Improved Solar Still for Water Purification

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Abstract: According to the 2010 Malawi Demographic and Health Survey (MDHS), about 65% of households in Malawi do not have access to treated water. Distillation is one technique used for treating water. Many distillation methods are available but they are either energy intensive or contribute to environmental degradation due to their nature. However, solar energy can be used as an alternative source of energy for water distillation. There are many designs of solar distillation systems but the most-widely used one is the conventional still. Internal surfaces of the walls of the conventional solar still (CSS) are commonly painted black to avert condensation of water vapor on the walls. However, the CSS suffers from low production of distilled water and there is, therefore, a need to improve its performance. In this study, two conventional stills were designed with an identical geometry but the internal surfaces of their walls were painted white. These solar stills were tested outdoors under the same meteorological conditions at the Malawi Polytechnic (15° 42' S, 35°02' E). Distillate output was measured during experimentation. It was found that the average daily distillate outputs were 2.55 kgm^{-2} and 2.38 kgm^{-2} for the experimental still and CSS respectively. In addition, the efficiency of the experimental solar still was 6.8% more than that of the CSS. It can therefore be concluded that painting the internal surfaces of the walls of the still white improves the distillate output of the still.

Keywords: Basin still, enhancement, experimental performance, passive solar.

1. Introduction

More than two-third of the earth's surface is covered with water [1]. Most of the available water occurs either as seawater or icebergs in the Polar Regions. About 97% of the earth's water is salty, while the rest is fresh water, of which less than 1% is within human reach [2]. This small percent is still adequate to support life on earth and is replenished through a large scale solar distillation process through what is known as the hydrological cycle [3].

Distillation is one of many processes that can be used for water purification. Most commercial stills and water purification systems require electrical or other fossil-fueled power sources [4]. The use of electricity in distillation apparatus, like in fractional distillation, is energy intensive. Air pollution, acid rain, global warming and climate change are but a few of the consequences that are attributed to use of fossil fuels and have been widely investigated [5-6].

Solar energy can be used to supply the energy required to heat water by making use of a solar still. A solar still operates on the same principle as that of rain formation: water from the ocean evaporates, then cools, condenses, and returns to earth as rainwater [7]. When the water evaporates, only pure water vapor is formed while contaminants are left behind in the still basin and the distillate flows to the collection gutter by gravity (Fig. 1). Solar stills have proven to be highly effective in providing safe drinking water. The effectiveness of distillation for producing safe drinking water is well established and recognized [8]. The efficiency of a still is based on the amount of useful energy that the still converts as a function of the incoming total radiation. In the case of this project, the source of energy is a non-consumptive and free, yet irregular in its availability. The energy varies depending on the time of the day and also due to seasonal and climatic changes. For high efficiency the solar still should maintain a high temperature of the feed (un-distilled) water which can be obtained if a high proportion of the incoming radiation is absorbed by the feed water as heat. Hence a system with low absorption glazing and a good radiation-absorbing surface are required. There is also a need to keep heat losses from the floors and walls low and make the water shallow enough so that there is less to heat. The efficiency is also affected by the temperature difference between the feed water and the condensing surface. The difference needs to be large enough so that condensation is enhanced and this can be achieved if the condensing surface absorbs little or none of the incoming radiation.

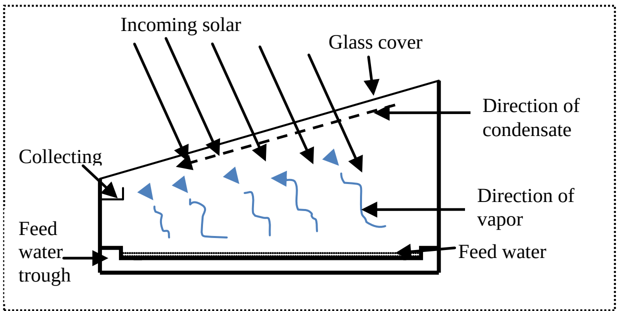

Figure 1. Basic operation of a conventional solar still.

In Malawi about 90% of the population lives in rural areas. According to the 2010 Malawi Demographic and Health Survey (MDHS), about 65% of households in Malawi do not have access to treated water. As a result water-related diseases, including cholera and typhoid, are common. Statistics also indicate that only 72% of the rural population has access to safe water in comparison to 96% of the urban population [9]. The government intends to increase this access to 74% by the year 2015 [10].

2. Experimental

This research was aimed at comparing two conventional stills that were fabricated in a similar way differing only in the way they were painted in their internal surfaces. They were installed at the same place, facing North, so that they were subjected to same climatic conditions. In this study two conventional stills were constructed that differed in their absorptivity and reflectivity of the inside surface of the stills. The parameters of the stills are given in Table 1. One of the stills was painted white on the internal surfaces of the walls of the box. This was in order to reflect the incoming solar radiation to the feed water with an attemp to increase the water temperature and at the same time keep the temperature of the condensing surface low. The basin liner was painted black to increase the capacity of solar radiation absorption. As a control, the other still was painted black on all the internal surfaces of the walls including the basin liner to be consistent with the designs of current conventional solar stills.

Table 1. Design parameters of the ASS and CSS.

Parameter	Value	
	ASS	CSS
Area of collecting surface	0.76 m^2	0.76 m^2
Area of basin	0.68 m^2	0.78 m^2
Tilt angle of cover	16°	16°
Thickness of Glass, m	0.004	0.004
Height of backside	0.42 m	0.42 m
Height of front wall	0.21 m	0.21 m
Width	0.94 m	0.94 m

Temperatures were recorded every two hours from 08:00 - 16:00 hrs. Temperatures T_b, T_d, T_e and T_h of the feed water and that near the condensing surface T_a, T_c, T_f and T_g (Fig. 2) were recorded using four Emil Yellow-back mercury thermometers with a tolerance of 0.3°C on each of the stills, two located in such a way that the thermometers are in contact with the feed water to measure the its temperature and two located near the glass condensing surface to measure the temperature of the condensing surface. The ambient temperature was recorded hourly using an ELE data logger (model MM900). A sealed platinum resistance PTFE sensor housed in an aluminum louvered radiation screen, with a range of -20°C to +70°C and accuracy of 0.2°C at 20°C, was connected to the logger for the collection of the temperature data. The distillate was collected through the outlet in Emil BS 604 graduated Pyrex measuring cylinders, with a tolerance of ±2 cm^3, every time the temperature was recorded. Solar radiation data was collected using a BPW34 silicon photodiode radiation sensor, with a spectral sensitivity range of 400 – 1100 nm, which was coupled to a SDL-1 Solar Data Logger that was installed at an incline similar to that of the still and which collected data at intervals of 15 minutes. The value of the latent heat of vaporization was taken from data tables depending on the average temperature attained by the feed water.

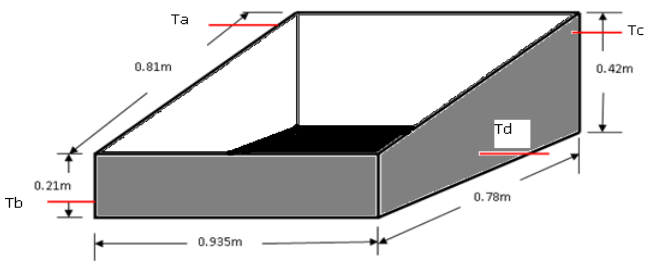

Figure 2. A perspective diagram showing the ISS.

The study was done in the months that the site receives the highest amount of solar radiation. The data was collected from 27 September 2010 to 10 October 2010. The project was carried out in Blantyre, Malawi, at the Malawi Polytechnic (15° 42' S, 35°02' E) on a roof top of T2 Workshop at a height of 6.0 m. This site was chosen because of its flat terrain and because it was free of any solar obstruction from nearby trees and buildings. The climate of Malawi consists of two seasons: dry (May to October) and wet (November to April) [11] and is greatly affected by its location in the tropical zone at an altitude of 1097.61 m above sea level. Blantyre is cool with temperatures ranging from 11.4°C to 28.1°C. The city experiences rainfall almost all year round but with most of it falling between November to March.

The efficiency of a solar still was calculated by using the energy method as proposed by Jansen, 1985 [12]:

$$\eta = \frac{APH}{3600G}$$

where P is the daily production, H is the latent heat of vaporization, A is the collecting area and G is the daily total insolation.

3. Results and Discussions

3.1 Meteorological Conditions

The amount of sunshine hours was around 11.5 which was an average of the daily sunshine hours during the duration of data collection. The daily average insolation was about 20.81×10^6 Jm^{-2}. The ambient temperature during the project duration ranged from 19°C to 34°C with the highest temperatures always observed around 11:00-13:00 hrs.

3.2 Distillate Productivity

Fig. 3 shows the hourly distillate yield on 5 October 2010. It was found that the improved solar still (ISS) started to distill earlier than the conventional solar still (CSS) on almost all the test days and therefore recorded high distillate yield at 8 hours. At 10 and 12 hours the CSS produced more distillate than the ISS but there was a reversal in the late hours as the ISS produced more distillate than the CSS. Cumulatively though it was found that the ISS produced more distillate than the CSS as shown in Fig. 4.

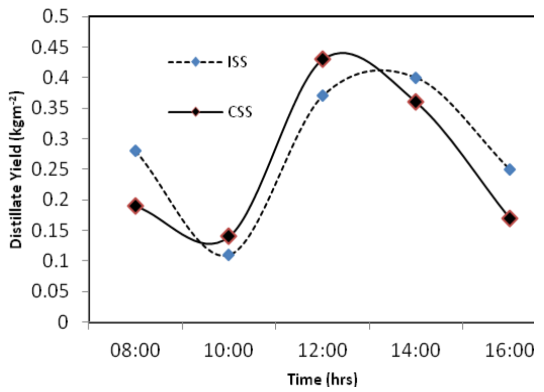

Figure 3. Hourly profile of distillate yield on 5 October 2010 at the Malawi Polytechnic.

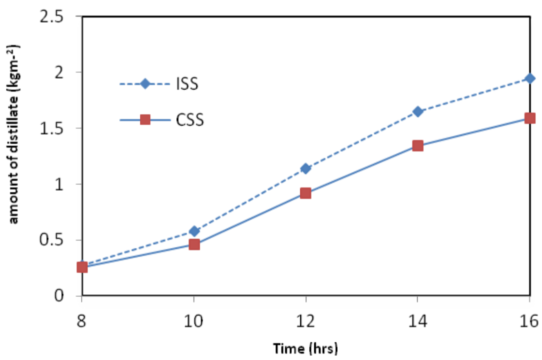

Figure 4. Cumulative amount of water collected in the stills on a selected day (16 October, 2010).

It was found that the improved still collected an average of 2.549 kgm^{-2} per day as compared to the 2.383 kgm^{-2} per day for the conventional still. In their study a single slope still, with a feed water depth of 0.01 m, Vivendi and Tiwari, 2009 produced a daily average of 1.4 kgm^{-2} [13]. Tiwari and Tiwari (2005) found a daily yield of up to 1.714 kgm^{-2} in their study. Fig. 5 shows the daily variation of the distillate yield and it is shown that the ISS produced more yield than the CSS.

A paired samples t-test was conducted to compare the distillate yields for the ISS and the CSS. It was found that there was a statistically significant difference in the distillate yields for the ISS and the CSS at 95% confidence interval (p-value = 0.000). $t(38) = -1.427$, $p = 0.000$,

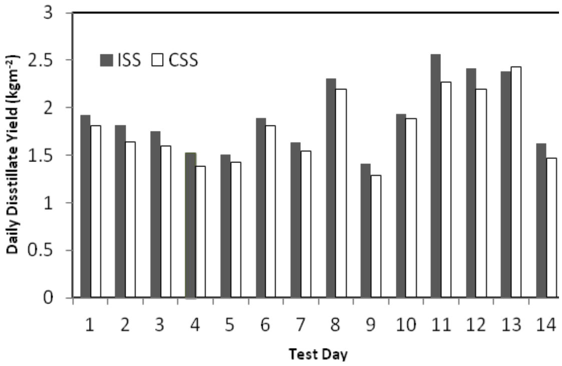

Figure 5. Daily distillate yields for the period of the project for the ISS and CSS.

3.3 Efficiency

Data from the two stills was collected and analyzed. The efficiency of the improved still varied from 25.9% to 32.9% with an average value of 29.3% and that of the conventional still varied from 25.4% to 31.1% with an average efficiency of 27.4%. Symth et al. (2002) [15] found efficiencies of no more than 28.5% in their study on the operating performance of a simple basin type passive still. The efficiency of the improved solar still was found to be 6.9% higher than that of the conventional still under the same climatic conditions. This is in agreement with the hypothesis that was made in this study. It must be noted that this method for calculating the efficiency was used because the temperature method could not be relied on because of the way the temperature data was collected. Fig. 6 shows the daily efficiencies of the ISS and CSS. It can be seen that the ISS recorded higher efficiencies than the CSS.

A paired samples t-test was carried out to establish to compare the efficiency of the ISS and the CSS. There was a statistically significant difference in the mean efficiencies of the ISS and the CSS. $t(26) = -2.555$, p-value = 0.000).

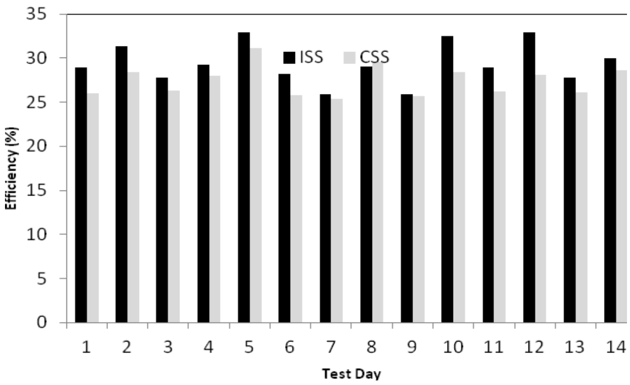

Figure 6. Comparison of daily efficiencies for the ISS and the CSS.

4. Conclusions

There is an urgent need for clean potable water in many countries of the world including Malawi. While most urban populations have access to clean potable water, many people in rural areas do not. There are many ways that can be used to improve the quality of water and one way is through distillation. A number of methods that utilize sources of energy other than solar are used to purify water to (be safe for drinking).

Our study found that painting the internal surfaces of the walls of the still white improves the distillate output of the still. This was done by comparing outputs from two stills that were sited at the same location. The amount of distillate varied from 1.452 to 3.208 kgm^{-2} and 1.730 to 3.380 kgm^{-2} with an average of 2.383 and 2.549 kgm^{-2} for the CSS and the ISS respectively. The quality of the water after distillation agreed with standards required for safe drinking water which underlines the fact that the distillation was satisfactory. The average efficiencies of the stills ranged from 25.9% to 32.9% as compared to 25.4% to 31.1% for the ISS and the CSS, respectively. The improved still was found to be 6.9% more efficient than the conventional still. A new design of solar still has been developed and tested with results showing that it performs better than the conventional still. From these observations, it is seen that the ISS is more efficient than the CSS under the same conditions, a result attributed to the white surface of the inside of the ISS.

It is however recommended that still temperatures need to be taken using thermocouples and a data logger to eliminate errors due to the use of mercury thermometers. The use of measuring cylinders for feeding the solar still could have been introducing air into the stills thereby limiting evaporation and hence lowering the distillate yield. A continuous feed from a tank is therefore recommended to avoid this problem.

References

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