Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Experimental Investigation of Parameters Affecting Productivity of Single Slope Basin Type Passive Solar Still

Shah Nawaz Ansari [a], Nawraj Bhattarai[b], Sanjaya Neupane [c]

[a, b, c] *Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE, TU, Nepal*
[a] ansari.nawaz1406@gmail.com, [b] nawraj.bhattarai@pcampus.edu.np, [c] sanjaya@pcampus.edu.np

Abstract
Water is one of the basic needs for sustaining life on earth. A significant portion of the water present on earth is not suitable for direct usage despite being a renewable energy source. The world's drinkable water supply is steadily decreasing, with depletion occurring most prominently due to rising population, urbanisation, industrialisation and environmental pollution. One-third of the population of the world lives in countries where there is insufficient availability of fresh water. The solar desalination method can solve the problem in future if proper research and development are done. One of the devices which are based on the solar desalination method is solar still. The problem of potable water can be solved by solar still without any implementation of high-grade energy or costly energy. Solar still could be used in remote areas where there is the unavailability of electricity as a solar still is completely based on solar energy. Solar still faces the major challenge of desalinated water's low productivity. Thus, the study and research on various operational and design parameters is most needed. Hence, this research investigates the key parameters of single slope basin type solar still and their effect on its productivity. The effect of basin water depth, ambient temperature, basin temperature, etc., on the water productivity has also been investigated.

Keywords
Water Desalination, Solar Energy, Single Slope, Solar Still, Passive Still, Productivity, Evaporation, Condensation

1. Introduction

Water is known as one of the basic need for human beings required simultaneously with food to eat and air to breathe sustaining life on Earth as per current situation. Water and the life of human beings are immensely interrelated to each other. Water is considered to be playing as one of the pivot roles in the development and welfare of any civilisation. Each and every field associated with human life are directly or indirectly dependent on clean drinking water. Due to this reason, the availability of pure and clean water is considered as major global issue as per the current scenario of the world.

Water is the most unique and invaluable gift to living beings from nature that is abundantly present on Earth. More than seventy percent of the Earth is covered by water, but the majority of this percentage is not suitable for direct human usage. Out of total available water on Earth, ninety-seven percent is in the ocean in the form of saline water, approximately two percent of water is covered by ice in polar regions, and only remaining one percent can be used to fulfil the need of plants, animals and human life that is available in the forms of lakes, rivers and underground water. Though this small share of accessible clean water is sufficient to lead human life and other usage, the rapid population growth and fast industrialisation is narrowing the access to potable water [1].

Water Desalination is an effective method to raise the supply of clean potable water as per the increasing demand. Water desalination is a traditional and old method for converting saline water into potable clean water. It is one of the sustainable solution for providing clean drinking water in most of the countries. Desalination of water provides access to clean potable water which can result in many socio-economic benefits such as better health and hygiene, improvement in quality of life, enhanced living standards, improvement in social interactions and so on [2]..

More than one billion people of the world are facing the challenge of unavailability of pure drinking water in which majority of the people are from rural areas as per the estimation of the World Health Organization. Water purification techniques such as electro dialysis, multi-stage evaporation and reverse osmosis are power-intensive processes, making it not feasible for remote areas. Such difficulties could be easily solved by the successful integration of renewable energy sources to the desalination process [3].

Solar energy is present in abundance quantity in remote areas due to which opportunity of using solar energy sources for desalination of water can be utilised. Application of solar energy for the desalination of water is considered as one of the most promising and economical method. The main reason for using solar desalination process is that solar energy is present in abundance and there is no challenge of spacing in the remote areas [4].

2. Literature Review

The device used for distillation or desalination of water by the application of solar energy actively or passively, as a result of which potable and clean water is obtained for consumption by human beings, is termed as 'solar still'. The working principle of solar still is based phenomenon of evaporation and condensation taking place inside it. Solar still could be appeared as an alternative method for fulfilling potable water demand in the rural areas as commercial distillation process in such areas are not feasible due to the unavailability of electricity and expensive fossil fuels. Since solar energy is immense, abundant, clean and pollution free, the device is very economical and feasible [5].

Despite various advantages, solar still suffers from the issue that the production of distillate water or desalinated water is very low. The major challenge with solar still is to enhance productivity without compromising its low cost [6]. Hanson et al. (2004) stated single slope solar still as one of the most efficient methods for removing non-volatile water impurities. Some researchers also suggested solar still for the distillation of alcohol [7].

Madhlopa (2012) studied the behaviour of depth of water on the internal heat and mass transfer occuring in single basin double slope solar still. The study concluded that the productivity is inversely proportional to basin water depth. That means the productivity of the solar still is increased when the basin water depth is decreased in the basin [8].

Qahtan A. et al. (2014) experimentally and numerically researched the consequences of water film flowing over the transparent inclined glass. The research stated that it is appropriate to use glazed water film to improve thermal and decrease the cooling loads for glazed buildings [9]. Deshmukh and Thombre (2017) stated that the effect of different parameters such as operational, design and climatic parameters on the productivity and performance of the solar still based on different numerical and experimental studies. One major parameter examined was the solar radiation, a tilt angle of glass angle, depth of saline water and blackened material [10].

3. Methodology

This section provides the detail of the method used for the completion of research from idea generation phase to the completion phase. It gives brief about formula used, instrumentation details and experiment methods.

3.1 Mathematical Formulations

The present model takes the reference of equations developed by Dunkle. Various conditions were assumed for the simplicity of the analysis [11].

- There is no any leakage from the solar still
- The heat capacity of basin water and insulating material used in solar still is considered to be negligible.
- Physical properties of water is considered constant at different temperatures

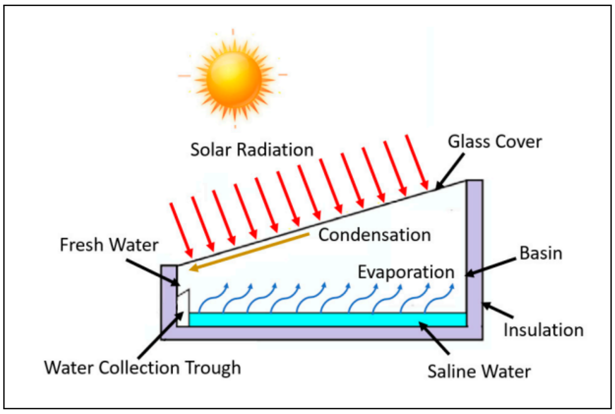

Figure 1: Heat Transfer phnomenon involved in Solar Still

Figure 1 portrays different types of phenomenon due to which heat transfer takes place inside solar still. Heat transfer process inside solar still is evaluated by dividing into various parts such as glass, basin, input saline water, internal heat transfer process for the ease in evaluation of heat transfer distribution and temperature rates inside solar still [12].

Expression is formulated in term of temperature of water (T_w), temperature of basin (T_b), and glass temperature (T_g). The provided input parameters of the solar still are temperature of glass, initial temperature of water and initial temperature of basin. The partial vapour pressure (P_g) and water pressure (P_w) can be obtained by the use of following equations [13].

$$P_w = \exp\left(25.317 - \frac{5144}{T_w + 273}\right) \tag{1}$$

$$P_g = \exp\left(25.317 - \frac{5144}{T_g + 273}\right) \tag{2}$$

The difference in temperature between the water inside the basin and the internal surface of glass is the main reason for natural convection. Rate of convective heat transfer (Q_{Cwg}) and heat transfer coefficient (h_{Cw}) between water and the inner glass surface is expressed as follows.

$$Q_{Cwg} = h_{Cwg} \times (T_w - T_g) \tag{3}$$

$$h_{cwg} = \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{268900 - P_w}\right]^{1/3} \tag{4}$$

The generation of evaporation heat transfer occurs when the vapour pressure is less than the saturation pressure of the liquid inside the solar still. It arises in between the mass of water and the inner glass surface of solar still.

$$Q_{Ewg} = h_{Ewg} \times (T_w - T_g) \tag{5}$$

$$h_{Ewg} = 16.28 \times 10^{-3} \times h_{Cwg} \left(\frac{(P_w - P_g)}{(T_w + T_g)}\right) \tag{6}$$

The production of radiation heat transfer takes place due to the emission of internal energy among two bodies having different temperatures. The two bodies in this case is mass of water and the surface of glass of solar still. The expression for heat transfer and heat transfer coefficient due to radiation is expressed as following.

$$Q_{Rwg} = h_{Rwgi} \times (T_w - T_g) \tag{7}$$

$$h_{Rwg} = \varepsilon_{eff}\sigma \left[\frac{(T_w + 273)^4 - (T_g + 273)^4}{(T_w - T_{gi})}\right] \tag{8}$$

It depends on the water's emissivity (ε_w) and glass's emissivity (ε_g) . The relation is given by the following equation:

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1} \tag{9}$$

The rate of total heat transfer (Q_{Twgi}) and the total heat transfer coefficient (h_{Twgi}) occuring internally inside solar still can be given as the summation of convection, evaporation and radiation rates which are expressed follows.

$$Q_{Twg} = Q_{Cwg} + Q_{Ewg} + Q_{Rwg} \tag{10}$$

$$h_{Twg} = h_{Cwg} + h_{Ewg} + h_{Rwg} \tag{11}$$

Solar Still's hourly productivity can be calculated as follows.

$$m_{ew} = \frac{Q_{Ewg}}{L_{ev}} \tag{12}$$

Solar Still's daily productivity can be then obtained as follows.

$$M_w = \sum_{i=1}^{24} m_w \tag{13}$$

3.2 Solar Still Fabrication

Solar Still is an insulated box made of metal and wood, covered by inclined transparent glazing material. A dimension of SSSS is shown in figure. The present fabrication of solar still consists of a rectangular basin made by GI sheet. The material for the component of solar still was selected as per the better properties, availability and cost of material. The basin area was taken as 1.0 mX0.8 m. The doublewalled body was constructed, and thick glass wool was sandwiched between the inner GI sheet wall and the outer plywood wall in order to insulate the basin so that minimal heat loss occurs.

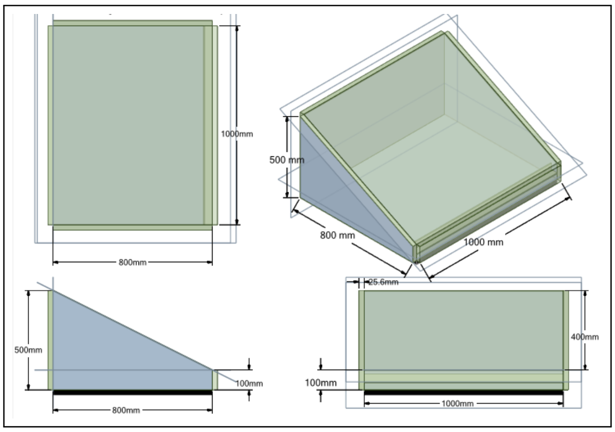

Figure 2: Design of Solar Still made drawn from SpaceClaim.

The inner basin area, which is responsible for absorbing heat, was painted black to increase the absorptivity. Aluminium foil was placed on the inner side walls of the basin for proper reflection of solar radiation towards the basin surface. A transparent glass material of thickness 5 mm was used as glazing material that was placed over the inclined face of solar still. The glass cover was inclined at a latitude angle towards the south, Kathmandu. The experiment was performed on the terrace of Balaju School of Engineering and Technology.

The various steps involved in fabrication are:

1. Fabrication of support structure in order to give support to the SS.

2. Cutting the plywood for making outer body as per the dimension.

3. Marking, Cutting and Folding GI sheet as per the dimension for internal component of SS.

4. Painting the base of the GI sheet black and assembly outer plywood, inner GI folded sheet and glasswool on the support structure.

5. Attaching aluminium foil and giving possible passage for water inlet and outlet.

6. Cutting and placing 5 mm thick glass as glazing material on the top of the SS.

7. Check for leakage and further proceeded to experiment.

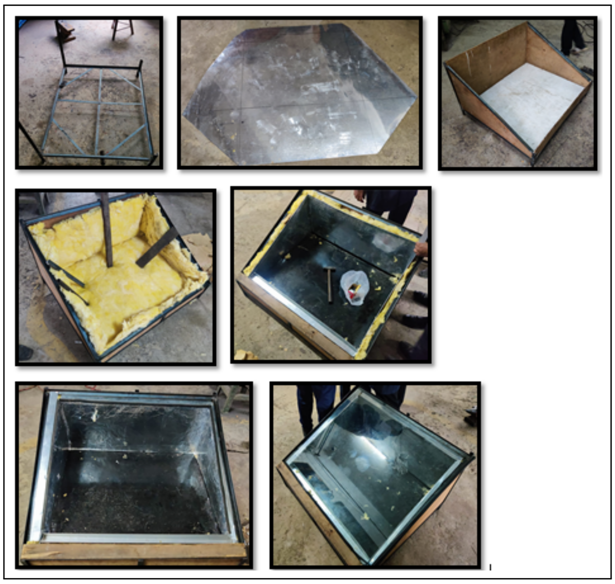

Figure 3: Steps of Fabrication of Experimental Solar Still

3.3 Data Collection

Both primary as well as secondary data was used during the experiment. The experiment was conducted for the daytime period of 12 hours from 7:00AM to 18:00 PM. Following methods was used for taking readings of various data:

- Thermocouple: K-type thermocouple was used for measuring and taking readings of the ambient, basin and glass temperature of solar still.

- Digital Multimeter: Mars DMM-90 digital multimeter was used to take the reading from the thermocouple.

- Department of Hydrology and Meteorology (DHM), Kathmandu: The data for hourly solar irradiance and wind speed was taken from the Department of Hydrology and Meteorology, Kathmandu.

4. Results and Discussions

The experiment was performed at the roof of Balaju School of Engineering and Technology (BSET), Kathmandu for the period of 11 hours from 7AM in the morning to 18PM in the evening. Each major data such as ambient temperature, basin temperature and glass temperature of solar single was taken with the help of thermocouple connected to the digital multimeter. Furthermore, the data of wind speed and solar irradiance was taken of TIA substation from the Department of Hydrology and Meteorology (DHM), Kathmandu.

Table 1: Various data obtained after experiment

T(h)	I(t)	V_w	T_a	T_w	T_g	$m_{ew}(exp.)$
07:00	94.6	1.4	20.4	20.8	16	0
08:00	94.6	1.2	23	25	19	0.004
09:00	575.9	3.1	24.7	33	25	0.01
10:00	799.8	2.9	26.1	46	35	0.051
11:00	969.1	4.3	27	52	37	0.082
12:00	1078.6	4.4	27.9	70	47	0.352
13:00	1049.2	4.9	28.3	68	44	0.318
14:00	527.4	4.6	27.8	59	43	0.142
15:00	497.3	4.4	27.6	53	37	0.112
16:00	584.1	5.2	27.7	52	36	0.106
17:00	533.1	4.3	27.8	50	34	0.092
18:00	273.5	3.8	27.1	41	32	0.018

Table 2: Various data obtained after from calculation

P_w	P_g	h_{cwg}	h_{ewg}	$m_{ew}(Th.)$
2461.41	1840.32	1.50	3.15	0.007
3150.31	2209.59	1.61	4.12	0.011
4947.03	3150.31	1.78	6.52	0.023
9814.42	5517.62	2.01	12.78	0.062
13217.64	6145.35	2.25	17.25	0.114
30330.69	10321.66	2.71	38.39	0.391
27776.79	8865.04	2.73	34.96	0.371
18453.77	8421.30	2.33	23.80	0.168
13875.21	6145.35	2.30	18.08	0.128
13217.64	5828.05	2.30	17.26	0.122
11983.71	5225.47	2.29	15.72	0.111
7591.88	4681.75	1.87	9.84	0.039

The unit of I(t) is W/m^2, V_w is m/s, $T_a/T_w/T_g$ is ^0C, P_w/P_g is Pa., h is $W/m^2.^0C$ and m_{ew} is kg/m^2h

Equation discussed in the earlier section was applied to determine hourly productivity of solar still. Finally the theoretical productivity is compared with the experimental productivity. The overall result of the solar still taken over a period of 11 hours at Kathmandu is provided in given table. Table 1 shows various results obtained after experiment and Table 2 shows calculations over a period of 11 hours at Kathmandu.

Based on the result and data obtained in table 1, various curves was plotted using excel software in order to obtain the behaviour pattern of various parameter. Figure 4 shows the plot for the solar irradiation verses time of the day. The curves shows that maximum solar radiation occurs at 12:00. The sudden decrease was due to the cloudy weather at respective time.

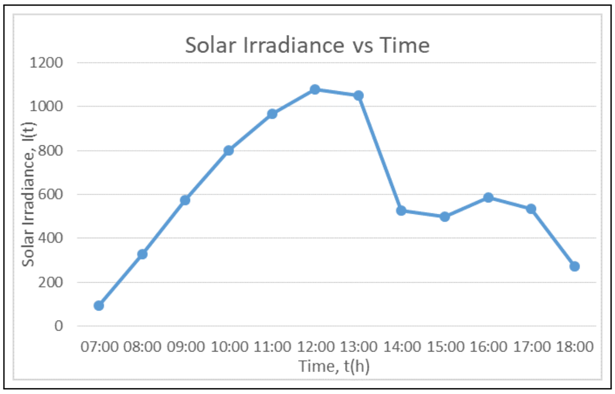

Figure 4: Plot between solar irradiance and time

Figure 5 shows the plot of behaviour of different temperatures i.e., the ambient temperature, temperature of water inside basin and temperature of glass cover with respect to the time of the day. The curves are quadratic in nature with maximum value occurring as 27.9, 70 and 47°C at 12:00. It was noticed that this high temperature is due to high irradiance and various heat transfer process going to the glass.

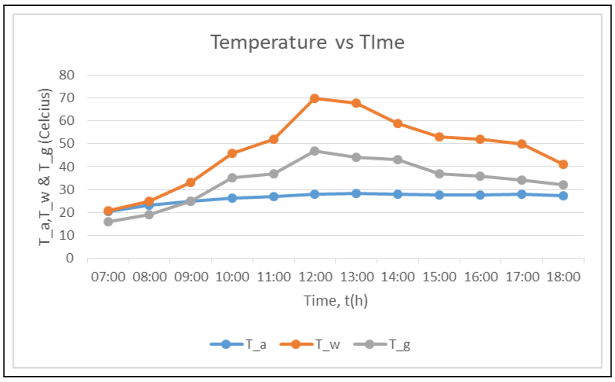

Figure 5: Plot between ambient temperature, water temperature, glass temperature and time

Figure 6 shows a curve plotted between the difference of partial pressure at water and glass temperatures. It shows that Partial pressure follow the similar trend as water temperature and glass temperature. Partial pressure rises at the mid of the day due to high temperature and high solar irradiance. Figure 8 shows the curve behaviour between wind velocity and water temperature. As the wind some time, temperature decreases as wind velocity decreases.

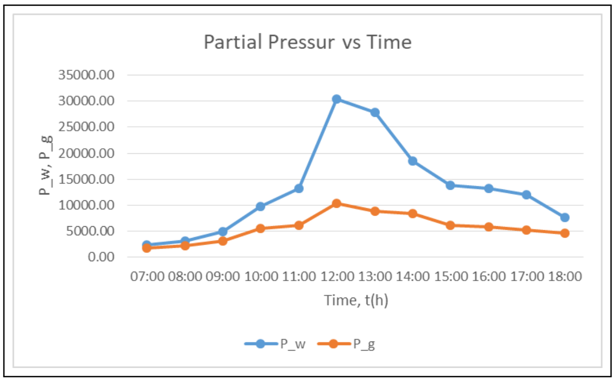

Figure 6: Plot between Partial pressure of water, glass with time

Figure 7 shows the curve behaviour between wind velocity and water temperature. As the wind velocity rises basin temperature also rises. After some time, temperature decreases as wind velocity decreases.

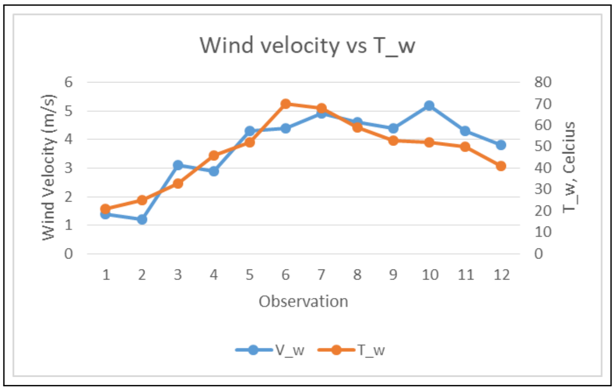

Figure 7: Plot between wind velocity and water temperature

Figure 8 shows the curve between wind velocity and hourly productivity. It shows till some point productivity increases with increases in wind velocity but after certain point productivity starts decreasing.

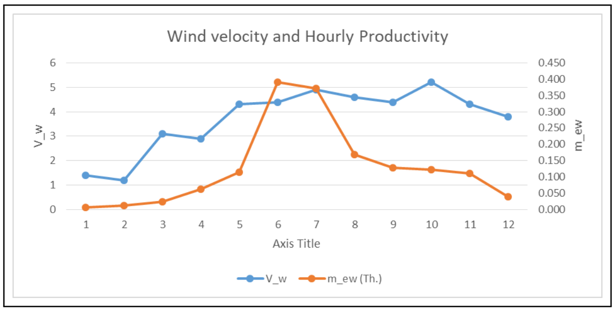

Figure 8: Plot between wind velocity and hourly productivity

Figure 9 shows the behaviour of hourly productivity with respect to ambient temperature, water temperature and glass temperature. It shows that as the temperature of glass and water rises, the production of distillate also rises.

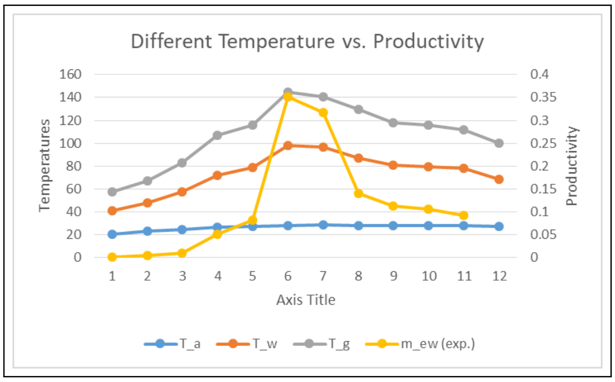

Figure 9: Plot between amibient, water, glass temperature and hourly productivity

Figure 10 shows how solar irradiance impact on hourly productivity. The curve shows similar trend. As solar radiation falling upon solar still goes on increasing, hourly productivity also increases. As solar irradiance decreases, hourly productivity also goes down.

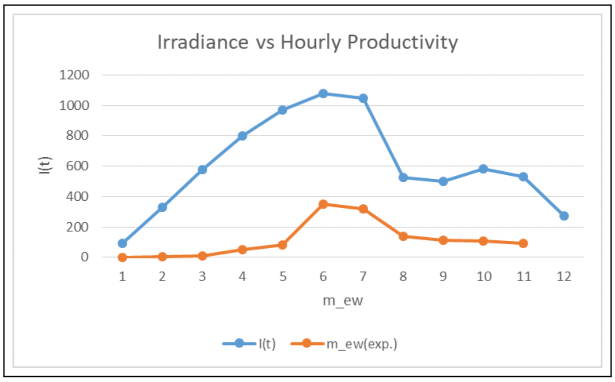

Figure 10: Plot between solar irradiance and hourly productivity

Figure 11 shows the comparison between the value obtained by using equations and the experimental value of hourly productivity. Both theoretical and experimental productivity are in good agreement with each other as they show similar trend.

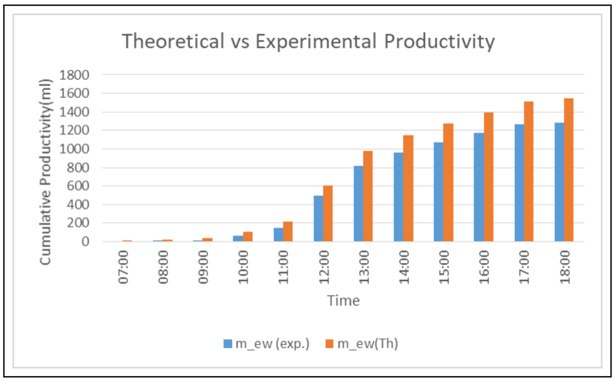

Figure 11: Comparison between daily cumulative theoretical and experimental productivity

5. Conclusions and Recommendation

Solar Still fabrication was done to perform testing and based on the obtained data, analysis was made under actual conditions of Balaju, Kathmandu. Experimental investigation was done on various parameter based on which it can be concluded that the major parameter that affect the productivity of solar still is the temperature of glass, basin along with total solar irradiance and wind speed. The experimental result showed that it is in good agreement with the theoretical value and similar trend between theoretical and experimental value has been observed. There is some error and difference between both results due to the losses encountered in real environment conditions during experiment.

The productivity can be enhanced if these parameter could be enhanced. For example, using different material of basin to increase heat transfer process. Similarly, material of glass and basin could also help in enhancing the temperature of glass and basin due to which productivity could be enhanced.

Acknowledgments

The author acknowledges Department of Hydrology and Meteorology, Kathmandu for providing required data for the research. The author also acknowledges Mr. Ishwar Lal Shrestha, Mechanical Coordinator and Er. Sudeep Sah of Balaju School of Engineering and Technology for continuously guiding during the fabrication works.

References

[1] Shihe Zhou, Luyuan Gong, Xinyu Liu, and Shengqiang Shen. Mathematical modeling and performance analysis for multi-effect evaporation/multi-effect evaporation with thermal vapor compression desalination system. *Applied Thermal Engineering*, 159:113759, 2019.

[2] M Muraleedharan, H Singh, M Udayakumar, and S Suresh. Modified active solar distillation system employing directly absorbing therminol 55–al2o3 nano heat transfer fluid and fresnel lens concentrator. *Desalination*, 457:32–38, 2019.

[3] AE Kabeel and Mohamed Abdelgaied. Improving the performance of solar still by using pcm as a thermal storage medium under egyptian conditions. *Desalination*, 383:22–28, 2016.

[4] Mohammad Ali Pakdel, Mahdi Hedayatizadeh, Seyed Mahmoud Tabatabaei, and Naser Niknia. An experimental study of a single-slope solar still with innovative side-troughs under natural circulation mode. *Desalination*, 422:174–181, 2017.

[5] Bhumit Solanki and Jatin Patel. Recent developments in solar desalination with thermal energy storage. *International Journal of Engineering Research and Applications*, 7:28–36, 2017.

[6] Mojtaba Edalatpour, Ali Kianifar, and Shamsoddin Ghiami. Effect of blade installation on heat transfer and fluid flow within a single slope solar still. *International Communications in Heat and Mass Transfer*, 66:63–70, 2015.

[7] A Hanson, W Zachritz, K Stevens, L Mimbela, R Polka, and L Cisneros. Distillate water quality of a single-basin solar still: laboratory and field studies. *Solar energy*, 76(5):635–645, 2004.

[8] A Madhlopa. Theoretical and empirical study of heat and mass transfer inside a basin type solar still. *Energy*, 136:45–51, 2017.

[9] Abdultawab Qahtan, SP Rao, and Nila Keumala. The effectiveness of the sustainable flowing water film in improving the solar-optical properties of glazing in the tropics. *Energy and Buildings*, 77:247–255, 2014.

[10] HS Deshmukh and SB Thombre. Solar distillation with single basin solar still using sensible heat storage materials. *Desalination*, 410:91–98, 2017.

[11] RV Dunkle. Solar water distillation: the roof type still and a multiple effect diffusion still. In *Proc. International Heat Transfer Conference, University of Colorado, USA, 1961*, volume 5, page 895, 1961.

[12] YAF El-Samadony, Wael M El-Maghlany, and AE Kabeel. Influence of glass cover inclination angle on radiation heat transfer rate within stepped solar still. *Desalination*, 384:68–77, 2016.

[13] Abhay Agrawal, RS Rana, and Pankaj K Srivastava. Heat transfer coefficients and productivity of a single slope single basin solar still in indian climatic condition: Experimental and theoretical comparison. *Resource-Efficient Technologies*, 3(4):466–482, 2017.