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Experimental Investigation and Performance Analysis of Single Slope Solar Still

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Abstract- Shortage of good drinking water supply is one of the major challenges facing the global community especially developing and under developed countries, like Nigeria. However, these challenges can be overcome through the use of solar stills for water distillation which is considered as a viable option for converting dirty water to distillate. The solid particles (dissolved minerals) which were left behind at the basin during the distillation process gradually accumulated and cause basin corrosion and/ or low yield, in order to have a sustainable and working solar distillation technology, this paper presents an experimental investigation and performance analysis of single slope solar stills of identical basin area (0.35 m^2). The stills includes; still D_1, (conventional with galvanized iron basin), still D_2, (galvanized iron basin with 4inch hand hole attached at the side), still D_3,(conventional with blacked ceramic basin), and still D_4, (Ceramic basin with 4 inch hand hole attached at the side). The result obtained show that stills D_1, and D_2 with galvanized iron (GI) basin revealed higher productivity of 580ml/day and 510ml/day respectively, compared to stills D_3, and D_4, which have 340ml/day and 315ml/day respectively. Further results indicate that still D1 with galvanized iron at the basin and hermetic seal has greater efficiency and distillate productivity of 54.06 % compared to stills D2, D3 and D4 which have daily efficiency and productivity of 50.91 %, 28.20 %, and 27.97 % respectively. This however, indicates that the adoption of 4 inch hand hole in solar still design can help in reducing the particles deposits at the basin to minimize basin corrosion.

Keywords Ceramics; Galvanized iron; Basin; solar still; heat transfer; heat loss.

1. Introduction

Energy and water are two basic essential commodities that provide a good living standard [1]. These commodities play a vital role in socio-economic development of the nation [2]. Shortage of portable drinking water is a major challenge that affects almost all the developing countries, such as Nigeria. Nowadays, as the world population growth increases, more industrial and Agricultural activities take place. This tends to increase the water usage and contaminate more surface water. In recent years, much concern is given to the development of sustainable technology for water purification, where solar distillation is among the techniques considered to be the alternative option for converting dirty or brackish water in to portable drinking water, being it cheapest and most convenient method [3, 4].

Solar distillation is a water purification technology which uses solar energy to purify contaminated water through a process of greenhouse effect and hydrological cycle [5, 6]. Single slope solar distiller is one of the commonly available solar distillation devices in use today. Single slope and double slope form the basic design of basin type solar still [7]. The performance of the basin type solar distiller is affected by several parameters, the most basic are; metrological (such as solar radiation intensity, surrounding air temperature, relative humidity etc), thermal and physical parameters of the basin materials (thermal conductivity, density etc), operating parameters of distiller (water level and initial temperature of water at the basin) and design parameters (orientation and inclination angle) [8]. However, different studies were conducted to improve the still productivity base on these parameters. Sampathkumar et al [9] performed a historic review and revealed that a maximum yield can be obtain when the inclination angle is equal to the latitude of the location. Considering the facts that other parameters, such as glass temperature and wind speed can influence the distillates output, Tiwari et al [10] conducted performance investigation of passive solar still at different water levels (depths). The results revealed that the annual yield was higher for medium and low water depths, and lower for high water depths in summer compared to winter. They also found that for low and medium water depths evaporative energy fraction superseded radiative energy fraction during the summer whereas for high depth the opposite was the case.

In an attempt to address the ignored challenge of basin corrosion, Umar et al [1] carried out comparative performance study on the efficiencies of three solar still with different design: two still are made up of galvanized iron basin (removable top cover and non removable top cover) and the other one is made up of blackened ceramic with non removable top cover. The results showed that solar distiller with galvanized iron and non removable top revealed higher efficiency, followed by the still with blackened ceramic basin. They recommended that the still with blackened ceramics could be used despite its low performance compared with galvanized iron and Non-removable top still due to its non corroding advantage over galvanized iron basin still [11]. However, during the distillation process using solar energy, water evaporates leaving behind dissolved metals (and minerals) and other biological contaminates at the basin, which tends to corrode the entire basin area with time and cause low distillate yield.

A Literature survey indicates that few studies have been published about the effect of corrosion on the basin [12 – 14]. Regular washing (probably once a month) depending on minerals and residues left on the basin is a step to mitigating this problem. To achieve this objective, modifications were made on regular solar still by creating a hole on one side for easy entrance of hand. This may probably have an effect on the still performance. To further investigate this effect, experiments were carried out to evaluate the performance of four identical basin ($0.35m^2$) type single slope solar stills with different design modification, named Still D_1 (with galvanized iron basin), still D_2 (with galvanized iron basin side 4 inch hand hole), still D_3 (with ceramic basin), and still D_4 (with ceramics basin side 4 inch hand hole) simultaneously, under the prevailing weather condition in Aliero, Kebbi State, Nigeria. The 4 inch hand hole is to serve as means through which the deposited minerals could be washed and flush away via the down hole.

1.1 Solar still description and principles of operation

Solar radiation transmitted in to the still through transparent cover (mostly glass) is absorbed at the basin and heats the water, thereby rising its temperature [15]. This results in evaporation of water molecules to the cover. Therefore, heat is being transferred from water molecules to the glass cover through evaporation, convection, and radiation. The heated water evaporates in form of vapour leaving behind at the basin liner mostly dissolved metals, minerals and microbes through thermal diffusion and condenses on the underside of the cover due to ambient and glass temperature difference. The condense water slip down in to the trough channels that guide it in to a container placed outside for distillate collection [15]. The schematic diagram of distillation process is presented in Fig. 1.

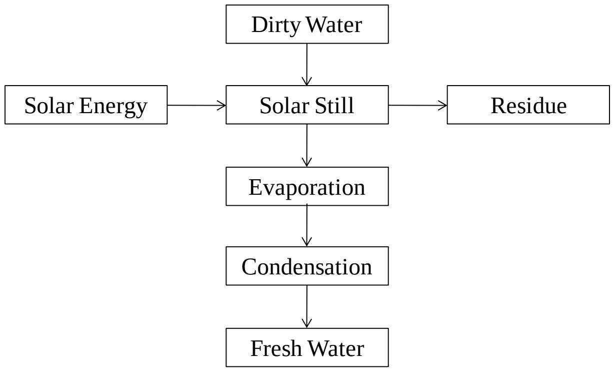
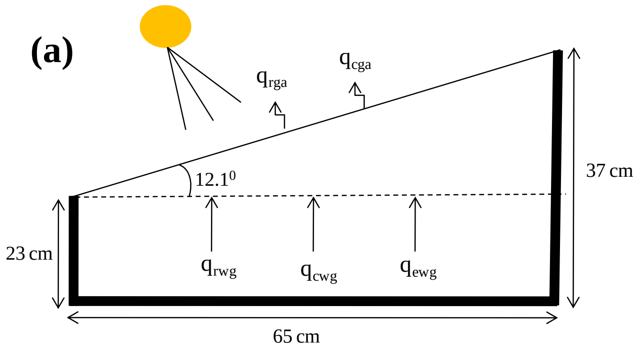


Figure 1: Schematic of Solar Distillation Process.

2. Methodology

Experimental test was carried out under prevalent climatic condition of Kebbi State University of Science and Technology (KSUST) Aliero, in Kebbi State, Nigeria, located at latitude 12° 17′37′′N and longitude 4°28′5′′E, on 6th September 2015. Four identical stills labelled as still D_1, still D_2, still D_3 and still D_4 were filled with small amount of water (at 15 mm depth) to achieve fast heating and maximum evaporation, as low depth give better yield [6,10]. The stills D_1 and D_2 were made from the same basin material; galvanized iron (GI) sheet coated with black paint to enhance their absorption, while basin of stills D_3 and D_4 were made of blackened ceramics of 7 mm thickness. In addition a 4 inch diameter hand hole pipe was attached to the side of Still D_2 and D_4 with a very tight removable cap to ensure airtight in order to minimize heat loss as a result of modification and also enable washing way of the residues accumulated at the basin area during the process through the hole. The basin of the stills were insulated with 2 inch form and 0.5 inch wooden casing to avoid heat loss. The transparent glass of 90% transmittance was used at top cover. Typical cross-section of conventional solar still and still with 4 inch at the side cross-section are shown in Fig. 2 (a) and (b) respectively.

(a)



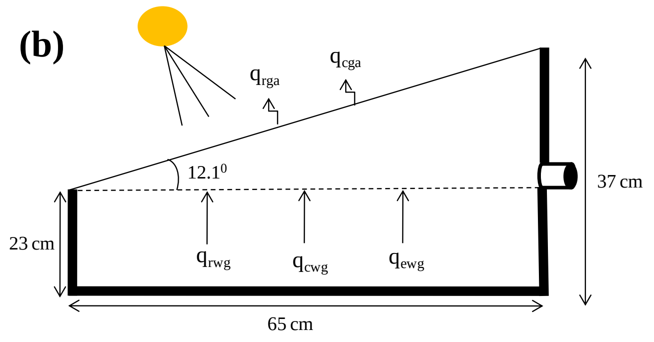


Figure 2: Schematic diagram of (a) conventional (b) modified solar stills

The solar stills, D_1, D_2, D3 and D_4 were exposed to solar radiation horizontally at the same level with their glasses cover inclined at 12.1°, which is almost same with the latitude of the testing area (Aliero town) in order to have maximum reception of solar radiation, as maximum yield can be obtain when the inclination angle is equal to the latitude of the location [9]. The solar stills D_1 , D_2, D_3 and D_4 were filled with contaminated water from University reservoir to a depth 15 mm, with each unit oriented towards the sun. The fed in water is heated by the solar radiation which rises its temperature and result to vapour formation. The vapour formed condenses at the glass cover due to temperature difference. The data was recorded after every 20 minutes from 9:00 am to 6:00 pm local time on the testing day. A total of nine (9) thermocouple channels were used, where a unit is fixed on glass cover and water in the basin of each of the four solar still as well as the outside environment to measure the glass temperature, basin water temperature and ambient temperature. Other parameters measured were wind speed using anemometer and solar radiation using Pyranometer. The amount of distillate was also measured using 500 ml calibrated measuring cylinder.

3. Theoretical Framework and Thermal Analyses of the Solar Stills

The solar distillation process is governed by the following heat energy balance equations.

3.1. Solar Energy Equations Of The Glass Cover (q_g)

The thermal energy balance equations of the glass cover are given by eq. (1) [8].

$$q_{lga} + C_g \frac{dT_g}{dt} = \mathrm{I}\alpha_g + q_{ewg} + q_{rwg} + q_{cwg} \quad (1)$$

Where $q_{lga} = (q_{cga} + q_{rga})$, is the glass surface heat loss to ambient air.

3.2. Heat Energy Balance for Water in the Basin

The energy in form of heat from the hot water at the basin is being lost to enclosed air, when water evaporates to the glass cover, by convection, to the glass, by radiation and through the bottom and side of the still, by the conduction [16].

$$I\alpha_w\tau = q_u + q_l \quad (2)$$

Where q_u $(= C_w \frac{dT_w}{dt})$ is the rate of useful heat and q_l $(= q_{ewg} + q_{rwg} + q_{cwg} + q_b)$ is the overall heat losses from water to glass cover and bottom: i.e q_r is radiative, q_c convective , q_e evaporative , q_b is the conductive loss from water basin . Equation (2) can be written as eq. (3), which is the heat energy balance equation of single slope basin solar still at basin water as given by [10], in accordance with first law of thermodynamics.

$$I\alpha_w\tau = q_{ewg} + q_{rwg} + q_{cwg} + q_b + C_w \frac{dT_w}{dt} \quad (3)$$

3.3 Total Heat Energy Balance of the Single Slope Solar Still

The total heat energy balance on the still can be expressed in eq. (4) as given by [10]

$$I\alpha_w\tau + I\alpha_g = q_{rga} + q_b + C_g \frac{dT_g}{dt} + C_w \frac{dT_w}{dt} \quad (4)$$

Where α_g is the absorbance of glass. The radiative heat transfer (q_{rwg}), from water surface to the condensing cover can be calculated from eq. 5.

$$q_{rwg} = h_{rwg}(T_w - T_g) \quad (5)$$

h_{rwg} is the radiation heat transfer coefficient from water surface to glass, which is given by [13].

$$h_{rwg} = \varepsilon_f \sigma \left(\frac{T_w^4 - T_g^4}{T_w - T_g}\right) \quad (6)$$

ε_f is the effective emittance between the water surface and the glass cover and given by [23] as eq. (7).

$$\varepsilon_f = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right) \quad (7)$$

The radiation heat transfer from water surface to glass can be re-written as eq. (8) [5].

$$q_{rwg} = F\sigma(T_w^4 - T_g^4) \quad (8)$$

F is the shape factor.

The basin surface and glass cover of single slope solar still are considered as two parallel plates. This geometry determines the shape factor and for lower tilted angle solar still like this, the shape factor is assume to be equal to 0.9, which is the emissivity of water. Therefore, eq (8) can be re-expresses as eq (9) [8].

$$q_{rwg} = 0.9\sigma(T_w^4 - T_g^4) \quad (9)$$

The rate of heat loss by convection from water surface to glass cover in the still can be computed from eq. (10).

$$q_{cwg} = h_{cwg}(T_w - T_g) \quad (10)$$

h_{cwg} is the convection heat transfer coefficient from water to glass.

The empirical relationship for the convective heat transfer coefficient was suggested by Dunkle [16] as given by eq. (11).

$$h_{cwg} = 0.884[T_w - T_g + \frac{(P_w - P_g)}{268.9\times10^3 - P_w} T_w]^{1/3} \quad (11)$$

P_w and P_g are the saturated partial pressures of water Vapour (N/m^2) at water and glass temperature respectively and given by eq. (12) and eq.(13) [16].

$$P_w = \exp[25.31 - (\frac{5144}{T_w})] \quad (12)$$

$$P_g = \exp[25.31 - (\frac{5144}{T_g})] \quad (13)$$

The evaporative heat loss (q_{ewg}) for water surface to glass cover can be computed from eq. (14) [17].

$$q_{ewg} = h_{ewg}A_w(T_w - T_g) \quad (14)$$

h_{wg} is the evaporative heat transfer coefficient from water to glass cover and is written as eq.(15) [17].

$$h_{ewg} = 16.273x^{-3}h_{cwg}(\frac{P_w - P_g}{T_w - T_g}) \quad (15)$$

An empirical equation for computing evaporative heat loss was given by Dunkle [19] as expressed by eq. (16).This can also be considered as another relation that could be used for calculating evaporative heat loss

$$q_{ewg} = 16.28 \times A_w h_{cwg}(P_w - P_g) \quad (16)$$

The convective heat loss (q_{cga}) from glass cover to ambient air can be calculated from eq. (17).

$$q_{cga} = h_{cga}(T_g - T_a) \quad (17)$$

h_{cga} is the glass and ambient air convective heat is transfer coefficient and expressed by eq. (18)

$$h_{cga} = 2.8 + 3.8V \quad (18)$$

V (m/s) is the wind speed.

The heat loss by radiation from glass cover to sky (q_{rga}) can be calculated from eq. (19) as given by [8].

$$q_{rga} = \varepsilon_g\sigma\,(T_g^4 - T_s^4) \quad (19)$$

T_s is called radiant sky temperature. The average value of T_s is considered to be 12K less than the ambient temperature (ie $T_s = T_a - 12$) for the practical purposes [8].

Therefore, the total heat losses can be determined as the sum of $(q_{cwg} + q_{ewg} + q_{rwg} + q_{cga} + q_{rga})$.

The total heat transfer coefficient from the water surface to the condensing cover can be calculated as the sum convection, radiation and evaporative heat mass transfer coefficient within the distiller and is given by eq. (20).

$$h_1 = h_{cwg} + h_{ewg} + h_{rwg} \quad (20)$$

3.4. Experimental Efficiency

The daily efficiency ($\eta_{\exp(d)}$) of stills can be calculated using eq. (21) [20, 21].

$$\eta_{\exp(d)} = \frac{\sum m\times L_w}{\sum I\times A\times t} \quad (21)$$

Where m, L_w, A and t are daily sum of mass condensate collected, latent heat of vaporization of water, daily mean solar radiation, glass cover area and time for the collection respectively.

4. Results and Discussion

The experimental investigation and performance analysis of basin type single slope solar still have been conducted in this study. The experimental data recorded were hourly averaged and used for computation of heat transfer coefficient, heat losses and efficiencies of the stills under study using equations described in section 3, in order to evaluate the performance of stills. The results obtained from this study are presented in Fig. 3-13.

Figures 3 and 4 are graphs showing the variation of solar radiation, ambient temperature and wind speed with time. It can be observed from the figures that both radiation and temperature are roughly proportional, with the former reaching its peak (977 W/m^2) at 15.00 hours and the later (300 K) at 16.00 hours. Wind speed is also fairly proportional to the solar radiation. Maximum speed (2 m/s) is recorded at 17.00 hours.

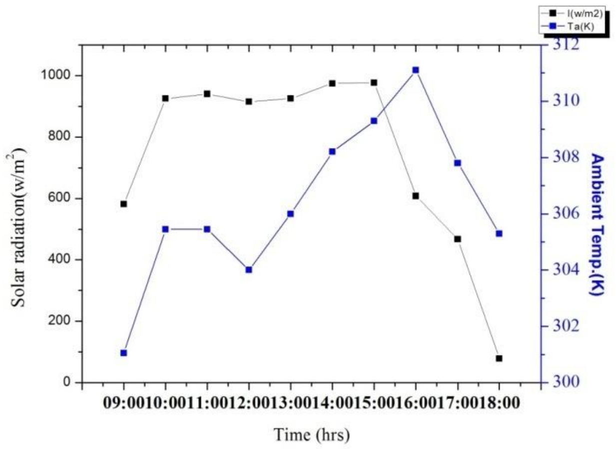


Figure 3: Graphs of solar radiation and ambient temperature versus local time

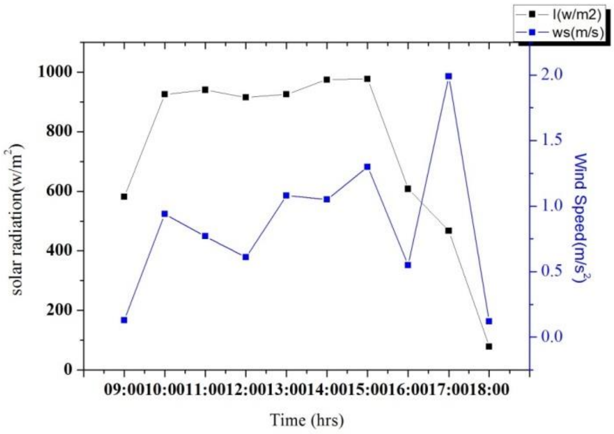


Figure 4: Graphs of solar radiation and wind speed versus local time

Figure 5 shows the temperature differences between water and glass cover for the four stills D1, D2, D3 and D4. These temperature differences define the performance of solar still. The highest temperature difference (T_w-T_g) for the still D1, D2, D3 and D4 are 29 K, 18 K, 14 K and 13.6 K respectively. It can be observed that still D1 has the highest temperature difference followed by D2, D3 and D4. Though the higher temperature difference of water and glass were not attained at the same time for the still, this could be attributed to the different in design, either in terms of basin materials or modification made at the side of stills D2 and D4 (4 inch hand hole attach to their side). Despite the fact that still D1 and D2 basin are made from same materials, the fig. shows a wide difference between them, this is due to side modification on D2. The stills with galvanised iron (GI) as basin materials recorded the highest temperature difference compared to stills D3 and D4, whose basins were made with blacked ceramic. This is due to higher thermal conductivity of GI as compared to the ceramic.

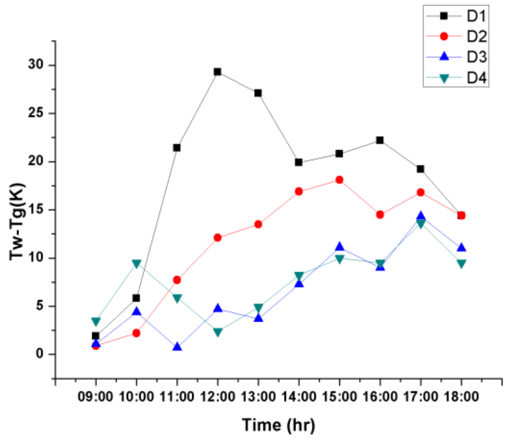


Figure 5: Plot of (T_w -T_g) with Time of the Day.

Fig. 6 and Fig. 7 show hourly and daily total heat losses from the four stills D1, D2, D3 and D4. The daily total heat losses for stills D1, D2, D3 and D4 are 714.64 W/m^2, 480.38 W/m^2, 298.01W/m^2 and 247.90 W/m^2 respectively. It can be observe from the plot that the total heat loss from still D1 is higher followed by D2 and D3, whereas D4 has the least heat loss among the stills. This reveals that the total heat loss inside the solar still is due to high temperature of water at the basin, which can be attributed to high thermal conductivity of the basin material and air tight sealing of the still.

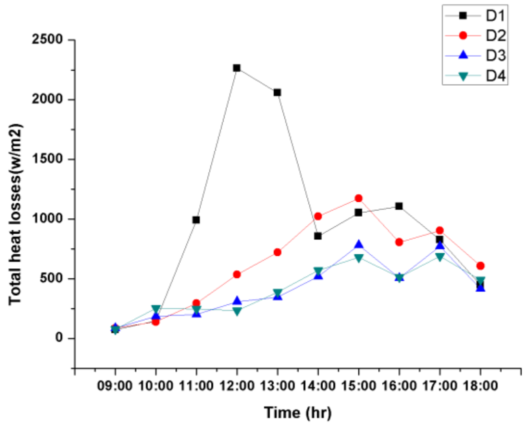


Figure 6: Hourly Computed total heat losses of the stills.

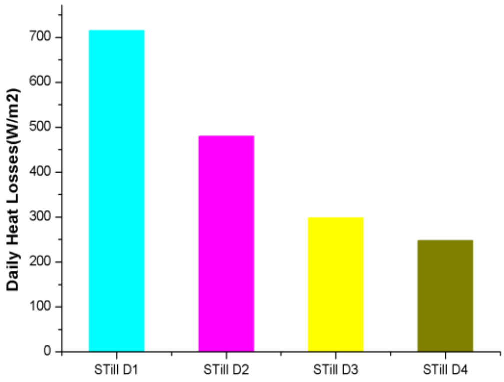


Figure 7: Daily total heat losses of the stills.

Figure 8 shows that during the late hours of the testing period (evening hours ie from 4:00pm to 6:00pm), the basin water temperature is slightly greater for stills D4 and D3 compared to stills D1and D2, which shows higher basin water temperature at the early hours of the testing period (morning) when the solar radiation is high. This is attributed to the material (ceramic) at the basin, which has the ability to store heat for a longer period.

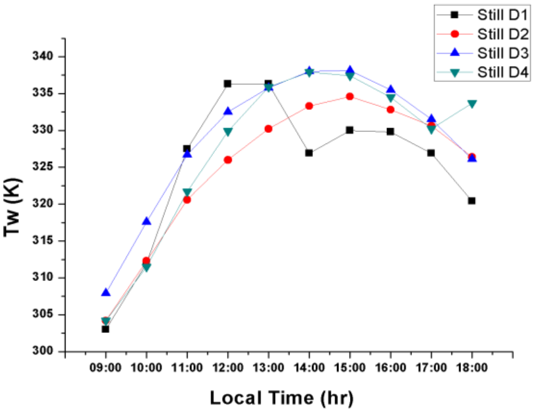


Figure 8: Hourly variation of basin water temperatures.

Figure 9 and 10 show the hourly and daily yield of the stills. The daily productivity of the stills D1, D2, D3 and D4 are 1.66 l/m^2/day, 1.46 l/m^2/day, 0.97 l/m^2/day, and 0.90 l/m^2/day respectively. This shows that the amount of distillates collected per day is affected by hermetic sealing of the still. This indicates that the side modification (4 inch hand hole attached at the side) made on stills D2 and D4 has affected the evaporation rate due to non-air tight at the side. It is important to note that even though the conventional type still could produce more distillate yield than the still with ceramic basin; the latter is more suitable when a long lasting device devoid of corrosion and less maintenance demand is desirable.

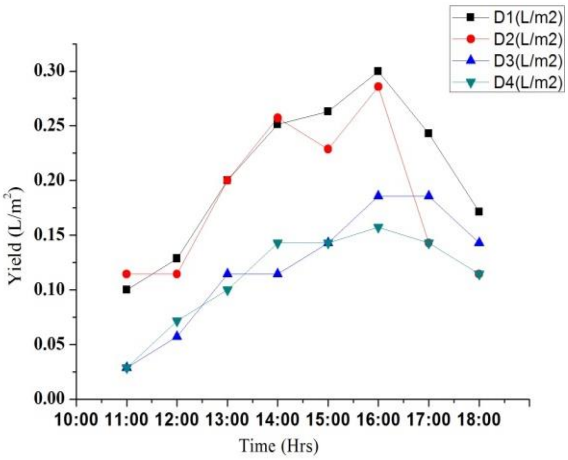


Figure 9: Variation of hourly distillate of solar stills with time.

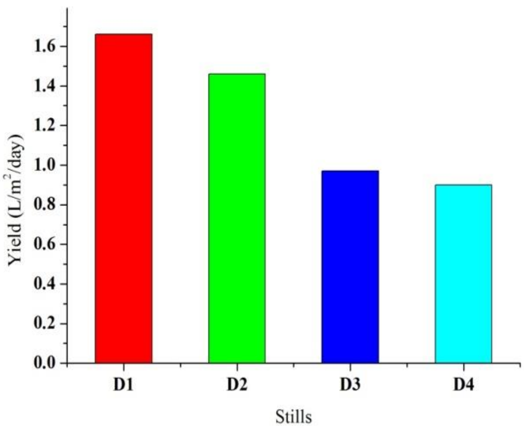


Figure 10: Comparison of the daily yield for the stills.

Figure 11 shows that the daily efficiencies of the stills D1, D2, D3, and D4 are 54.06%, 50.91%, 28.20% and 27.97% respectively. This indicates that still D1 and D2 (with galvanized iron basin) have the highest efficiencies compared with still D3 and D4(with ceramics basin). This is due to higher thermal conductivity of the basin materials, whereas the variation between still D1 and D2 and also still D3 and D4 could be attributed to side modification made on stills D2 and D4.

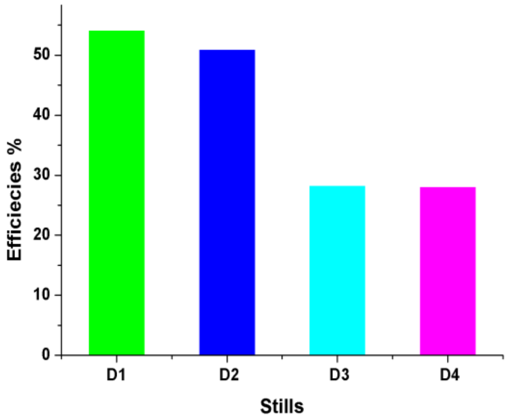


Figure 11: Comparison of the efficiencies of the stills.

Figure 12 and Figure 13 present the hourly and daily total mass heat transfer coefficient (radiative, convective and evaporative) respectively. From the Figures it can be notice that, still D1 has the highest total heat transfer coefficient compared to D2, D3, and D4. This is due to high convective, radiative and evaporative heat transfer and also high water temperature within the distiller. According to [22], the radiative and evaporative heat transfer depends on the water temperature at the basin of the still.

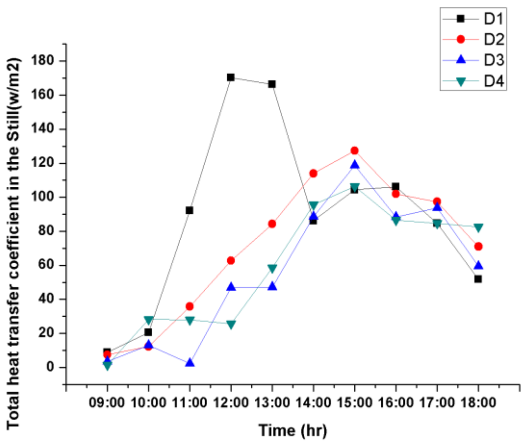


Figure 12: Variation of total heat transfer coefficient of the stills with day time.

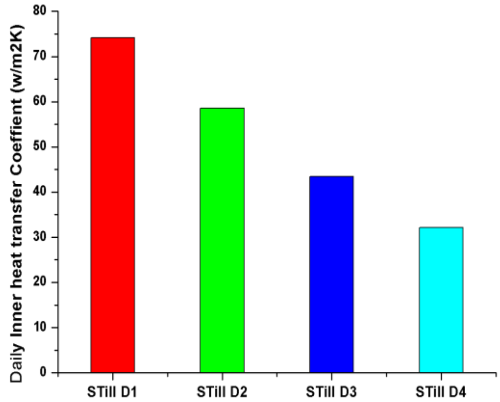


Figure 13: Daily total inner heat transfer coefficient of the still.

5. Conclusion

The performance of four different single slope solar stills has been experimentally investigated and analysed in this study. From the results obtained, still D1 with galvanized iron at the basin and hermetic seal has greater efficiency and distillate productivity of 54.06 % and 1.66 $l/m^2/day$ respectively compared to stills D2, D3 and D4 which have daily efficiency and productivity of 50.91 % and 1.46 $l/m^2/day$; 28.20 % and 0.97 $l/m^2/day$; and 27.97 % and 0.90 $l/m^2/day$ respectively. The variation in the efficiency and yield between the still with 4 inch attachments and those without the attachment (and of the same basin materials) is very small, which is less than 4%. Based on this result, the side attachment of 4 inch hand hole can be adopted in the still design since it has negligible effect on the performance of the still.

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References

[1] V.R. Rajesh, K. Harikrishnan, K.K. Chaithanya, S. Salim "Performance Evaluation of a Solar Desalination System integrated with a Fresnel lens Concentrator." *International Journal of Renewable Energy Research (IJRER)* Vol. 6(1): 250-253, 2016
[2] M.SH. Lipu, M.S. Uddin, M.R.A. Miah, "A feasibility study of solar-wind-diesel hybrid system in rural and remote areas of Bangladesh." *International Journal of Renewable Energy Research (IJRER)*, Vol. *3*(4), pp.892-900, 2013
[3] H.N. Panchal, P.K. Shah, "Effect of Varying Glass cover thickness on Performance of Solar still: in a Winter

Climate Conditions." *International Journal of Renewable Energy Research (IJRER)*, Vol. *1*(4), 212-223, 2012

[4] S. Umar, U.K. Muhammma, A. Yakubu, M. Musa, and M. Abubakar, "Comparative Performance Study of Efficiencies for Three Different Solar Water Distillers", *Equity Journal of Science and Technology*, Vol.3(2), pp.99-104, 2015.

[5] A.K. Singh, Y. P. Yadav. "Measured Performance and Theoretical Validation of a Concentrator Assisted Solar Distillation System." A paper presented at the 3rd The International Conference on Renewable Energy Research and Applications, on 19-22 Oct 2014 Milwakuee-USA

[6] J. O. Ozuomaba, C.C. Edebeatu, M.F. Opara, M.C. Udeye, and N.A. Okonkwo, "The performance of a solar water distillation Kit Fabricated from local Materials", *Research Journal of Chemical Science*,Vol.2(3), pp 64-67, 2012.

[7] U.H. Ibrahim, Y. Maksha, D.P. Abalis, and I.S. Ibrahim, "Experimental Investigation of the performance of Basin Type single Slope Solar Still", *International Journal of Scientific and Technology Research*, Vol.3(3), pp169-174,2014.

[8] H.P. Garg, J. Prakash, *Solar Energy Fundamentals and Application*, First Revised Edition, Tata McGraw-Hill Publishing company Limited, New Delhi,2000, Chap.6, pp176-188.

[9] K. Sampathkumar, T.V. Arjunan, P. Pitchandi, and S. kumar "Active solar distillation- A detailed review", *Renewable sustainable Energy Review*,Vol.14 pp1503-1526, 2010.

[10] G.N. Tiwari, S.K. Shukla, I.P. Singh, "Computer modelling of passive/active solar still by using innerglass temperature" *Deslination*, Vol.154, pp. 171-185, 2003.

[11] E.M. Toygar, A. Yazar, T. Bayram, M. Tastan, O.F. Kaya, H. Çalmaz, "Design and development of solar flat mirror and heat storage system." In *Renewable Energy Research and Application (ICRERA), 2014 International Conference on* (pp. 821-827). IEEE

[12] V. Velmurugan, M. Gopalakrishnan, R. Raghu, K. Srithar. Single basin solar still with fin for enhancing productivity. *Energy Conversion and Management*, Vol. 49(10), 2602-2608, 2008.

[13] F.F. Tabrizi, M. Dashtban, H. Moghaddam, K. Razzaghi. Effect of water flow rate on internal heat and mass transfer and daily productivity of a weir-type cascade solar still. *Desalination*, Vol. 260(1), 239-247, 2010.

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

[15] M.K. Gnanadason, S.P. Kumar, V.H. Wilson, A. Kumaravel, and B. Jebadason, "Comparison of performance analysis between single basin solar still made up of Copper and GI", *International Journal of innovative Research in science, Engineering and Technology*, Vol.2(7), pp 3175-3183, ,2013.

[16] G.D. Rai, Solar *Energy Utilization Text Book for Engineering Students*, Khanna Nai Sarak, New Delhi, India,2000

[17] S.M. Radwan, A.A. Hassanain, M.A. Abu-Zeid, "Single slope Solar still for Sea Water Distillation", *World Applied Science Journal*, Vol.7(4), pp. 485- 497, 2009.

[18] G.N. Tiwari, *Solar Energy Fundamentals, Design, Modelling and Applications*, Alpha Science International Limited, Pangbourne, UK, 2002, Chap.3, pp110-112.

[19] R.V. Dunkle, "Solar water Distillation: the roof –type still and a multiple- effect Diffusion still", *International Development in Heat transfer*, ASME, Proceedings International Heat Transfer, University of Colorado, Part V: 89, 1961.

[20] S.M. Radwn, A.A Hassanain, M.A. Abu-Zeid, "Single Slope solar Still for Sea water Distillation", *World Applied Science Journal* 7(4): 485-497, 2009.

[21] M.T. Chaichan, H.A. Kazem, "Using Aluminium Powder With PCM (paraffin wax) to Enhance Single Slope Solar Water Distillation Productivity in Baghdad–Iraq Winter Weathers." *International Journal of Renewable Energy Research (IJRER)*, *5*(1), 251-257

[22] H.E. Gad, Shams El-Din Sh., A.A. Hussien, Ramzy Kh., "Thermal analysis of a Solar till Performance: An experimental study", *Solar energy*, pp. 122: Pp 900-909, 2015.