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Investigation of the Effect of Angle of Cover Inclination on the Yield Of A Single Basin Solar Still Under Makurdi Climate

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ABSTRACT
Five single basin solar stills with varying angles of inclination of the covers but having the same aperture area of 0.24m^2 were designed and constructed. Angles of inclination of 4^o, 7^o, 10^o, 13^o and 15^o were chosen arbitrarily. Measurements of temperature, solar radiation and ,volume of water produced were carried out for eight (8) days. The data was used to compute the efficiencies of the stills. The still with an angle of inclination 15^o had the highest efficiency of 0.585 and also produced the highest mean volume of water produced of 62.9cm^3. The results indicate that the optimum angle of inclination for simple basin solar stills for Makurdi location is greater than 15^o as shown by the characteristic trend lines for the water volume/efficiency against cover inclination. This is a useful observation and will erase the usual tendencies of utilizing low angles as efforts to optimize still productivity in Makurdi continue.

KEYWORDS: *Solar still, angle of inclination, insolation, temperature difference, daytime yield, characteristic trend line.*

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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 [1]. Apart from drinking, pure water is needed to meet the requirements of medical, pharmacology chemical and industrial applications [2].Solar energy is the light and radiant heat from the sun that influence the earth’s climate and weather and sustain life. Water power comes from the sun, because the sun aids evaporation of water, which produces rain on condensation which fills up lakes and reservoirs. Wind power comes from the sun, unequal heating of air masses word wide results in wind movement or kinetic energy. The intensity of extra-terrestrial radiation often referred to as the solar constant is fairly and is estimated to be 1353W/m^2 but varies according to wave length. The value of extra-terrestrial radiation is attenuated by the effect of absorption mainly by ozone, water and carbon-dioxide molecules, and scattering by dust particles, air molecules and water vapor. These result in the decrease in the amount of infra-red radiation reaching the earth’s surface [3].

Makurdi on latitude 7.7^{0}N and longitude 8.73^{0}E 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 (Itodo & Fulani, 2004)[4]. Since there is a large body of water in Makurdi (River Benue) and so much radiation from the sun, solar still technology can be gainfully employed to positively impact the situation of shortage of portable water in Makurdi [5].The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. The sun’s energy heats water to the point of evaporation. As the water evaporates, water vapor rises, then condensed on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is the water cleaner than the purest rain water. A simple solar still basically only needs sunshine to operate. There are no moving parts to wear out [2, 6, 7].

Solar distillation could offer a real and effective solution for families in these locations to clean their water supplies on-site. Solar still has been proven to be the best solution to solve water problem in remote arid areas. Purifying water through distillation is a simple yet effective means of providing drinking water in a reliable and cost-effective manner. 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 [8-11]. 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 [12-15]. 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 [16-20]. 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. However, the increase in the system productivity with high system cost may increase also the average annual cost of the distillate[21, 22]. 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. This is because the abundant solar distillation feedstock (water) provided by the River Benue and the immense solar radiation that Makurdi is reputed for almost all year round can be harnessed to positively impact the availability of drinking water. Specific work has been done by [23] in investigating the effect of coupling a pre-heat tank and a reflector to a simple basin still at Makurdi. Also, [5] 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.

There are some important factors that influence the rate of production of water in solar stills. These include climatic, thermal laws and solar still design factors. The amount of solar radiation a solar still receives is the single most important factor affecting its performance. The greater the amount of energy received, the greater will be the quantity of water distilled. Production is also associated with the thermal efficiency of the still itself. This efficiency may range from 30 to 60%, depending on still construction, ambient temperatures, wind velocity and solar energy availability [24-27]. Slope of transparent cover; the angle at which the transparent cover is set influences the amount of solar radiation entering a solar still. When sunlight strikes glass straight on, at 90^0 to the surface, about 90% of the light passes through tip the glass a little, so that it strikes at a grazing angle of 80^0, and only a few percent is lost [28]. A glass cover that is no more than 5 to 7cm from the water surface will allow the still to operate efficiency. Conversely, as glass-to-water distance increases, heat loss due to convection becomes greater, causing the still's efficiency to drop. Some important stills have been built following the low slope design concept for the glass cover, yet using a short, steeply sloping piece of the glass at the rear [3].

Solar still production is a function of solar energy (insolation) and ambient temperature. Production rates in the southwest U.S can average about 2 litres per day in the winter to over 6 litres per day during the summer per square metre. The intensity of solar energy falling on the still is the single most important parameter affecting production [29]. 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 energy utilized in vaporizing water in the still over the amount of incident solar energy on the still (Q_t in J/m^2). These can be expressed as:

Solar still production, $$M_e = \frac{Q_e}{L} \quad (1)$$

Solar still efficiency, $$\eta = \frac{Q_e}{Q_t} \quad (2)$$

Typically efficiencies for single basin solar stills approach 60% [3, 30]. 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 (for example, glass bottles). Stills are modular and for greater water production requirements, several stills can be connected together in series and parallel as desired [23].

A variation in the glass cover angle of inclination should affect the dynamics of condensation and movement of the water along the inner surface of the cover [31, 32]. This work attempts to investigate the effect of the angle of inclination of the cover on the still's yield. It is an attempt to study how the angle affects the driving force of a still operation and ultimately identify a suitable cover angle of inclination for Makurdi that gives optimal daytime yield.

II. MATERIALS AND METHODS

Five basin solar stills were considered with different angles of inclination. The basin solar stills were constructed and their performances evaluated at the Engineering Complex, University of Agriculture Makurdi. Detailed design analysis of the stills is not presented, most design parameters were selected based on availability of materials and convenience. The summary of the design parameters of the solar stills are given in Table 1. The angles of inclination of the stills used were 4^0, 7^0, 10^0, 13^0, and 15^0. The still boxes were constructed with plywood; epoxy gum was used to seal up the spaces where the plywood boards were nailed together to reduce heat loss in the system. The troughs were constructed with 1*mm* thick steel sheets and painted black in order to enhance adsorption of heat by the water. They were snugly fitted into the plywood boxes before being covered with the glass. A collection trough made of aluminum was fitted at the end of the glass slope to collect and channel the distillate through a flexible hose into a plastic storage container outside the still. The experiment involved measuring and documenting the temperature difference between the inner surface of the glass and the water using a thermocouple; the ambient temperature which corresponded with the temperature of the outer surface of the glass covers of each still; the solar radiation values using a Daystar Sun meter; for every hour from 8:00am to 5:00pm. The volume of water distilled from the different stills was measured using a measuring cylinder at the end of the day and documented. Twice the volume of water collected was added to the still every evening to reduce the salt build up in the still. The results were then analyzed and conclusions drawn.

2.1 Description of the System

Table 1 shows a summary of the design specifications for the stills. For each of the five stills constructed, a 60*cm* × 40*cm* × 7*cm* mild steel tank is snugly fitted in a wooden plywood box of length 60*cm* and width 40*cm*.

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

Parameters	Dimensions (cm)
Length of tank	40
Width of tank	60
Height of tank	7
Volume of water in the tank	4800
Length of distillate collector	60
Thickness of the wood	1
Angles of inclination	4^0, 7^0, 10^0, 13^0, 15^0
Width of glass covers	63
Length of glass covers	44
Thickness of the glass covers	0.5

The height at one end of the wooden box is maintained at 9*cm* and at the other end is varied through 12*cm*, 14*cm*, 16*cm*, 18*cm* and 20*cm*, to give the angles of inclination of 4^0, 7^0, 10^0, 13^0, and 15^0 respectively. One end of the two wires of a thermocouple is fixed to the inner surface of the glass and the end of the second of the two wires is fixed with its end near the bottom of the tank. The five stills are mounted on a level plane with their widths along the North-South direction. The supply port is fitted with a flexible hose through which water is added into the trough manually. The distilled output collection port is linked to the plastic storage container through a flexible hose lower than the still in elevation for water flow by gravity. Plate 1 shows the 5 single basin solar stills used for the study. .

Plate 1: The five stills used for the study

III. RESULTS AND DISCUSSION

Table 2 shows the mean values of temperature difference between the inner glass surface and the water, efficiency and volume of output water for each still. It also shows that the still with the cover inclined at 15^0 recorded the highest yield and had the highest efficiency. Incidentally, it had an overall mean temperature difference between the cover inner surface and water in the still of about 5.16 ^{0}C which is not the highest. This could be due to the fact that the volume of air between the water surface and the glass cover was relatively large as compared to the other stills. However, this result indicates that higher angles may result in greater yield. This fact is clearly shown by the characteristic trend lines of the relationship between volume of water/still efficiency with the angle of inclination in figs. 6 and 7. On a general note without any specific assertion, it can be conveniently reported that the observation will erase the tendency of using low angles of cover inclination probably because the climatic conditions at Makurdi location is favorable for the system.

Table 2: Mean Temperature difference between inner glass surface and water, Efficiencies and Volume of Output Water for the Stills

Angle (^{o})	T_{md}(^{0}C)	η	V_m (cm^3)
4	5.45	0.516	54.25
7	5.35	0.475	49.86
10	5.05	0.543	57.12
13	5.21	0.528	55.50
15	5.16	0.585	61.63

Figs. 1 to 5 show the variation of the volume of distilled water with the insolation. The relationship seen for each still is adequately linear as expected since the amount of insolation directly affects the rate of distillation. The main differences between the graphs are the slope and the intercept on the volume of output water axis as shown in the equations of the lines. The value of the slope for the still with angle of inclination 10^0 is highest followed by that of still 15^0. This implies that with every rise in available insolation, the increase in yield is greatest in still 10^0 followed by still 15^0. The intercepts indicate approximate still outputs when the insolation is 0 *W/m^2*. The intercept for still 7^0 is about 24*cm^3* which is greatest of all the five stills followed by that for still 15^0 with about 22*cm^3*. The difference seen in the value of the intercept for the stills is due to the ability of the inner surface of their glass covers to cool to temperatures that would aid condensation of spontaneously evaporated water molecules.

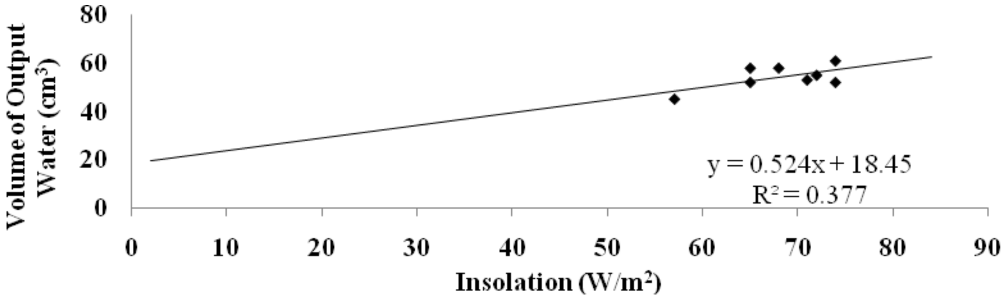

Fig. 1: variation of volume of water collected with insolation for the still with cover inclined at 4^o.

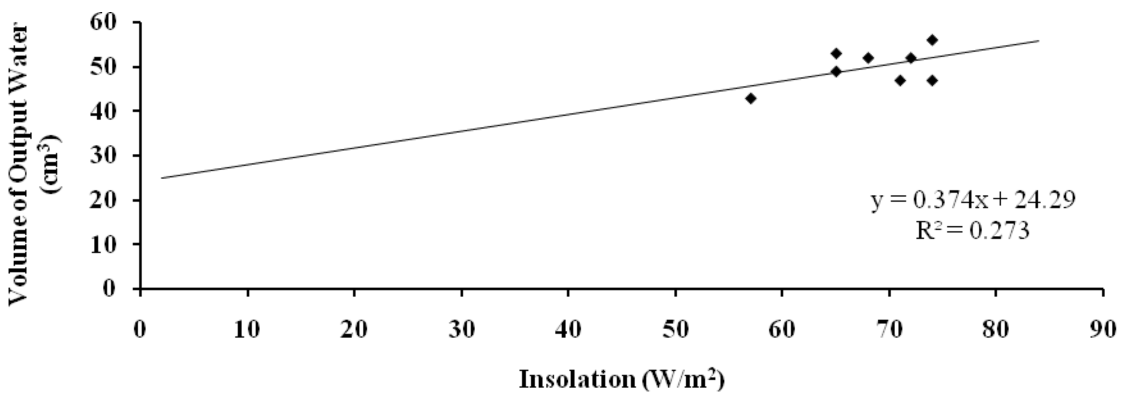

Fig. 2: Variation of Volume of Water collected with Insolation for the Still with Cover Inclined at 7^o.

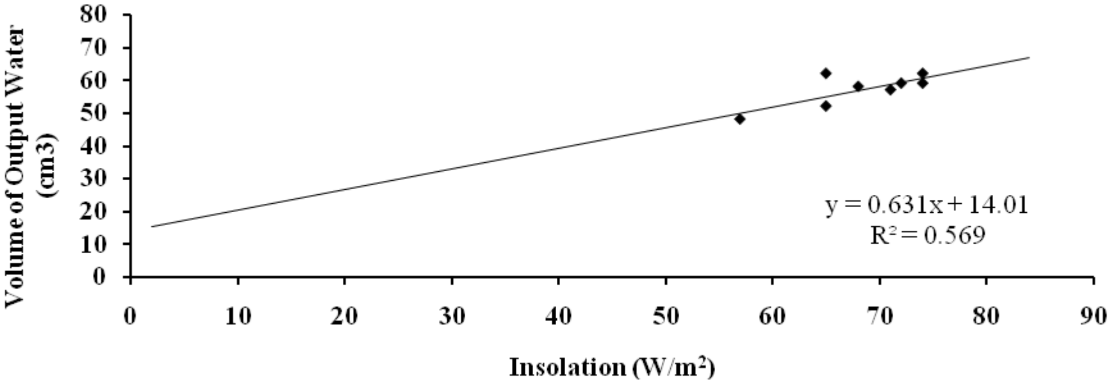

Fig. 3: variation of volume of water collected with insolation for the still with cover inclined at 10°.

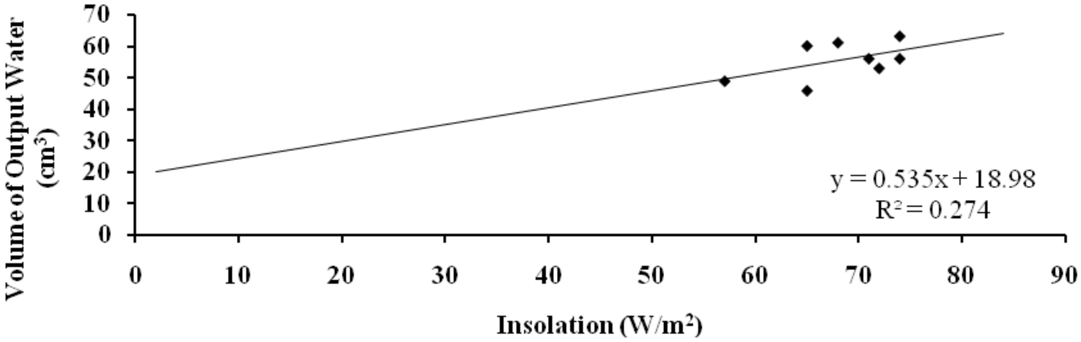

Fig. 4: variation of volume of water collected with insolation for the still with cover inclined at 13°.

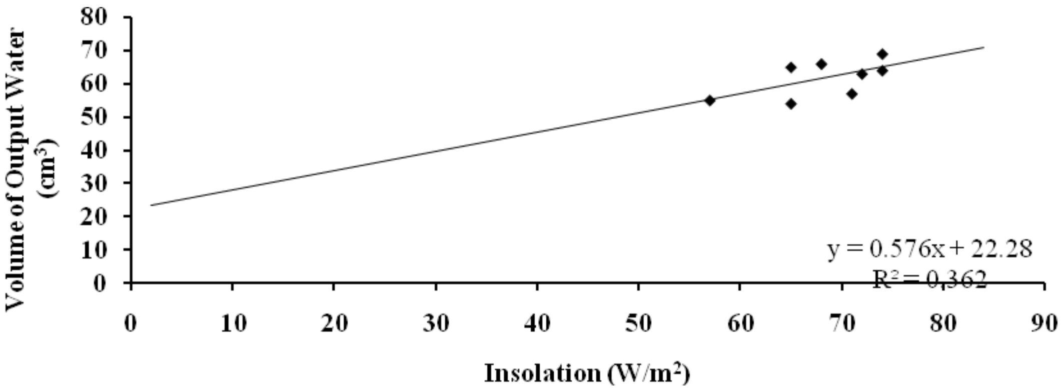

Fig. 5: variation of volume of water collected with insolation for the still with cover inclined at 15°.

Fig. 6 shows a gradual increase in still yield with increasing cover angle of inclination. Fig. 7 corroborates this, showing the increase in efficiency with the cover of inclination. Generally from the results of this study, the still with cover angle of inclination of 15° had a higher efficiency and yield than the others. This is indicated in *Figures 6* and *7* with an overall mean efficiency of 0.585 and output of about 62 cm^3. This translates to approximately 258.3 cm^3 per m^2 of still aperture area since the approximate still aperture area used for the study was 0.24 m^2. The trend line equations from *Figures 6* and *7* indicate that for 0^0 angle of inclination, the still can have an efficiency of about 0.461 with an output of 48.4 cm^3.

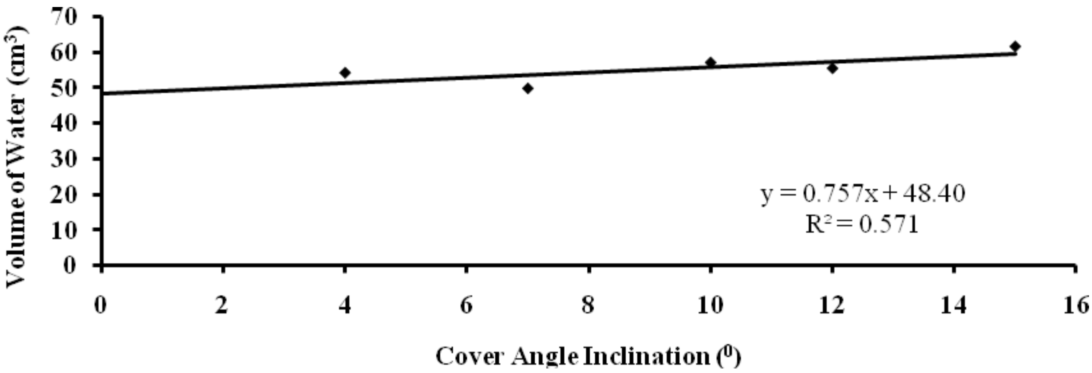

Fig. 6: variation of overall mean volume of water with mean cover angle

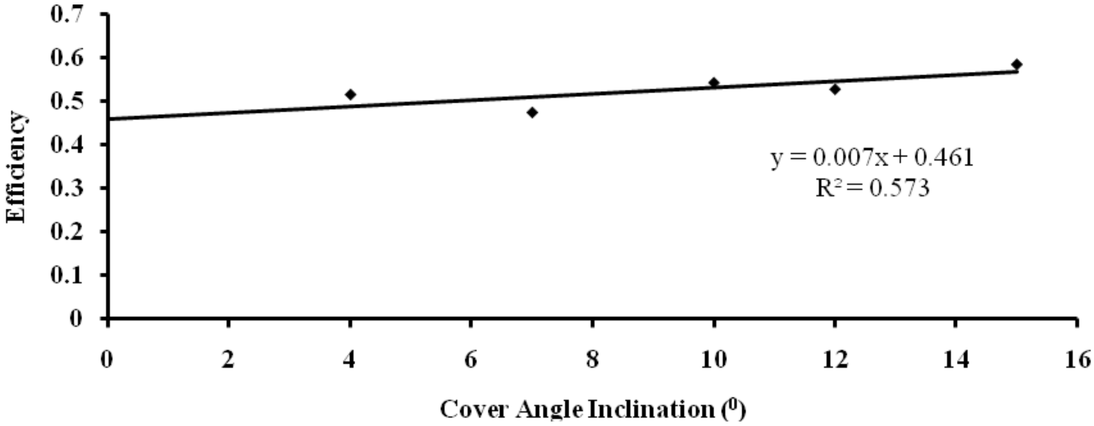

Fig. 7: variation of overall still mean efficiency with mean cover angle

IV. CONCLUSION AND RECOMMENDATIONS

Having observed the performance of stills with different angles of inclination, it can be partially established that the optimal still cover inclination for Makurdi location is higher than 15^0 as indicated by the characteristic volume/efficiency versus inclination of cover trend lines. It is a partial conclusion because a more rigorous work with larger angles of inclination. However, the observation from this study has effectively erased the existing tendency of using low angles and obtaining reasonably acceptable results due primarily to the climatic conditions of Makurdi. The trend lines also indicate that for 0^0 angle of inclination, the still can have an efficiency of about 0.461 with an output of 48.4 cm^3. This represents significant suitability of the still technology for water production in the location. Also, the equations can be used to predict the efficiency and output of stills of similar aperture areas operating under the same conditions at the location.

Due to recent changes in climatic factors, there might be changes in the best angle of tilt recommended for Makurdi. Hence, there is a need for further and continuous work in this area in order to obtain more accurate angles for optimum yield. Variations using higher angles will be undertaken in conjunction with other site-specific findings. Also, enlightenment campaigns on the application and advantages of solar still technology should be carried out.

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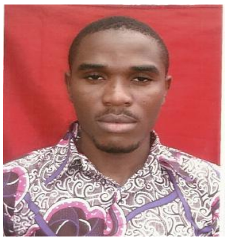

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