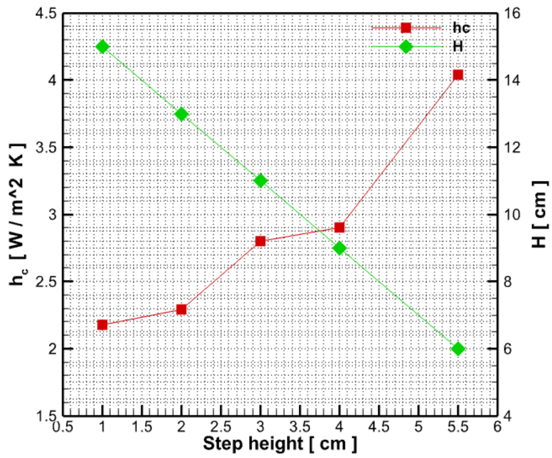


Figure 15. Heat transfer convection and mean distance between the steps and glass (H)

Their quantitative values for each case are shown in Table 8. Vorticity of fluid in this case, is shown in Figure 16 and it can be seen that like productivity and h_c have incremental trend by increasing the step height and this behavior is due to smaller space for wet air circulation. It means the vortexes on the steps must have more variation in their path direction and this variation lead to more heat and mass transfer. Hence, the productivity and h_c increase by increasing the step height and vice versa.

TABLE 8. Heat transfer coefficient and mean distance between steps and glass (H) for various step height

Step height (cm)	Heat transfer coefficient [$W/m^2 K$]	H (cm)
1	2.18	15
2	2.29	13
3	2.8	11
4 (Exp. model [37])	2.9	9.07
5.5	4.04	6

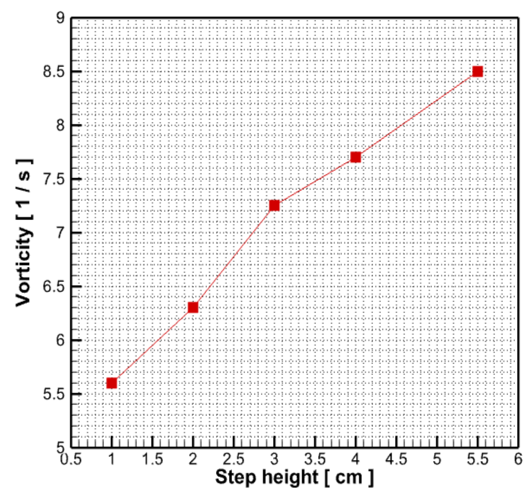


Figure 16. Vorticity variation vs step height of solar still

7. CONCLUSIONS

In this study, numerical simulation was performed on the stepped solar still to estimate the productivity and heat transfer criteria. For this purpose, mass, momentum and energy equation with species transport equation solved simultaneously, then by using mass fraction and temperature profiles and also Equations (13) and (14) productivity and Nusselt calculated. After validating the trend between this simulation with the reported experimental data and theoretical model, the variation in the geometry, the productivity and heat transfer coefficient were investigated. Results shows heat transfer and productivity extremely affected by change geometrical parameters which here discussed about glass cover angle and step heights. Some significant results which obtained are as follow:

- Geometry is one of the main factors in the productivity; the less space in solar still is equivalent to more productivity and vice versa. Therefore, based on this simulation by changing in the angle of the head of solar still, the productivity increases up to 70% and reaches to 1250 mL/m^{2}h and by variation of the step's height increases up to 91% and reaches to 1400 mL/m^{2}h. It was shown that the step height variation is more efficient in productivity because it gives higher increase in the productivity.
- Nusselt number unlike heat transfer coefficient decreases with decreasing solar still cavity volume and vice versa. Simulation indicated for up to 57° cover angle, the Nusselt decreased and heat transfer coefficient (h_c) significantly increased. The heat transfer coefficient varies from 2.72-3.36 W/m^2 K, Nusselt from 10.9 to 8.16. Hence, there should be an optimum point and needs more investigation.
- Nusselt number varies as the solar still geometry changes, this variation is having reverse effect with h_c and direct effect with mean distance between water and glass (H). The largest Nusselt was obtained is 11.34 for H=15cm and the least Nusselt is 8.5 for H=6cm.
- The maximum freshwater production occurs for the step height of 5.5cm which was 1400 mL/m^{2}h. Therefore, due to the experimental restrictions for changing the angle of glass cover, it is better to use this parameter to enhance the productivity.
- It was noticed that anywhere the vorticity increases, the heat transfer coefficient and the productivity increase too. Therefore, a physical conclusion can be inference from this numerical calculation is that vortexes are the main mechanism that affected on the heat transfer and productivity.

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Persian Abstract

چکیده

در این مقاله، مطالعه‌ای عددی در حوزه‌ی بهره وری و انتقال حرارت در آب شیرین کن خورشیدی پلکانی با تغییر زاویه پوشش شیشه و ارتفاع پله‌ها مورد بررسی قرار گرفته است. بدین منظور از معادلات پایستگی جرم، حرکت، انرژی و انتشار استفاده شد. علاوه بر این، شبیه سازی عددی با داده های تجربی موجود تایید شده است. نتایج شبیه سازی نشان داد که بیشترین میزان تولید آب شیرین در مقایسه با شرایط راه اندازی آزمایشی که در ارتفاع پله 4 سانتی متر و زاویه پوشش شیشه ای 60.23 درجه است، متعلق به ارتفاع پله 5.5 سانتی متر با $1400\ mL/m^2\ h$ یعنی افزایش 91 درجه و بسیار کمتر است. برای ارتفاع پله 1 سانتی متر با 350 میلی لیتربرمترمربع ساعت، یعنی 52 درجه کاهش می یابد. بیشترین افزایش عدد ناسلت برای زاویه 55 درجه با $Nu=12.03$ با افزایش 29٪ و بسیار کمتر برای زاویه 65 درجه با $Nu=8.16$ با کاهش 12٪ بدست آمد. علاوه براین، بیشترین وکمتر تغییر ضریب انتقال حرارت برای ارتفاع پله 5.5 سانتیمتر با $h_c=4.04\ W/m^2K$، با 39٪ افزایش و برای ارتفاع پله 1 سانتی متر با $h_c=2.18\ W/m^2K$، با 24٪ کاهش یافت.