Afropolitan Journals

ISSN: 3027-2114 www.afropolitanjournals.com

Experimental Study on the Effects of Beeswax as Absorber for Solar Still

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DOI: *https://doi.org/10.62154/ajesre.2024.016.010397*

Abstract

An experimental study on the effects of beeswax incorporated in the construction of the absorber for a solar still was conducted. As part of the study, two solar stills of the same geometry were constructed with the same water depth and volume. The one without a phase change material (PCM) was used as the control still, while the other with beeswax as a phase change material laid at the bottom of its basin to serve as an absorber was used as the experimental still. The experiments were conducted in the thermodynamic laboratory of JS Tarka University, Makurdi, Nigeria, between 10.00 am and 5.00 pm for two weeks. 16 litres of water were used for each still, corresponding to 100 mm depth. The stills were kept side by side and exposed to sunshine from 10.00 am to 5.00 pm for three days. Temperatures of the water at inlet and in the still were measured. HT-9815 digital thermocouple was used to determine the temperature of water in the basin and that of the inner glass cover. SM206 solar power meter was used to measure the amount of solar energy incident on the still's collector. The results showed that the still with beeswax as phase change material (experimental still) has an improved thermal efficiency enhancement of 109.30% as compared to the still without a phase change material with a thermal efficiency enhancement of 86.1%. This implies that beeswax is a good phase change material for solar stills, and the use of beeswax should be encouraged as it is non-toxic and organic.

Keywords: Beeswax, Phase Change Material, PCM, Clean Water, Sustainability, Solar Still.

Introduction

The consistent increase in paucity of clean drinking water especially in remote communities has been a major cause of concern globally (Shahsavari and Akbari, 2018). Although water is said to be naturally abundant in rivers, lakes and underground reservoirs, constituting about 70 % of the earth, research has shown that only 2.5 - 3 % of this is fresh, out of which only 0.4 % is drinkable while about 1.6 % is polar ice caps and glacier (Benson, 2018). In recent times, water purification processes have become of important, and despite technological advancements, about 14.7 % of the earth's population still lack access to clean water, a crisis which has led to ground water overdraft, diminished agricultural yields, regional conflicts over scarce water resources, inadequate access to water for sanitation and waste disposal amongst others (Olsson, 2015; World Health Organization, 2016).

In developing nations such as Nigeria, lack of adequate potable water has taken the lead among causes of death of children (Peter and Umar, 2018: Odipe *et al.,* 2019; Manta *et al.,* 2021). This results from the presence of micro-organisms and dissolved substances in the water, causing dysentery which eventually leads to diarrhea and fatal dehydration (Surendhiran *et al.,* 2017). It has been estimated that due to persistent demand for clean water, its availability will be short by 56 % by 2025 - 2030, likely causing about 1.8 billion people to experience water scarcity in several regions of the world (World Water Organization, 2010; Udmale *et al.,* 2016).

Solar distillation is one of the most reliable, cost-effective methods of purifying water employing only the free power of the sun as its energy source in a still (Fang *et al.,* 2019). It is a functional system that harnesses solar thermal energy to produce drinkable water through distillation, which involves evaporation and condensation, where the water evaporates to leave contaminants behind (Obayemi *et al*., 2014; Gao *et al.,* 2019; Zhang *et al.,* 2019). This process is however yet to achieve commercial status due to limitations on the volume of water it can produce. As a result, researchers are constantly seeking ways to enhance its productivity. One method being explored is to increase its thermal efficiency by utilizing absorbers incorporating materials with large energy storage capabilities. These store energy during peak hours of sunshine to release them during low radiation periods, thereby sustaining production.

Several phase change materials such as salt hydrates, paraffin waxes, fatty acids, and sugar alcohols can be used for latent heat storage applications (Liu *et al.,* 2017). Paraffin waxes represent the most suitable option for solar still applications, due to their consistent melting temperatures, abundance and low price (Kabeel and Abdelgaied, 2016; Jahanpanah *et al.,* 2021). However, they usually suffer from relatively lower thermal conductivity and high volumetric expansion ratios (Putra *et al.,* 2016; Ahmed, *et al.,* 2022). Previous studies on the effects of paraffin wax used as PCMs for thermal storage in solar stills include Mohammad and Farshad (2011), who studied the behavior of cascade still incorporating materials for storing latent heat. Behaviors of the solar still incorporating PCM and without it have been modelled mathematically with the results indicating a better distillate productivity for the PCM incorporated still (31% higher) than the solar still without PCM. Arunkumar *et al.* (2018) studied the effect of thermal storage material on the yield of a concentrating hemispherical basin still. The results showed a 26 % improvement on the yield of the still with PCM.

One other material that has been shown to have good PCM properties is Beeswax. Beeswax can be classified as an organic PCM originating from organic materials. It comprises of esters of fatty acids and long-chain alcohols. The empirical formula for beeswax is C15H31COOC30H61, which consists of palmitate, palmit oleate, hydroxyl palmitate, and oleate esters of long-chain aliphatic alcohols (Putra, *et al.,* 2016).

Beeswax shares the advantages of organic PCMs which have been noted as being largely available, with acceptable melting temperatures of 30 °C - 60 °C, having high latent heat of fusion, good chemical stability, non-corrosiveness and no/very low super cooling (Sharma *et al.,* 2021; Putra *et al.,* 2016). The major disadvantage of organic PCMs (Low thermal conductivity) can be overcome through the use of additives such as nano-particles of highly conductive materials (Putra *et al.,* 2016; Ouikhalfan *et al.,* 2016; Ahmed, *et al.,* 2022). Furthermore, beeswax is a waste derived from bee farms mostly located in rural areas who coincidentally, mostly lack good water supply. Its utilization will therefore add more value to bee farming and enhance good water supply.

In spite of all the promising results obtained on beeswax as a PCM, no studies on its use in solar stills have been reported. This study therefore sought to determine the usability of beeswax as a PCM in solar stills.

Statement of the Problem

Although beeswax has been proven to have good PCM properties, its engineering applications, especially in the area of solar still have been limited. However, it holds the potential to make solar still construction cheaper and therefore enhance the availability of clean water especially in rural areas where it is mostly available, and where clean water is also mostly scarce. This study therefore investigated the effects of the use of beeswax as a PCM on the performance of a single slope, passive solar still in Makurdi, Benue state, Nigeria. The study sought information on the organic, non-poisonous biodegradable material which could be used to enhance clean water supply for better livelihood in remote areas.

Aim and Objectives of the Study

The aim of this study is to enhance clean water availability through the use of locally available, cheap materials for infrastructural development, such as clean water production apparatus for remote areas. Specific objectives of the study included:

1. To design and construct a single slope, passive solar still with beeswax as absorber.
2. To determine the clean water production capacity of the constructed solar still.

Significance of the Study

The information provided by this study will contribute to the existing body of knowledge about solar still, which will help in developing better clean water infrastructure (solar stills) for remote areas that will result in significant socio-economic and environmental impacts.

Materials and Methods

The material specifications for the solar still, and the equipment used for the study are presented in Table 1.

Table 1: Materials Specification for Components of the Solar Still and Equipment

S/N	Component	Material
1	Frame	Mild Still (25 ×25 ×5) mm angle bar
2	Basin	Stainless still (1 mm thick)
3	Body	Laminated MDF board
4	Top cover	Transparent glass (4 mm thick)
5	PCM	Beeswax (15 mm thick)
6	Distillate Collection Tank	Plastic
7	Distillate Collection Hose	Plastic
	Equipment	**Model**
1	Solar Power Meter	SM206
2	Digital Thermocouple	HT-9815

Solar Still Design and Construction

Two stills of identical geometry were constructed; one was without a PCM (Control still), while the other had a PCM laid at the bottom of its basin to serve as an absorber (Experimental still). The thickness of the PCM was factored in the design and construction of the basin to ensure that the depth of water was the same for the two stills. The depth of the basin for the experimental still was 215 mm. The still was made up of several components as presented in Table 1, and shown in plate 1. The orthographic and exploded views of the stills are shown in Figures 1 and 2 respectively. A 15 mm thick PCM layer made of yellow beeswax obtained from a local bee farm in Makurdi, Nigeria was spread at the bottom of the experimental still's basin. Provisions were made on the side of the stills to allow access for the thermocouple probe for the measurement of inner glass surface and water surface temperatures.

Plate 1: Complete Solar Still Assembly

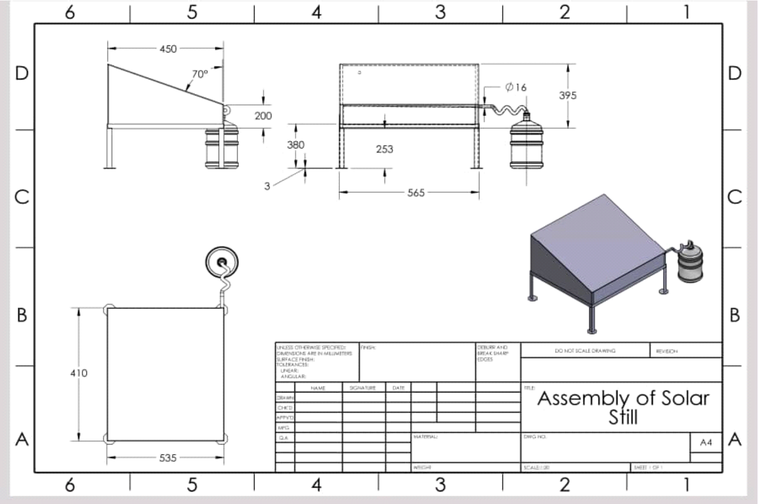
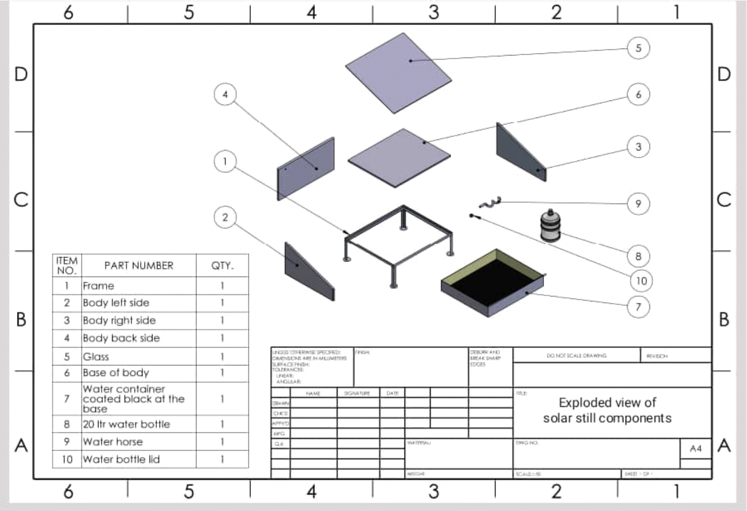


Figure 1: Orthographic View of the Solar Still



ITEM NO.	PART NUMBER	QTY.
1	Frame	1
2	Body left side	1
3	Body right side	1
4	Body back side	1
5	Glass	1
6	Base of body	1
7	Water container coated black at the base	1
8	20 ltr water bottle	1
9	Water horse	1
10	Water bottle lid	1

Figure 2: Exploded View of the Solar Still

Experimental Setup

The experiments were conducted in the thermodynamic laboratory of JS Tarka University, Makurdi, Nigeria, between 10.00 am and 5.00 pm for two weeks. 16 litres of water was used for each still, corresponding to 100 mm depth. The choice of this depth was guided by the findings of Bhargva and Yadav (2021). Measurements were taken at 30 minutes intervals throughout the daily period of experiment. This was repeated twice at weekly intervals to accommodate weather fluctuations, and the average values of parameters measured were found and used appropriately. Both stills were subjected to same conditions with precautions taken to avoid shading of the still throughout the period of experiment.

The SM206 solar power meter was used to measure the intensity of solar radiation on the still's surface in W/m^2. HT-9815 digital thermocouple was employed to determine the temperatures of the inner glass and water surfaces and at inlet and outlet of tills (°C) at the same time using its four probes. A digital temperature sensor was used to monitor the ambient temperature throughout the period of the experiments.

Parameters used in measuring the stills' performance include inner glass and water surfaces temperature difference, overall yield and thermal efficiency. The following relations were used to determine the parameters:

$$\Delta T = T_w - T_g \qquad (1)$$

T_w and T_g are the water and the glass temperature respectively.

Where $T_w = T_{wp}$ (for experimental still); T_{wc} (for control still), $T_g = T_{gp}$ (for experimental still); T_{gc} (for control still), $\Delta T = \Delta T_p$ (for experimental still); ΔT_c (for control still). Therefore, the enhancement in temperature difference as a result of using PCM was found using the relation

$$\sum \Delta T = \sum \Delta T_p - \sum \Delta T_c \qquad (2)$$

Where $\sum \Delta T_p =$ Whole day temperature difference for experimental still, $\sum \Delta T_c =$ Whole day temperature difference for control still.

The overall yield of still was constantly measured with a graduated cylinder at 30 minutes intervals. These values are the instantaneous yield (Y_c for control still, and Y_p for experimental still)

∴ Overall yield enhancement was determined thus:

$$\sum Y = \sum Y_p - \sum Y_c \qquad (3)$$

Where $\sum Y_c =$ Sum of all instantaneous yield for control still throughout the day, $\sum Y_p =$ Sum of all instantaneous yield for experimental still throughout the day.

Furthermore, thermal analysis was conducted to ascertain the effect of the PCM on the thermal efficiency of the still. The useful thermal energy gained by the stills (Q) was determined as the function of the quantity of water evaporated, and the following relation was used (Prakash, *et al.,* 2022).

$$\eta = \frac{Q}{AI(t)} = \frac{mC_p(T_2 - T_1)}{AI(t)} \qquad (4)$$

Where A = Area of still

I = Solar radiation received by still

m = mass of distillate

C_p = Specific heat capacity of water at constant pressure

t = Daily period of experiment

T_2 = Temperature of water at outlet of still

T_1 = Temperature of water at inlet of still

Results and Discussion

The results of this study are presented in Figures 3 - 6, with effects of the use of beeswax as absorber in the basin of the single slope passive solar still on various performance parameters.

Variation of Solar Intensity

Figure 3 shows the progressive variation of solar intensity between 10.00 am and 5.00 am for the days the experiments were conducted as measured with SM 206 solar power meter. It shows that solar radiation expectedly rose to its peak (1175 W/m^2) at 12.00 noon, then declined gradually to (128 W/m^2) by 5.00 pm. The minor fluctuations were caused by varying cloud thickness in the sky.

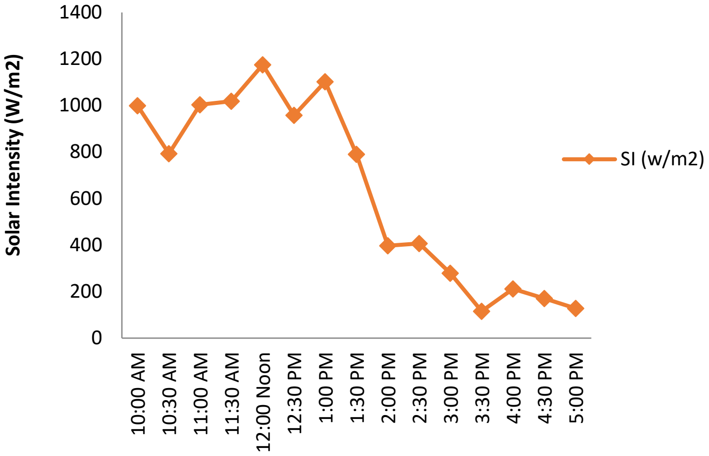


Figure 3: Variation of Solar Intensity with Time of Day

Temperature Variation

Figure 4 represents the variation of ambient temperature (*AT*), inner temperature of glass for control still (T_{gc}), inner temperature of glass for experimental still (T_{gp}), surface temperature of water in basin for control still (T_{wc}) and the temperature of water surface in basin for experimental still (T_{wp}) with time of day and solar radiation intensity. It further shows that the ambient temperature only slightly rose from 30.6 °C through its peak (37.1 °C) at 2:00 am and declined gradually to 36.8 °C at 5:00 am. It expectedly remained below the still's inner temperatures throughout the duration of the experiment, indicating that the still actually collected and stored solar thermal energy to enhance its function. The inner temperatures of glass T_{gc} and T_{gp} followed a similar trend of starting low at 10:00 am, gradually rising to 53.00 °C and 53.60 °C, and then declined gradually to 35.00 °C and 49.3 °C respectively. Note that between 10:00 am and 1:00 pm, T_{gp} remained lower than T_{gc}. This is attributable to the presence of the PCM in the basin which absorbed and stored part of the thermal energy through phase change. However, between 1.00 pm and 5:00 pm, T_{gp} rose and remained higher than T_{gc} indicating that the PCM was able to maintain higher temperatures in the still by releasing the stored energy as the need arose. Similarly, T_{wc} and T_{wp} followed a similar trend with T_{wc} rising faster while T_{wp} rose slowly but steadily until 12:30 pm when they became equal and T_{wp} overtook T_{wc} after 1:30 pm and remained higher with a smoother curve till 5:00 pm, indicative of the influence of the PCM, which released energy gradually and continuously to the water making it easier to evaporate.

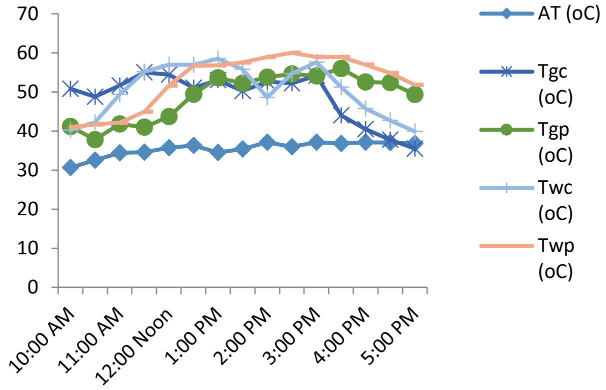


Figure 4: Temperature Variation with Time of Day

Variation of Temperature Difference and Yield of Stills

Figure 5 shows the temperature difference (ΔT) and yield (Y) of the control and experimental stills. It shows that the experimental still maintained a positive and steadier temperature variation between the inner glass and water surface throughout the period of experiment. For the control still, the temperature variation between glass and water surface was negative (glass surface had higher temperature than water surface) between 10:00 am and 11: 30 pm. This is attributable to lack of energy storage in the control still's basin. The figure also shows that the experimental still also had more yield than the control still throughout the experimental period. This is testimonial to the energy storage capability of the PCM and its ability to release the stored heat to steadily maintain higher water temperatures that enhanced evaporation. This has resulted in an overall enhancement in cumulative temperature difference and yield of stills as shown in Figure 6. This shows that the beeswax has the potential to increase the yield of solar still per unit area of basin, hence increasing productivity and reducing cost of the still.

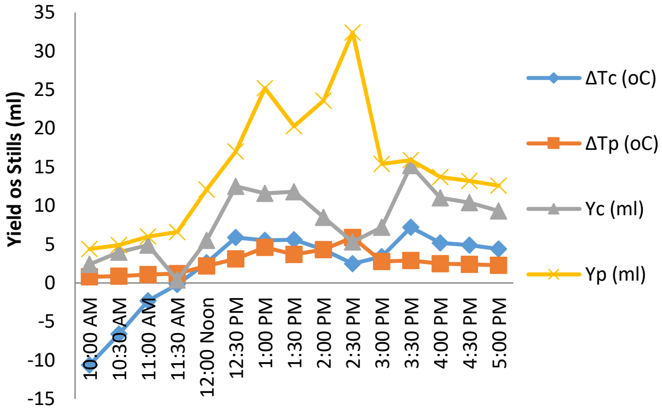


Figure 5: Variation of Temperature Difference between Inner Glass Surface and Water Surface and Yield of Stills with Time of Day

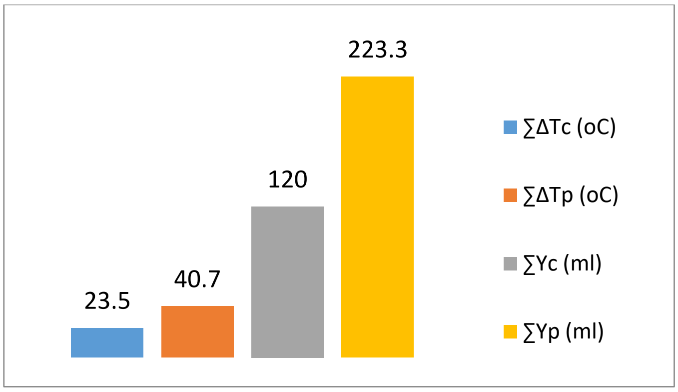


Figure 6: Cumulative Temperature Difference between Inner Glass Surface and Water Surface and Yield of Stills

Thermal Efficiency

Figure 7 shows that the experimental still had a higher efficiency (18 %) than the control still (8.6 %), further confirming the effect of the beeswax PCM. This gave an efficiency enhancement of 109.30%. This result agrees with the result of Prakash *et al.* (2022) in the efficiency range for single slope solar still. These results corroborate the findings of Putra *et al.* (2016), Putra *et al.* (2020), and Ramnanan-Singh (2012), who reported that beeswax is a good PCM with good energy storage capabilities due to its superior thermal properties such as high latent heat of fusion, specific heat and melting point compared to other materials. This shows that beeswax has the potential to revolutionize still construction through cost reduction by replacing expensive absorber materials and enhanced performance.

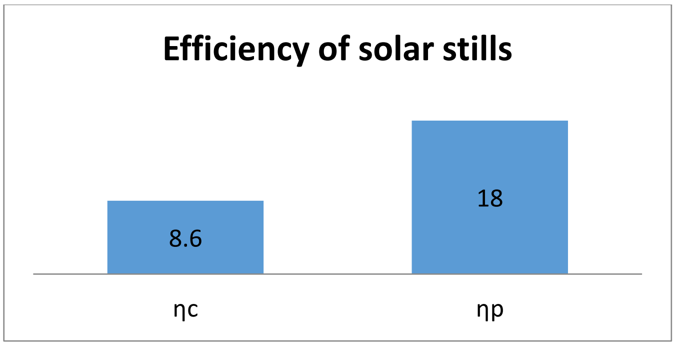


Figure 7: Efficiency of Control (η_c) and Experimental (η_p) Stills

Conclusion and Recommendation

This study investigated the use of beeswax as a PCM in a single slope solar still with the goal of evaluating its effects on the still's performance. Temperature distribution and thermal efficiency were used as performance parameters. The study shows that using beeswax as PCM in the solar still significantly stabilized the temperature profiles during the fluctuations of solar radiation. The PCM incorporated still kept the temperature relatively constant, making the distillation process more effective in comparison with the still without a PCM.

Improved thermal efficiency was also observed in the still incorporating beeswax as PCM. Thus, the PCM minimized heat loss at night and offered a steady heat source on overcast days.

The results obtained are experimental and there is need for this technology to be tested at a large scale to further ascertain its viability. Also, the experiment needs to be tested in other climatic zones to ascertain it applicability there too. Further research is also needful on was from different species of bees to check specie related variability.

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