

RESEARCH ARTICLE

Engineering

Numerical investigation to determine the optimal tilt angle of single slope solar still during summer season

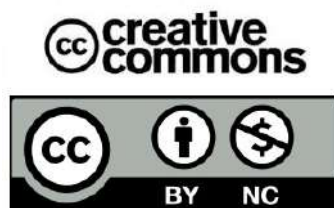
Investigación numérica para determinar el ángulo de inclinación óptimo de un destilador solar inclinado durante la temporada de verano

Muhammad Uzair  ^{1*} | Asad A. Naqvi  ^{1*} | Muhammad Uzair

Yousuf  ^{1*}

¹Solar Energy Lab, Department of Mechanical Engineering, NED University of Engineering & Technology, Karachi, Pakistan.

Correspondence
Muhammad Uzair
Email: uzair@neduet.edu.pk



Editors: Robert Paul Salazar

How to cite: Muhammad Uzair et al., Numerical investigation to determine the optimal tilt angle of single slope solar still during summer season, TECCIENCIA, Vol. 17, No. 32, 29-39, 2022
DOI:<http://dx.doi.org/10.18180/tecciencia.2022.32.3>

Abstract. Water, a basic human need can be purified by different techniques like membrane distillation, boiling and solar still. Among all types, solar still is considered to be the most economical and simpler one. In this study, the geometrical aspects of the solar still for Karachi by varying the tilt have been simulated. The study is conducted by varying the height and length of the solar still by keeping the constant glass surface area and by varying the height and length of the glass cover while keeping the constant basin area. The study is conducted between the time duration from 08:00 to 18:00 hours which is generally the sunshine duration for Karachi. The simulation results are verified with the experimental results which shows the good agreement with each other. For constant glass cover area, the maximum mass production of water has been observed at a tilt of 60° while for constant basin area the maximum tilt is observed for 24.8° equal to the latitude of Karachi. For both the cases, the maximum temperature of water and glass and maximum mass production of water is observed at around 13:00 hours.

Keywords: Solar still, optimal tilt angle, constant basin area, constant cover area.

1 | RESUMEN

El agua representa una necesidad humana básica, ella se puede purificar mediante diferentes técnicas como la destilación por membrana, la ebullición y el destilador solar. Entre todos los tipos, el alambique solar se considera el más económico y sencillo. En este estudio, se han simulado los aspectos geométricos de este dispositivo solar de Karachi variando la inclinación. El estudio se lleva a cabo variando la altura y la longitud del destilador solar manteniendo constante el área de la superficie del vidrio variando la altura y la longitud de la cubierta de vidrio mientras se mantiene constante el área del estanque. El estudio se lleva a cabo entre las

* Equally contributing authors.

8:00 y las 18:00 horas, que generalmente es la duración del sol en Karachi. Los resultados de la simulación se verifican con los resultados experimentales que muestran una buena concordancia entre sí. Para un área de cubierta de vidrio constante, la máxima producción en masa de agua se ha observado a una inclinación de 60° , mientras que para un área de cuenca constante, la inclinación máxima se observa para $24,8^\circ$, igual a la latitud de Karachi. Para ambos casos, la temperatura máxima del agua y del vidrio y la máxima producción masiva de agua se observa alrededor de las 13:00 horas.

Palabras clave: : Destilador solar, ángulo de inclinación óptimo, área de cuenca constante, área de cobertura constante.

2 | INTRODUCTION

There is nothing more fundamental to life than water. About 71% zone of our earth is covered with water and rest is the land [1]. About 3% of available water is in its pure condition which is the fresh water and from which 0.3% water is drinkable [1]. At the present, 1.4 billion of individuals of the world lack access to water [2]. Therefore, they need to use the polluted water. However, due to use of polluted water, 2.4 billion of people suffer from diseases (like cholera, typhoid) and these spread infections results the death of around 2 million people each year [1]. According to a study, at any given time, practically 50% of the clinics are involved of patients experiencing waterborne sicknesses around the world. Because of the growing human population, the water crisis has become an extreme issue, the rivers, lakes etc. are drying and getting too dirtied to be utilized. More the half of the world's wetland has vanished. Around 348 million individuals face serious water shortage. They live in districts where the water resources are adequate to meet water needs by 2025 [2].

Pakistan is confronting a critical water crisis for several past years and ranks 3rd in the world in facing water crisis. The serious issues due to which Pakistan faces the water crisis are Wastage of Water, water storage, and over growing population [3]. First major problem of the water crisis is the water wastage. Pakistan squanders water of worth 25 billion every year with two third of water being waste in irrigation due to system leakages. In some places of Pakistan where there is no water shortage, people have no any concept of saving water rather they live a very tension free life because they have no any idea of water crisis in Pakistan. On the other hand, Water storage is also one of the biggest problems of water crisis in Pakistan. Pakistan currently have only 30 days water storage [3] compared with India having 130 days water storage capacity and United states of America with 900 days water storage capacity. These issues can be reduced by using different ways including public awareness campaigns, building dams, saving water and using advance innovations like automatic taps, automatic shutting motor sensor etc.

Water assets are common assets of water that are conceivably valuable. All living things need water to develop and reproduce. 97% of the water on the Earth is salt water and only 3% is new water; to some degree over 66% of this is solidified in cold masses and polar ice tops. The remaining unfrozen fresh water is found essentially as ground water; with only somewhat part present over the ground or perceptible in general [1]. Diverse desalination strategies have been made since clean water is one of the most urgent resources for human life. All around, the unit cost of new water creation will, by and large, decrease essentially, as the production scale has extended. Accordingly, super desalination plants have become a mainstream pattern in present day human progress. In any case, smaller scale desalination is as yet significant for some applications: (i) it could flexibly water in remote zones where a water supply line is not really accessible. (ii) It would be helpful for individuals who can't manage the cost of huge speculation for a water plant. (iii) It could likewise be helpful as a worldly water hotspot for some individuals, for example, migrants, campers, mariners, or overcomers of different calamities. There are different techniques available to either filter the water or making the salty water to drinkable. Disinfection method utilizes chlorine as purifying agent, by adding chlorine in the water kills viruses, microscopic organism and giardia [4]. Filtration removes sediments, microbes, large parasites and some of the heavy metals [5] present in water. Filters depend upon the size of pores which will purify the contaminants; a size of 0.2 microns is small enough to remove heavy metals like lead and copper. Filtration utilizes carbon and charcoal filters to absorb contaminants from water. Reverse Osmosis (RO) type of purifica-

tion method removes almost all kind of contaminants in water. It contains a membrane of very fine and small pores which are of a size sub atomic level. Water under great pressure passes through this membrane and almost every contaminant is left behind because of very small size of pores. RO water Plants uses this process to purify the boring water. But this type of method is expensive and requires a lot of maintenance. Boiling is the most common technique of water purification which is used almost everywhere. This technique can remove viruses, microbes and parasites. Water is allowed to boil for about 1minutes in order to remove all the germs [6]. Before boiling, water first passes through the filters in order to remove sedimentation and heavy metals and then it is boiled. Distillation removes almost every king of contaminants present in water. This method is of separating water from contaminants by first heating the water; the vapor produced due to boiling comes at the top of the container which is free from contaminants because the impurities cannot be contained in vapor form. This vapor is then collected from the top of the container and is cooled at room temperature. While Ultraviolet light (UV) light purification uses light of intensity more than sun, so its efficiency is greater than of sun light. This technique is so efficient that it can kill 99.99% of the microorganism present in water [6].The disadvantage of UV rays is that it cannot remove sediments, heavy metals and other particles.

Renewable energy is energy produced from sources that do not deplete or can be replenished within a human's lifetime. Most of the renewable energy is derived from sun [7]. So, in order to overcome the problem of water scarcity, solar energy being one of the forms of renewable energy can be used to distillate the water. Solar distillation uses solar energy to separate the impurities or contaminant from the water. The heat from the solar energy causes the water to evaporate and it is condensate and collected in a separate channel, hence leaving the salt and contaminant behind as it doesn't evaporate. There are different ways to use the sun energy to get pure water. One of the techniques is to use the solar stills. Solar still is a device which is used to distillate the water. Solar stills are probably the least complex methods of desalination. In solar still, saline water is evaporated by solar heat and condensed to turn out to be pure water. In spite of the fact that it is old, crude instrument, yet it is as valuable for many individuals. It very well may be just made out of ease basic material, for example, plastic sheet or jugs. In this way, it could be effortlessly introduced and worked. It can be simply made out of low-cost common material, making it relatively the best alternative among the other renewable energy methods. Solar still can purify from almost every kind of contaminants present in water by boiling water through sun light and separating vapor and contaminants. Also, the UV rays play great role in killing almost 99.99% of the germs present in water. The process of solar distillation taking place through the solar still devices can be generally classified into two different kind of modes, i.e. Passive Solar Still and Active Solar Still [8]. Among different types of stills available, Single slope solar still, also known as the conventional slope solar still, is considered as the simplest type of solar still [9].

The productivity of a solar still depends upon three factors i.e., ambient, operating and design conditions. Ambient conditions include isolation, ambient temperature and wind velocity while operating condition comprise of water depth, still orientation and inlet temperature of water. Furthermore, design conditions incorporate various solar still designs, covering slope, module designs and membrane. Numerous scientists have researched the impact of solar radiation on still productivity and their outcomes show that solar still productivity increases with increasing incident solar radiation [10]. Moreover, Okeke et al shows that solar radiation heats up the liquid to evaporate it and lose heat. Morse and read [11] used diagnostic articulations to decide the impact of various factors like solar radiation, wind velocities, ambient temperatures, and heat loss changes on the productivity. The outcomes appear to support the thought that solar radiation is necessary to the cycle [12]. Rahbar and Esfahani [13] reported that solar radiation and ambient temperature have a direct effect on still performance.

Productivity increments with diminishing cover temperatures. The temperature difference between glass and water enlarges with diminishing cover temperature, which thusly improved the natural circulation of air mass inside the still. Also, the convective heat transfer from the cover to the environment increments when both evaporative and convective heat transfer between the basin water increments to make up for high wind speeds [14, 15, 16]. El-Sebaii researched the effects of wind velocity on the outcomes of active and multi-effect passive stills and found that the yield increases with increasing wind velocity [17], [18]. Many researchers have researched the effect of the variation in ambient temperatures on solar still productivity and

found that a small change in ambient temperature of about 5 degree centigrade can bring a 3% increment in solar still productivity. [8], [10]. The impact of the collection of residues on glass plates upon solar transmittance with varying tilt angles has been widely observed, and it was found that transmittance is unequivocally related to dust collection. It was likewise inferred that the statement of residue is legitimately connected to the tilt angles. As a matter of actuality, as the testimony of residue expands, the degree of transmittance drops [19].

Malik et al. [20] performed the optimization of solar still using phase change material. They analyzed the energetic and exergetic modeling using MATLAB codes. The proposed model showed environmentally friendly output at low cost. Rehman [21] performed a geometrical optimization of a single slope solar still and proposed an optical-irradiance model. AS Jaimes et al. [22] did experiments to improve the quality of distilled water for Colombia. They found exponential decrement in efficiency with the increase level of water in the collector. Attia et al. [23] performed experiments to improve the productivity of solar still in winter using nanoparticles. The results showed an increase in the productivity in the presence of nanoparticles. Balachandran et. al., [24] performed experiments to prove the positive effect of nanomaterial on the performance of single slope solar still. Hoque et el. [25] also performed experiments to analyses the productivity of solar still and the results showed the negative effect of water level on the productivity of fresh water. Abed et al. [26] did experiments to analyze the performance of multistage passive solar panels. Also, Sasikumar et al [27] experimentally analyzed the passive inclined solar panel basin. Results showed a decrease in the still energy and exergy efficiency at higher flow conditions.

In this study, different geometrical aspects are analyzed to enhance the productivity of single slope solar stills. The aim of the present study is to investigate the influence of the inclination angle of the glass cover at certain location and to determine the optimal tilt angle to obtain the maximum productivity. The effects of geometrical dimensions of the solar still on its mass productivity are also investigated.

3 | METHODOLOGY

A three-dimensional transient numerical simulation was performed using commercially available Computational Fluid Dynamics (CFD) software package ANSYS CFX (Version 16.1). The study was done using RNG $k - \epsilon$ turbulence model with standard wall function. The RNG model was established using Re-Normalisation Group (RNG) methods to renormalise the Navier-Stokes equations, to account for the effects of smaller scales of motion. The RNG models provides an improved form of Epsilon equation which tries to account for the different scales of motion through changes to the production term. RNG models performs better than Standard $k - \epsilon$ for more complex shear flows, and flows with high strain rates, swirl, and separation. The transport equations for k and ϵ used in RNG Models can be written as:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + P_k - \rho \epsilon$$

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho \epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right] + C_{1\epsilon} \frac{\epsilon}{k} P_k - C_{2\epsilon}^* \rho \frac{\epsilon^2}{k}$$

where

$$C_{2\epsilon}^* = C_{2\epsilon} + \frac{C_\mu \eta^3 (1 - \eta/\eta_0)}{1 + \beta \eta^3}, \quad \eta = S \frac{k}{\epsilon}, \quad \text{and} \quad S = \sqrt{2 S_{ij} S_{ij}}.$$

The values of all of the constants (except β) are derived explicitly in the RNG procedure. The numerical simulation was performed to analyze the different aspect of geometrical orientations and sizes to enhance the productivity of single slope solar still. Solar still is an insulated box covered by an inclined transparent glass.

The inner basin area (0.8m x 1.0m) was selected as black to increase the absorptivity. A 5mm thick glass was placed over solar still. The other dimensions are mentioned in Fig. 1.

The hexahedral type meshing was used due to no involvement of curved surfaces in solar still and it can provide accurate result with less computation time required. After mesh sensitivity analysis, the total numbers of elements in mesh domain were found to be 120199. Mixture model was selected because it allows modeling of evaporation and condensation in closed domain with reasonable computational time. The number phases used were 3 and the slip velocity was taken into an account.

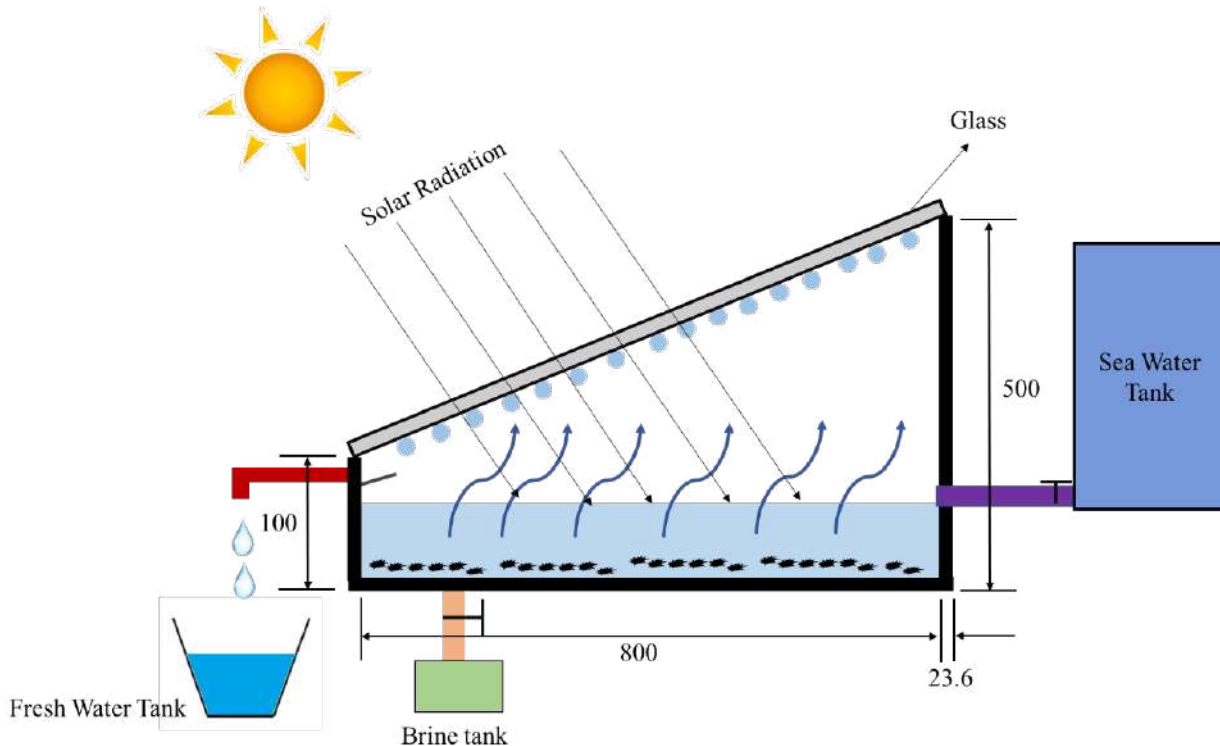


FIG. 1 Dimensions of single slope solar still.

The following assumptions were made during the numerical simulation process:

- All the walls are insulated therefore side walls were considered adiabatic with no leakage.
- At inlet of solar still velocity of air was assumed to be negligible.
- The physical properties of solids and fluids (specific heat, density and thermal conductivity) were considered as constants as temperature variation is not large.
- Film wise condensation was considered only.
- Only free convection is taken was considered and effect of wind velocity is neglected because ambient wind velocity was low.

The Rosseland or diffusion approximation for radiation is valid when the medium is optically thick, and is recommended for use in problems where the optical thickness is greater than 3. Rosseland model is cheaper and more efficient when optical thickness is greater than 3. In order to incorporate the radiation model, Rosse-land model was selected since the optical thickness is greater than 3. In addition to solar model, the solar load model was also used which include the effect of the solar radiation at a particular place in the model. The mesh orientation of the solar still was set in such a way that it was facing the south of the sun. Whereas the parameter like sun direction vector, direct solar irradiation and diffuse solar irradiation were computed from solar calculator. There are different parameters that are required to be inserted as input parameters in CFD

TABLE 1 Different parameters of material used in simulation

Material	Density $\frac{kg}{m^3}$	Specific Heat $\frac{J}{kgK}$	Thermal Conductivity $\frac{W}{mK}$	Viscosity(Kg/m-s)
Air	1.225	1006.43	0.0242	1.79E-05
Water-liquid	998.2	4182	0.6	0.001003
Water-vapor	0.5542	2014	0.0261	1.34E-05
Glass	2235	750	1.15	-
GI Sheet	7196	502	55	-

tool. Thermo-physical properties including thermal conductivity, density, viscosity and specific capacity of the materials used are tabulated in Table. 1.

To obtain accurate results, defining proper boundary conditions is very essential. The types of boundary conditions used during numerical study of the solar still are shown in Table. 2.

TABLE 2 Boundary Condition

Zone name	Zone Type	Description
Front wall	Wall	Adiabatic wall (Heat flux=0)
Back wall	Wall	Adiabatic wall
Side wall	Wall	Adiabatic wall
Glass	Wall	Convection losses
Absorber plate	Wall	Adiabatic wall

The distillate channel was specified as outlet with pressure-outlet condition. In solar still, the solar radiation first incident on the glass and then it passes and absorb by the absorber plate. So, the transmittivity of glass and absorptivity of absorber plate was taken into an account. After defining the phases, phase interaction was taken into an account. The two main interactions were mass and surface tension interaction between the phases. For mass interaction, two mass transfer mechanisms were specified i.e., mass transfer from water to vapor and then vapor to water. The mechanism used for this mass transfer is evaporation and condensation. The second phase interaction used is surface tension. The surface tension coefficient was specified as 0.072 n/m. the region adaption was used to specify the water present in the basin of the solar still. The depth of the water in the basin of still was assumed as 2.5cm. Convergence criteria for residual were set as follows:

- Criteria for residuals of continuity is 10^{-3}
- Criteria for residuals of velocity component is 10^{-3}
- Criteria for residuals of energy is 10^{-6}
- Criteria for residuals of turbulence kinetic energy (k) is 10^{-3}
- Criteria for residuals of rate of dissipation of turbulent kinetic energy \mathcal{E} is 10^{-3}

4 | VALIDATION

In order to validate the CFD model, the numerical results were compared with the experimental study performed by Amit [28]. The numerical results were in good comparison of experimental observations (Fig. 2). The experiment was held at Jaipur, India on 19th May 2014. The comparison was made using water temperature and had calculated the mass produced per unit area. The basin absorbs more energy which helps water to absorb more energy in order to evaporate. The temperature trend was same as the behavior of glass cover temperature but there was a slight difference in the values (Fig. 2) due to experimental and ideal conditions.

Fig. 3 shows the comparison between experimental and simulated mass produced by solar still. The experimental mass flow is 3.5 kg/m^2 and the simulated mass flow is 3.43 kg/m^2 . The unit kg/m^2 is generalized form for values per unit area. Slight difference is again due to ideal CFD results, the difference is results can be due to change in air velocity, change in direction of solar still, dust on solar still, natural errors etc.

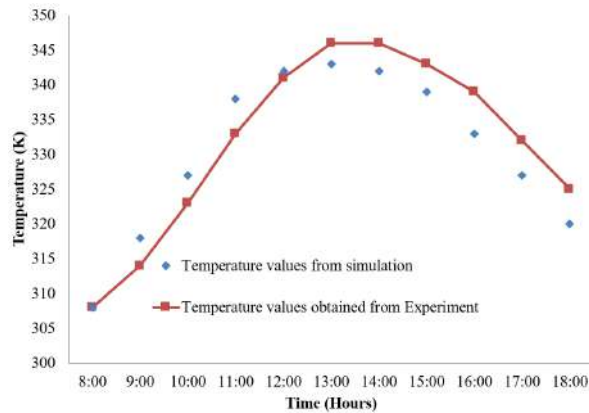


FIG. 2 Temperature of water (experimental v/s simulation result).

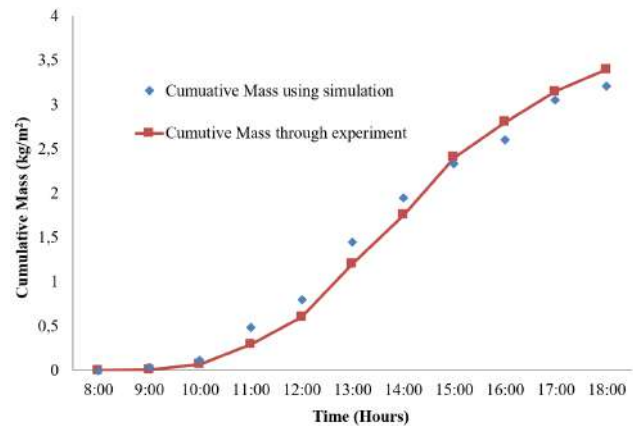


FIG. 3 Cumulative mass (experimental v/s simulation results).

5 | RESULTS AND DISCUSSIONS

After getting the validation, the numerical simulation was used to investigate the performance of single slope solar still at Karachi (24.8607° N , 67.0011° E). The impact of glass tilt angle on the efficiency can be the resultant of the effect of more than one dimension as the change of inclination angle of glass makes numerous changes in solar still dimensions. Therefore, the numerical simulation was performed in two different ways:

- Calculation of the mass flow at different angles by varying basin length and vertical height of solar still with constant glass area
- Calculation of the mass flow at different angles by varying glass length and vertical height of solar still with constant basin area.

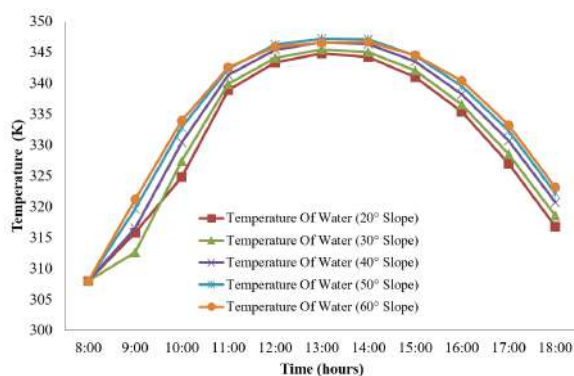


FIG. 4 Temperature of Water at different tilt angle with constant glass area.

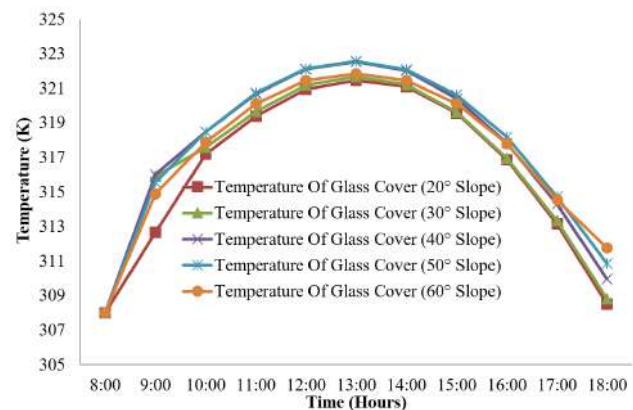


FIG. 5 Temperature of glass cover at different tilt angle with constant glass area.

5.1 | Constant glass area

It is always essential to find an optimal tilt angle of glass to enhance the productivity of solar still. Therefore, by keeping constant glass area of 0.881 square meter and checking production at different angles, it was noticed that the mass production increased by increasing tilt angle. The simulation results at different tilt angles are mentioned in Figs. 4, 5 and 6.

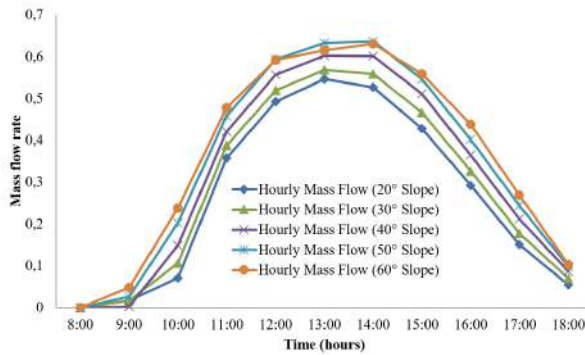


FIG. 6 Hourly mass flow rate at different tilt angle with constant glass area.

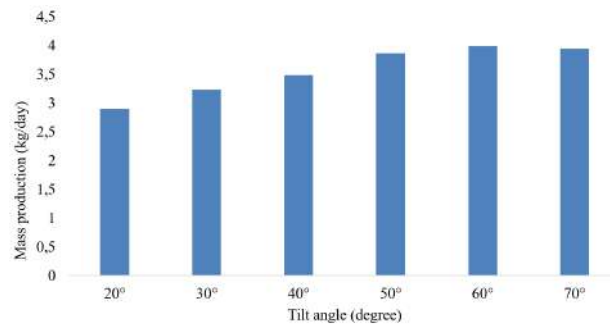


FIG. 7 Mass production at different tilt angles using constant glass area.

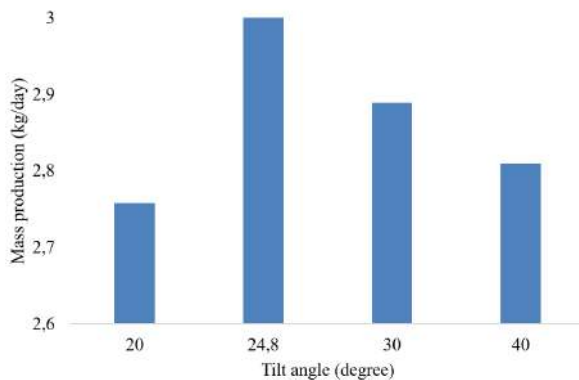


FIG. 8 Mass production at different tilt angles using constant basin area.

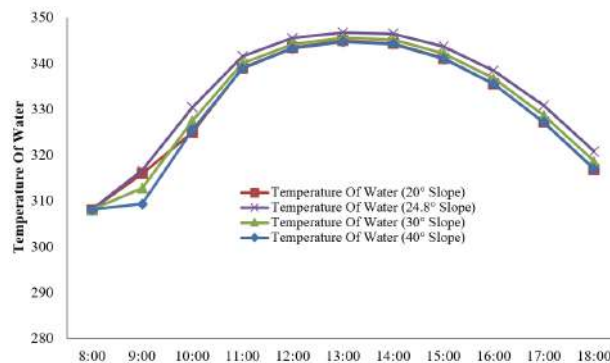


FIG. 9 Temperature of Water at different tilt angle with constant basin area.

The time duration selected for the study is from 08:00 to 18:00 hours which is the average sunshine duration or daylength of Karachi. The maximum practical tilt angle of glass that could be achieved was 60°; above this angle it is very difficult to get a practical length of one side of solar still. Also, due to increase in the tilt, the amount of reflected radiation increases, and ultimately there was a decrease in the still production. Fig. 4 and Fig. 5 show that maximum temperature of water and glass cover for all the possible tilts. It is evident from Fig. 4 and Fig. 5 that maximum temperature of both water and glass cover will occur between 12:00 and 13:00 hours. Generally, between 12:00 and 13:00 hours, solar noon is occurred and at that time the sun shine is higher in sky with higher intensity. Maximum amount of radiation is available which first strikes the glass and after being transmitted from glass, the radiation is being absorbed by water causing the water to evaporate into vapor form and vapor get stucked by the glass surface which ultimately causing the condensation of water at the inner surface of the glass. Also, from Fig. 4 and Fig. 5, the maximum temperature is occurred for the tilt of 60°. Fig. 6 shows the mass flow rate of water produced from the solar still at all the studied tilts on hourly basis. From Fig. 6, maximum flow rate will be occurred between 13:00 and 14:00 hours because maximum amount of water evaporates between 12:00 and 13:00 hours which causes the maximum condensation of

pure water between 13:00 and 14:00 hours. Also, from Fig. 6, it is evident that maximum amount of water is produced for 60°. Fig. 7 shows the mass of fresh water produced at different tilt angles using constant glass area. The mass production showed an increasing trend, however after 60° slope, the production decreased. At a slope of 60°, the maximum amount of water produced is around 4 kg/day. After increasing the tilt angle from 60° to 70°, the amount of pure water production is decreased from around 4 kg/day to around 3.5 kg/day. The pure water production is decreased because by increasing the tilt, the amount of reflected radiation increased and low quantity of radiation are being transmitted by the glass which ultimately results in low quantity of radiation absorbed by the water.

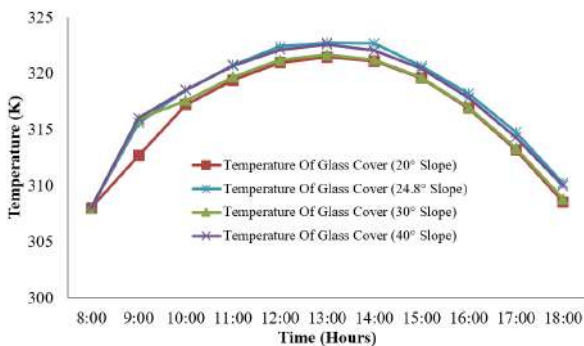


FIG. 10 Temperature of glass cover at different tilt angle with constant basin area.

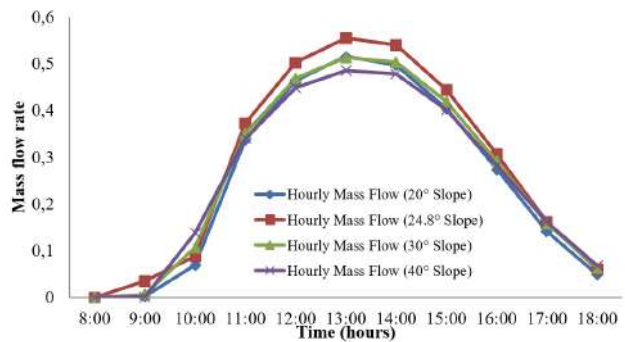


FIG. 11 Hourly mass flow rate at different tilt angle with constant basin area.

Conclusion

The geometrical aspects of the solar still for Karachi have been studied by simulations by varying the tilts. The tilt was varied by considering the two tilts:

- Changing the height of the solar still and the length of the basin while keeping the constant glass area.
- Varying the height of solar still and length of glass cover while keeping the constant basin area.

For both the cases studied, the results obtained from the simulations were in good agreement with the experimental values. It was found that for both the cases studied, the maximum temperature of water and glass covered will be occurred at around 13:00 hours, also, the mass flow rate of water produced is maximum at around 13:00 hours. For constant glass area, the maximum temperature of water and glass cover was occurred at 60°. The maximum mass production was observed at a tilt of 60°. When the tilt was increased from 60° to 70°, the decrement in water production was observed as major portion of radiation was reflected from back from the glass surface instead of being transmitted to the water. For constant basin area, the maximum temperature of water and glass cover was observed for a tilt of 24.8° equal to the latitude of Karachi selected for the study. For more detail study, effects of thickness of glass cover on the mass production of water from solar still can be studied.

References

- [1] D. BidyutJyotiGogoi, "Waterscarcity: A major concern for citizens (ijciet).," *International Journal of Civil Engineering and Technology*, 2019-06-06. <http://www.iaeme.com/IJCIET/index.asp>.
- [2] D. Seckler, R. Barker, and D. Molden, "Water scarcity in the twenty first," *Century"Internation Journal Of Water Resources Development*, 1999-03. DOI: 10.1080/07900629948916

- [3] D. B. Ahmed, "Water management: A solution to water scarcity in pakistan," *Journal of Independent Studies and Research – MSSE*, vol. 9 Number 2, 2011.
- [4] A. RazaKalair, Q. NaeemAbas, A. EsmatKalair, and N. Khan, "Water, energy and food nexus of indus water treaty: Water governance," 2019-04-10. DOI: [10.1016/j.wen.2019.04.001](https://doi.org/10.1016/j.wen.2019.04.001)
- [5] A. G. Buret, C. B. Amat, A. Manko, J. K. Beatty, M. C. Halliez, A. Bhargava, J.-P. Motta, and J. A. Cotton, "Giardia duodenalis: New research developments in pathophysiology, pathogenesis and virulence factors," 2015-07-11. DOI: [10.1007/s40475-015-0049-8](https://doi.org/10.1007/s40475-015-0049-8)
- [6] C. V. Mohod and J. Dhote, "Review of heavy metals in drinking water and their effect on human health," *International Journal of Innovative Research in Science, Energy and Technology*, vol. 2, 2013.
- [7] HusnainHaider, "Disinfection techniques of rural water supplies in developing countries," 2006.
- [8] "Types of renewable energy". renewable energy world.com." <http://www.renewableenergyworld.com/rea/tech/home>.
- [9] M. Malik, G. Tiwari, A. Kumar, and M. Sodha, *Solar Distillation*. Oxford, UK: Pergaman Press, 1982.
- [10] K. A. MojtabaEdalatpour, G. Ali Kianifar, and S. OmidMahian, "Solar stills: A review of the latest developments in numerical simulations," *Solar Energy*, 2016-06. DOI: [10.1016/j.solener.2016.03.005](https://doi.org/10.1016/j.solener.2016.03.005)
- [11] A. SafwatNafey, M. Abdelkader, A. Abdelmotalip, and A. Mabrouk, "Parameters affecting solar still productivity," *Energy Convers*, vol. 41, p. 1797–809, 2000.
- [12] A. Hayek and B. O., "The effect of using different designs of solar still in water distillation," *Desalination*, vol. 169, p. 121–7, 2004.
- [13] C. Okeke, S. Egarievwe, and A. AOE., "Effects of coal and charcoal on solar still performance," *Energy*, vol. 15, no. 11, p. 1071–3, 1990.
- [14] N. Rahbar and E. JA., "Experimental study of a novel portable solar still by utilizing the heat pipe and thermoelectric module," *Desalination*, vol. 284, p. 55–61, 2012.
- [15] E.-S. AA., "Effect of wind speed on some designs of solar stills," *Energy Convers Manag*, vol. 41, p. 523–38, 2000.
- [16] H. Yousef and M. Abu-Arabi, "Modelling and performance analysis of a regenerative solar desalination unit." *applied thermeng* 2004;24:1061–72."
- [17] D. RV., "Solar water distillation: the roof type still and a multiple effect diffusion still," in *Proceedings of the international conference of heat transfer*, vol. 108, p. 895–902, University of Colorado, 1961.
- [18] A. El-Sebaai, "Effect of wind speed on active and passive solar stills," *Energy Convers Manag*, vol. 45, p. 1187–204, 2004.
- [19] A. El-Sebaai, "On effect of wind speed on passive solar still performance based on inner/outer surface temperatures of the glass cover," *Energy*, vol. 36, p. 4943–9, 2011.
- [20] M. Malik, G. Tiware, A. Kumar, and M. Sodha, *Solar distillation*. Oxford, UK: Pergamon Press, 1982.
- [21] A. Nafey, M. Abdelkader, A. Abdelmotalip, and A. Mabrouk, "Parameters affecting solar still productivity," *Energy Conversion and Management*, vol. 41, p. 1797–809, 2000. DOI: [10.1016/S0196-8904\(99\)00188-0](https://doi.org/10.1016/S0196-8904(99)00188-0)
- [22] H. A. A., "Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors," *Renew Energy*, vol. 22, p. 525–40, 2001. DOI: [10.1016/S0960-1481\(00\)00093-8](https://doi.org/10.1016/S0960-1481(00)00093-8)

- [23] M. Malik, F. Musharavati, and S. Khanmohammadi, "Solar still desalination system equipped with paraffin as phase change material: exergoeconomic analysis and multi- objective optimization," 2021. DOI: [10.1007/s11356-020-10335-9](https://doi.org/10.1007/s11356-020-10335-9)
- [24] N. Rehman, "Optical-irradiance ray-tracing model for the performance analysis and optimization of a façade integrated solar collector with a flat booster reflector," *Solar Energy*, vol. 173, p. 1207–1215, 2018. DOI: [10.1016/j.desal.2019.01.026](https://doi.org/10.1016/j.desal.2019.01.026)
- [25] A. Santos Jaimes, H. Hernandez, and Z. Ramirez, "Experimental evaluation of a single slope solar still," *TECCIENCIA*, vol. 12, no. 22, p. 61–71, 2017. DOI: [10.18180/tecciencia.2017.22.7](https://doi.org/10.18180/tecciencia.2017.22.7)
- [26] M. Attia, A. Karthick, A. Manokar, Z. Driss, A. Kabeel, R. Sathyamurthy, and M. Sharifpur, "Sustainable potable water production from conventional solar still during the winter season at algerian dry areas: energy and exergy analysis," *Journal of Thermal Analysis and Calorimetry*, vol. 145, no. 3, p. 1215–1225, 2021.
- [27] G. B. Balachandran, P. W. David, R. K. Mariappan, A. E. Kabeel, M. M. Athikesavan, and R. Sathyamurthy, "Improvising the efficiency of single-sloped solar still using thermally conductive nano-ferric oxide," *Environmental Science and Pollution Research*, vol. 27, no. 26, 2020, p. 32191–32204. .
- [28] A. Hoque, A. H. Abir, and K. P. Shourov, "Solar still for saline water desalination for low-income coastal areas," *Applied Water Science*, vol. 9, no. 4, p. 1–8, 2019. DOI: [10.1007/s13201-019-0986-9](https://doi.org/10.1007/s13201-019-0986-9)
- [29] F. Abed, M. Kassim, and M. Rahi, "Performance improvement of a passive solar still in a water desalination," *International Journal of Environmental Science and Technology*, vol. 14, no. 6, 2017. DOI: [10.1007/s13762-016-1231-9](https://doi.org/10.1007/s13762-016-1231-9)
- [30] C. Sasikumar, A. Manokar, M. Vimala, D. Winston, A. Kabeel, R. Sathyamurthy, and A. J. Chamkha, "Experimental studies on passive inclined solar panel absorber solar still," *Journal of Thermal Analysis and Calorimetry*, vol. 139, no. 6, p. 3649–3660, 2020. DOI: [10.1007/s10973-019-08770-z](https://doi.org/10.1007/s10973-019-08770-z)
- [31] A. Kumar, "Cfd modeling and validation of a single slope solar still," *Department of Mechanical Engineering M.N.I.T.*



