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Investigation of the Effect of Cover Thickness on the Yield of a Single Basin Solar Still under Makurdi Climate

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ABSTRACT: *Five solar stills of the same size and configuration but with different glass cover thicknesses were designed, constructed and their performances evaluated. Still 1 had a sheet glass cover, still 2 had two sheets of glass lying on each other, still 3 had two sheets of glass with an airspace between them, still 4 had three glass sheets without airspace between, and still 5 had three glass sheets with an air space between each. A storage medium was designed and constructed to boost the night yield of the stills. The daily insolation, ambient, cover and water temperatures and the output for the five stills were measured. The efficiencies for the daytime operation were computed. The output volumes and efficiencies of the stills were compared. Still 1 had the highest mean water output volume of about 306 cm^3 and an efficiency of 24% indicating that for better daytime yield, a window glass solar still cover in Makurdi location should have a thickness in the region of 4 mm. Still 3 had the better night time yield which implies that the cover configuration could be exploited to boost overall still output.*

KEYWORDS : *Solar stills, output volume, glass cover thickness, insolation, temperature difference, daytime yield.*

I. INTRODUCTION

The growing need for potable water around the world, especially in developing countries cannot be over emphasized. The availability of potable water in sufficient quantities to persons or communities in the developing world is still a major problem. Many health disorders in rural communities in the developing countries have been traced to intake of contaminated water. Apart from drinking, pure water is needed to meet the requirements of medical, pharmacology chemical and industrial applications [1, 2]. Sources of raw water (groundwater upland lakes and reservoirs, rivers, canals and lowland reservoirs, rain water etc) are usually contaminated either by the presence of dissolved solids or pathogens in the water. Drinking water that contains pathogens or that contains unacceptable levels of dissolved contaminants or solids in suspension when consumed leads to widespread acute and chronic illness and is a major cause of death in many countries. In 2006 waterborne diseases were estimated to cause 1.8 million deaths each year while about 1.1 billion people lacked proper drinking water [3-5].

Sunlight is earth's primary source of energy. The solar constant is the amount of power that the sun deposits per unit area that is directly exposed to sunlight. The solar constant is equal to approximately 1368W/m^2 at a distance of one astronomical unit (AU) from the sun (that is, on or near earth). Sunlight on the surface of earth is attenuated by earth's atmosphere so that less power arrives at the surface – closer to 1000W/m^2 in clear conditions when the sun is near the zenith [6]. The total solar energy absorbed by the earth's atmosphere, oceans and land masses is approximately 3850000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3000 EJ per year in biomass. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined. Makurdi, the location of this study, is on latitude 7.7^0 and longitude 8.73^0 and receives an average insolation of 35430 kJ/m^2/day from an average 6.13 hours of sunshine with the highest and lowest in August and December respectively [7].

The use of solar thermal power to desalinate brackish water or to produce drinking water by distillation, although not as cost-effective as compared to other conventional methods of drinking water production in use, is very efficient in producing high quality (pure) drinking water. Solar distillation is carried out in a solar still. The basic principle of operation of a still is hinged on the principles of evaporation and condensation. The water in the still gets heated by the sun's energy, the water evaporates and condenses on the glass cover and is collected.

The still has very low maintenance requirements since it has no moving parts and uses the sun's energy to power its operation. Solar stills effectively eliminate all water borne pathogens, salts, and heavy metals, and produce ultrapure water that is proven to be superior to most commercial bottled water sources [8]. Although the solar still produces water with a high degree of purity, its output or yield per day is low. Several modifications of the still have been developed to increase its yield. It has been found that the difference in temperature between the water and the condensing glass surface affects the yield and the greater the difference, the greater the yield [9-13].Over the years many technologies/techniques have been developed to treat water and make it suitable for required demands. In general, the methods/techniques used in a water treatment plant include physical processes like filtration and sedimentation, biological processes such as slow sand filters or activated sludge, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light. Desalination of brackish water could also be carried out by distillation or reverse osmosis [14-16].

A single basin solar still has a top cover made of glass, with an interior surface made of waterproof membrane. This interior surface uses a blackened material to improve absorption of the sun's rays. Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation (short-wave) to pass into the still, which is mostly absorbed by the blackened base. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The base also radiates energy in the infrared region (long-wave) which is reflected back into the still by the glass cover, trapping the solar energy inside the still (the 'green house' effect). The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind [13, 17, 18]. The daily distilled water output (M_e in $Kg/m^2 day$) is the amount of energy utilized in vaporizing water in the still (Q_e in $J/m^2 day$) over the latent heat of vaporization of water (L in J/Kg). Solar still efficiency (η) is the amount of incident solar energy on the still (Q_e in $J/m^2 day$). These can be expressed as:

$$Solar\ still\ production, M_e = \frac{Q_e}{L} \tag{1}$$

$$Solar\ still\ Efficiency, \eta = \frac{Q_e}{Q_t} \tag{2}$$

Typical efficiencies for single basin solar stills approach 60 percent. General operation is simple and requires facing the still towards solar noon, putting water in the still every morning to fill and flush the basin, and recovering distillate from the collection reservoir. Stills are modular and for greater water production requirements, several stills can be connected together in series and parallel as desired. As water evaporates from the solar still basin, salts and other contaminants are left behind. Overtime, these salts can build to the point of saturation if the still is not properly maintained and flushed on a regular basis [1, 16, 19-21].This device is however not popular because of its low productivity. Over the last few years, there have been efforts to develop simple solar distillation technologies that could be applied in these locations to meet drinking water needs [22-26]. Various efforts have been embarked upon to improve the production rate of this device. The methods that have been attempted to increase the productivity ranges from decrease the volumetric heat capacity of the basin, attachment of additional sub-systems and other major departures from the simple configuration. The enhancement of the productivity of the solar desalination system, in a certain location, could be attained by a proper modification in the system design [27-36]. However, the increase in the system productivity with high system cost may increase also the average annual cost of the distillate [37, 38].

The Energy Systems Research Group of the Department of Mechanical Engineering at University of Agriculture, Makurdi has been working to further develop the technology and demonstrate its practicality as an innovative, effective, simple, and decentralized on-site water treatment system that can provide safe water in a cost effective and reliable manner. This effort began in earnest a few years ago and is still ongoing. Specific work has been done by [13] in investigating the effect of coupling a pre-heat tank and a reflector to a simple basin still at Makurdi. Also, [39] investigated the effect of a pebble thermal storage on the performance of a basin still. These and other unpublished works are aimed at making this simple technology to impact on provision of save drinking water in Makurdi Metropolis and its environs.Increasing the quantity of water produced by a single basin solar still has remained a major research focus in solar distillation. The objective of this study is to investigate the effect of the thickness of the cover on the yield of the still. A variation in the thickness of the glass cover of the still affects the transmission of heat through the glass and thus should affect the temperature of the inner surface of the glass and the difference in temperature between the glass and the water [40, 41]. The study is limited to the construction of five (5) solar stills with different cover thickness/configurations and studying the effect of the thickness on the yield of the still operation within Makurdi.

The abundance of brackish water in the form of the River Benue and abundant solar thermal radiation in Makurdi makes it suitable to operate solar stills in various parts of the town for the provision of potable water. This work is an attempt to study how the cover thickness affects the driving force of a still operation and ultimately identify a suitable cover thickness/configuration for Makurdi that gives optimal daytime yield as well as enhancing the night operation of the still.

II. MATERIALS AND METHODS

The basin solar stills used for the study were constructed and their performances evaluated at the University of Agriculture, Makurdi Engineering Complex. Most of the design parameters were selected based on availability of materials and/or convenience. The summary of the design parameters of the solar still and storage medium are given in Tables 1 and 2. Five glass configurations were considered. These are single paned glass cover of thickness 4mm, double paned glass cover with no airspace between them, double paned glass cover with a 4mm thick airspace between them, triple paned glass cover with no airspace between them, and triple paned glass cover with a 4mm thick airspace between them. The still boxes were constructed with plywood and the still basins with 1mm thick steel sheets painted black in order to enhance adsorption of heat by the water. The tests carried out involved measuring the ambient temperature which corresponds with the temperature of the outer surface of the glass covers of each still; the temperature of the inner surface of the glass covers as well as that of the water for every hour from 8:00am to 5:00pm using a thermocouple. The hourly solar radiation values were also measured using a Daystar Sun meter. The distillates from the different stills were collected at 5:00pm everyday and measured using a measuring cylinder and also documented. At 8:00am the night yield of the stills were also collected, measured and documented. The total output and distillation rates of each still were then computed. The results were then analyzed and conclusions drawn.

Description of the system : Fig. 1 shows a schematic diagram of the plan of the arrangement. For each of the five stills, a 48cm × 33cm × 10cm mild steel tank and a 38cm × 5cm × 10cm aluminum distillate collector are fitted in a wooden box of length 60*cm* and width 40*cm*. The angle of inclination of the glass covering each of the stills is 12^0 to the horizontal. One of the two wires of a thermocouple is fixed with its end near the bottom of the tank and the other is fixed with its end touching the inner surface of the glass cover. The five stills are mounted on a level plane above ground level facing south. The inlet pipes of the five stills are linked to a PVC pipe of diameter 1.27cm running along the stills from the first to the last. The PVC pipe is connected to the outlet tap from the storage medium tank via a flexible hose. The flexible hose is used to allow for slight changes in the elevation or orientation of the storage medium without affecting the position of the solar stills. Each inlet pipe is fitted with a tap that controls the flow of water into the still. The storage medium has a 43cm × 43cm × 20cm mild steel tank centrally fitted in a 73cm × 73cm × 35cm wooden box with black painted pebbles surrounding it. The storage medium is mounted on a stand such that it is higher in elevation than the five stills, this is arranged so as to have free flow of water from the storage medium to the stills as a result of the hydrostatic pressure head set up between the stills and the storage medium by virtue of difference in elevation. Plate 1 shows the five solar stills linked with the thermal storage system.

Table 1: Summary of Design Parameters for the solar stills used for the study

Parameter	**Dimensions**
Glass cover length	73*cm*
Glass cover width	73*cm*
Width of metal tank	43*cm*
Length of metal tank	43*cm*
Height of metal tank	20*cm*
Width of wooden box	73*cm*
Length of wooden box	73*cm*
Height of wooden box	35*cm*
Thickness of pebble gap (sides)	15*cm*
Thickness of pebble gap (base)	15*cm*

Table 2: Summary of Design Parameters for the storage medium

Parameter	**Dimensions**
Width of glass cover	40*cm*
Length of glass cover	57.7*cm*
Thickness of glass pane	0.4*cm*
Width of distillate collector	5*cm*
Length of distillate collector	38*cm*
Height of distillate collector	10*cm*
Width of tank	33*cm*
Length of tank	48*cm*
Height of tank	10*cm*
Insulation thickness for sides	2.5*cm*
Insulation for base	1*cm*
Width of wooden box	40*cm*
Length of wooden box	60*cm*
Angle of inclination of glass	12^0
Diameter for PVC pipe	$^1/_2$" (1.27*cm*)

Pipe Network

Fig. 1: Schematic diagram of the arrangement of the Stills with the Storage Medium

Plate 1: The set up of the five solar stills for the study

III. RESULTS AND DISCUSSION

Table 3 shows the mean temperatures, still output values, distillation ratios and efficiency for each still. Fig. 2 shows the variation of the daytime still output with the difference in temperature between the water and the inner surface of the glass cover. The trend clearly shows that the greater the difference in temperature between the water and the inner glass surface, the higher the yield. This is actually the driving force for simple basin still operation the reason for varying the cover thickness/configuration in this study is an attempt to improve the driving force. As seen from Table 3 the maximum mean difference in temperature of 4.2 ^{0}C was attained in the still 1 which also had the highest daytime water output of 306.3cm^3. The still 5 had the lowest difference in temperature between the water and the inner glass surface of - 0.9 ^{0}C, the negative sign indicating that the temperature of the inner glass surface was greater than that of the water, and consequently the mean daytime still output was 0. This means that the inner glass surface was too hot to allow the condensation of the water vapor.

Table 3: Mean Values of Measured and Computed Parameters for each Still

Still	$T_o(^0C)$	$T_i(^0C)$	$T_w(^0C)$	$T_w - T_i$ (^0C)	$V_d(cm^3)$	$V_n(cm^3)$	$V_d + V_n$ (cm^3)	V_d / V_e	V_n / V_e	η
1	44.3	48.4	52.6	4.2	306.3	72.4	378.6	0.064	0.015	0.24
2	42.8	48.8	51.3	2.5	177	85.1	262.1	0.037	0.018	0.1
3	41.3	50.9	52.0	1.1	75.3	66.7	142.0	0.016	0.014	0.058
4	42.1	49.7	50.0	0.3	0.0	0.0	0.0	0.000	0.000	0
5	40.9	52.5	51.6	-0.9	0.0	0.0	0.0	0.000	0.000	0

Fig. 2 shows that the water output per still decreases from still 1 with each of the other stills producing lower yields. Table 3 shows that the difference in temperature between the water and the inner glass surface also decreases in the same order. As previously hinted, stills 4 and 5 produced no distilled water throughout the period of the study and that is why they are not represented in fig. 3. Fig. 4 shows a comparison of the distillation ratios of the stills 1 to 5. This ratio compares the volume of distillate during the day (V_d) and night (V_n) to the volume of water available for distillation (V_e). It is not a measure of the efficiency of the still though it is an indication of it. For the two ratios used, V_d/V_e and V_n/V_e, still 1 expectedly had the highest value for V_d/V_e. V_d/V_e reduces exponentially with the cover thickness. The exponential nature could be as a result of the presence of an air gap in the cover of still 3 and probably some inconsistencies with the structures of the sheet glasses used. The variation of the weather could be another factor though the conditions were fairly constant for the period of the study. Still 2 on the other hand had the highest V_n/V_e, indicating better night performance. This appears to suggest that the optimum thickness of glass cover that is required for a significant yield for night time could be in the region of 8mm of window glass though further study needs to be carried out in order to be more specific. It is a good indication however for supplementary yield during the night when the sun is no longer shining. Still 2 probably was able to perform better at night due to the ability of the cover to retain more of the heat trapped during the day time.

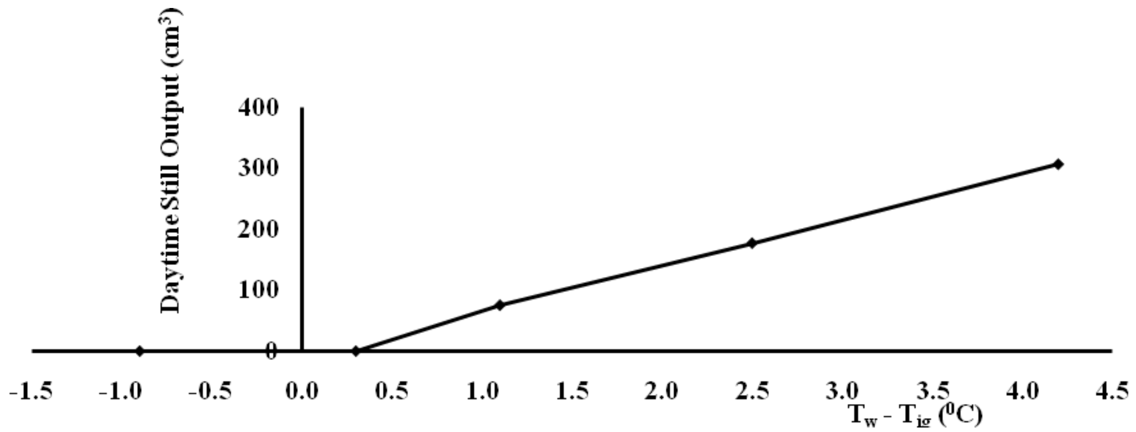

Fig. 2: variation of daytime still output with difference in temperature between the water and the inner glass surface

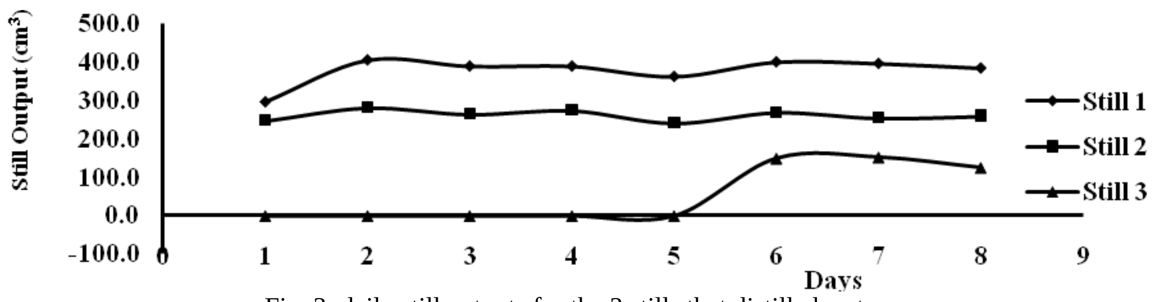

Fig. 3: daily still outputs for the 3 stills that distilled water

Fig. 5 to 7 show the variation of daytime still output with the available insolation for Stills 1 to 3. The relationship for stills 1 and 2 are adequately linear as expected since the available insolation directly affects the rate of distillation. The main differences between the graphs are the slope and the intercept on the still output axis as shown in the equations of the lines. The values of these for still 1 were higher and this could be traced to the fact that it had a cover of thickness half of that for still 2. The intercepts indicate approximate still outputs when the insolation is 0. The intercept for still 1 is about 124cm^3 which is greater than that for still 2 with about 20cm^3 (or about 16%). This difference is due to the ability of the inner surface of the cover of still 1 to cool to a relatively lower temperature than that for still 2 thereby aiding condensation of spontaneously evaporated water molecules. The curve for still 3 was a polynomial function. Apart from the fact that only three points were plotted (the days that it was able to produce water), the configuration of the cover (having an air gap of about 4mm between the glass sheets) could have been responsible for the departure from a linear relationship. It is worth noting that on the three days that still 3 produced some water, the hourly ambient temperatures were relatively slightly higher than those for the other days. This is a pointer to the fact that solar stills with relatively large cover thicknesses may thrive better under conditions of high ambient temperatures.

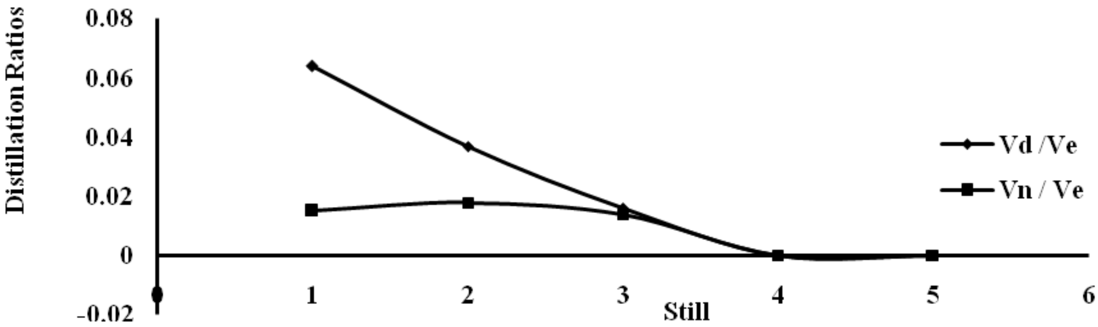

Fig. 4: daily distillation ratios for the study

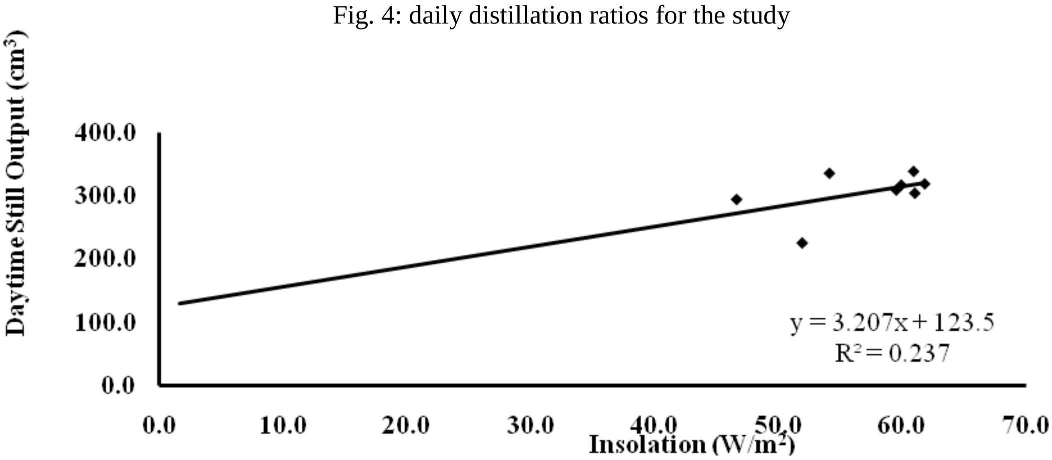

Fig. 5: variation of daytime still output with insolation for still 1

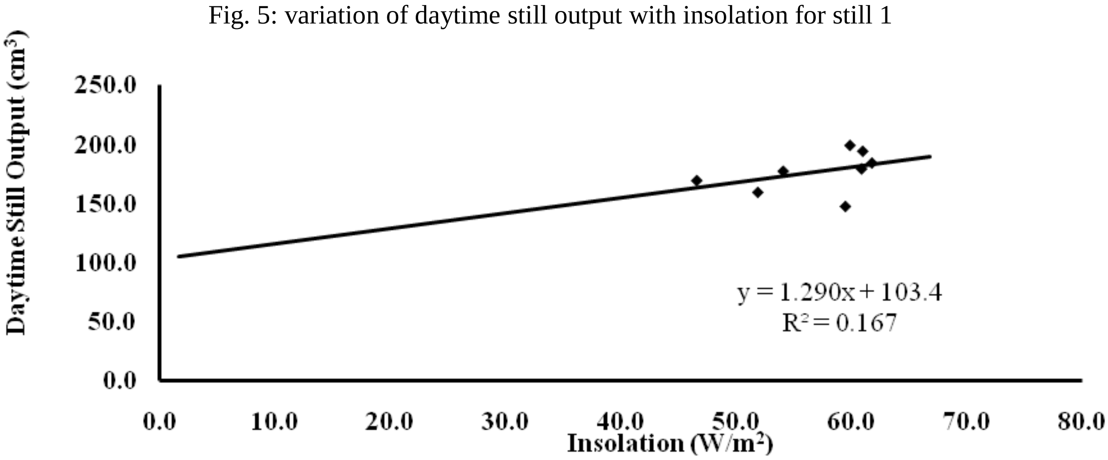

Fig. 6: variation of daytime still output with insolation for still 2

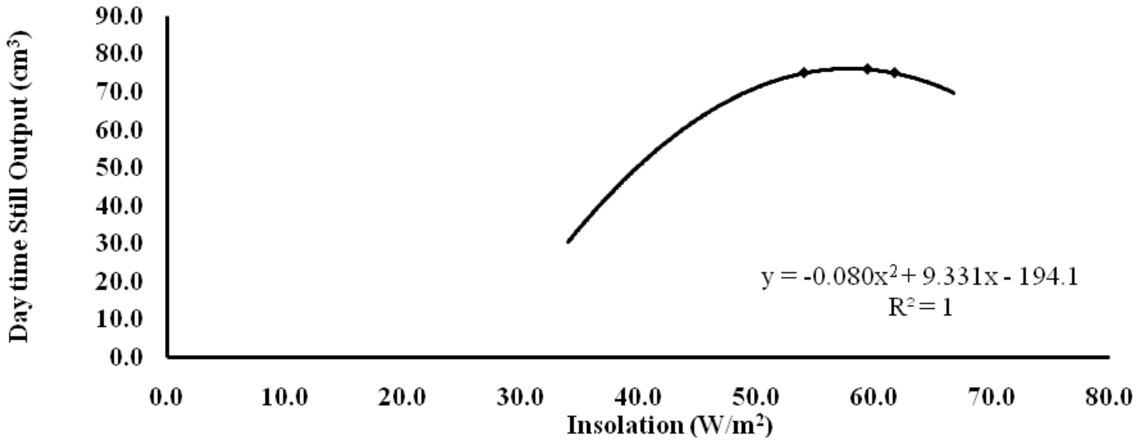

Fig. 7: variation of daytime still output with insolation for still 3

Still 1 has the highest efficiency of 0.24 or 24%. This adds weight to the fact that still 1 has the best yield. The negative slope of the graph indicates that the efficiency of the still decreases primarily with the cover thickness and/or configuration assuming that other parameters are effectively accounted for. The trend for this relationship is similar to that of the distillation ratios which lends weight to the earlier assertion that the distillation ratio is an indication of efficiency rather than a measure for it.

IV. CONCLUSIONS AND RECOMMENDATIONS

Having observed the behavior of stills operating with glass covers of different thickness, it can be said that optimum yield can best be achieved with solar stills operating with single-paned glass covers. From this study, a good approximation of the optimum thickness of solar still cover is in the region of 4mm of window glass. This of course is subject to other factors such as the structure of the cover material. Further work can consider composite layers of different materials but with the thickness being around 4mm. The limitation of the thickness of the still cover to this region of values is most suitable as it keeps the design of solar stills simple and the cost of design and construction minimal especially with the target end-users being low income earners and largely located in rural areas. Based on the results of this study, the following recommendations are hereby made:

[1] Thinner glass sheets as well as other transparent materials with thicknesses below 4mm should be used to determine the optimum still cover thickness.

[2] The configuration of the cover of still 3 (air gap between two glass sheets) be further developed for still night operation to complement the daytime yield from a still having a single layer cover.

REFERENCES

[1] Kopsch, O. (2003), How to Convert Salt Water into Pure Drinking Water using Solar Power, Rosendahl System, Hannover, Germany.

[2] United Nations, Water for People, Water for Life – UN World Water Development Report, 2003, UNESCO Publishing, Paris.

[3] I. A. Shiklomanov, Appraisal and Assessment of World Water Resources, *Water International, 25(1)*, 2000, 11-32.

[4] WHO, Combating Waterborne Diseases at the Household Level Part 1, 2007, World Health Organization.

[5] WHO & UNICEF, Water for Life: Making it Happen, 2005, World Health Organisation & UNICEF.

[6] S. Basu & H. M. Antia, Helioseismology and Solar Abundances, *Physics Reports*, *457(5–6)*, 2008, 217. doi:10.1016/j.physrep.2007.12.002. arXiv:0711.4590.

[7] I. N. Itodo & A. U. Fulani (2004), Development of a Passive Solar Crop Dryer with an Air Pre-heater Unit, *Proc. of the 5th International Conference and 26th AGM of the Nigerian Institution of Agricultural Engineers*, 24, 2004, 406 - 411.

[8] 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, 76(5)*, 2004.

[9] G. Singh, S. Kumar & G. N. Tiwari, Design, fabrication and performance evaluation of a hybrid photovoltaic thermal (PVT) double slope active solar still, *Desalination*, 2011, Article in Press, Elsevier Science Ltd.

[10] B. I. Ismail, Design and performance of a transportable hemispherical solar still, *Renewable Energy*, *34*, 2009, 145 – 150.

[11] M. A. Samee, U. K. Mirza, T. Majeed & N. Ahmad, Design and performance of a simple single basin solar still, *Renewable and Sustainable Energy Reviews*, *11*, (2007), 543 – 549.

[12] S.K. Harpreet, Performance of a Solar Still Predicted effect of Enhanced Evaporation Area on the Yield and Evaporation Temperature; *Solar Energy, 56*, 1996, 261-268.

[13] Ibrahim, J. S., Kuhe, A. and Edeoja, A. O. (2008), Performance Test of the Effect of Coupling a Preheat Tank and Reflector to a Basin Still under Makurdi Humid Climate, *Journal of Research in Engineering*, International Research and Development Journals, Uyo, Nigeria.

[14] CAWST, Household Water Treatment Guide, Centre for Affordable Water and Sanitation Technology, March 2008.

[15] L. García-Rodríguez, Renewable Energy Applications in Desalination: State of the Art, *Solar Energy, 75*, 2003, 381-393.

[16] R. E. Foster, W. Amos, & S. Eby, Ten years of Solar Distillation Applications along the US – Mexico Border, *Solar World Congress*, 2005, International Solar Energy Society, Orlando, Florida.

[17] O.O. Badran & H. A. Al-Tahaineh, The effect of coupling a flat-plate collector on the solar still productivity, *Desalination, 183*, 2005, 137– 142.

[18] G. Kronenberg & F. Lokiec, Low-temperature Distillation Processes in Single- and Dual Purpose Plants, *Desalination; 136*, 2001, 189-197.

[19] V. Gupta, G. Vogel, W. Amos, M. Cormier, R. E. Foster & S. Eby-Martin, Solar Distillation Applied in Texas, *Procs. of SOLAR 2003*, 2003, ASES, Austin, Texas.

[20] K. Wangnick, A Global Overview of Water Desalination Technology and the Perspectives. In: *Procs. of the International Conference Spanish Hydrologic Plan and Sustainable Water Management: Environmental aspects, water reuse and desalination,* 2001, Zaragoza, Spain.

[21] G. O. Schenck, *Handbook of Water Purification, "Ultraviolet Sterilization*", 1987, 530, Ellis Horwood Ltd., Chichester.

[22] H. Tanaka, Experimental study of a basin type solar still with internal and external reflectors in winter, *Desalination*, *249*, 2009a, 130 – 134.

[23] H. Tanaka, Tilted wick solar still with external flat plate reflector: Optimum inclination of still and reflector, *Desalination*, *249*, 2009b, 411– 415.

[24] K. K. Murugavel, K. K. S. K. Chockalingam & K. Srithar, Progresses in improving the effectiveness of the single basin passive solar still, *Desalination*, *220*, 2008, 677– 686.

[25] V. Velmurugan, M. Gopalakrishnan, R. Raghu & K. Srithar, Single Basin Solar Still with Fin for Enhancing Productivity, *Energy Conversion and Management*, *49*, 2008, 2602 – 2608.

[26] M. Boukar & A. Harmim, Development and testing of a vertical solar still, *Desalination*, (2003), 158 - 179.

[27] H. Tanaka, & Y. Nakatake, One step azimuth tracking tilted-wick solar still with a vertical flat plate reflector, *Desalination*, *235*, 2009a, 1– 8.

[28] H. Tanaka, & Y. Nakatake, Increase in distillate productivity by inclining the flat plate external reflector of a tilted-wick solar still in winter, *Solar Energy*, *83*, 2009b,785–789.

[29] A. M. El-Zahaby, A. E. Kabeel, A. I. Bakry, S.A. El-Agouz & O.M. Hawam, Enhancement of solar still performance using a reciprocating spray feeding system – An experimental approach, *Desalination*, 267, 2011, 209–216.

[30] K. K. Murugavel & K. Srithar, Performance study on basin type double slope solar still with different wick materials and minimum mass of water, *Renewable Energy*, *36*, 2011, 612 – 620.

[31] M., Sakthivel, S. Shanmugasundaram, & T. Alwarsamy, An experimental study on a regenerative solar still with energy storage medium - Jute cloth, *Desalination*, *264*, 2010, 24 – 31

[32] A.A. Al-Karaghouli & W.E. Alnaser, Performances of single and double basin solar-stills, *Applied Energy*, *78*, 2004, 347 – 354.

[33] J. A. Esfahani, N. Rahbar & M. Lavvaf, Utilization of thermoelectric cooling in a portable active solar still - An experimental study on winter days, *Desalination*, *269*, 2011, 198 – 205.

[34] A. J. N. Khalifa & H. A. Ibrahim, Effect of inclination of the external reflector on the performance of a basin type solar still at various seasons, *Energy for Sustainable Development*, *13*, 200), 244 – 249.

[35] A.M. Umar, "Relative Performance Evaluation of Pebble and Charcoals as Liners in Solar Stills", *Nigerian Journal of Renewable Energy, 2(2)*, 1991, 29-35.

[36] V. Velmurugan, K. J. N. Kumar, T. N. Haq & K. Srithar, Performance analysis in stepped solar still for effluent desalination, *Energy*, *34*, 2009, 1179 – 1186.

[37] A. E. Kabeel, A. M., Hamed, & S. A. El-Agouz, Cost analysis of different solar Still configurations, *Energy*, *35*, 2010, 2901 – 2908.

[38] N.M. Wade, Distillation Plant Development and Cost Update, *Desalination, 136*, 2001, 3-12.

[39] A. O. Edeoja, J. S. Ibrahim & M. Ekoja, Effect of a Thermal Storage Medium on the Performance of a Basin Solar Still in Makurdi, *International Journal of Engineering Science, 1(2)*, 2009, Pan-African Book Company, Ghana.

[40] H. Tanaka, Monthly optimum inclination of glass cover and external reflector of a basin type solar still with internal and external reflector, *Solar Energy*, *84*, 2010, 1959–1966

[41] K. V. Kumar & R. K. Bai, Performance study on solar still with enhanced condensation, *Desalination*, *230*, 2008, 51 – 61.