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The Performance of Modified Conventional Still Distiller with a Coupled External Passive Condenser: an Experimental Study

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Abstract:
Solar radiation plays an important role in the desalination process due to its abundance in areas with potable water shortage and also occupies an important position in renewable energies due to simplicity of application. Still distiller is viewed by researchers as suitable source of potable water because of low cost of fabrication, easy operation and zero emission technology. Studies by researchers is geared towards exploring new models to enhance the efficiency of solar stills and increase the production rates. The main aspiration of this work is to experiment the effect of incorporating a passive condenser into a modified conventional solar still to enhance daily productivity rate. It has been found that modified passive still distiller coupled with external condenser gives about 11.85% higher production rate as compared to the modified conventional still distiller. Daily and accumulated distillate yield for the still distillers have been studied and analyzed. As a result of the findings, the researchers recommend the sawdust padding around still distillers can maximize productivity leading to efficient water distillation in regions where that require still distiller usage. This recommendation has desired result of enhancing access to potable water in areas with water scarcity and do contribute to sustainable and cost-effective water purification method.

Keyword: passive still distiller, conventional still distiller, potable water, solar radiation, sawdust, distillate.

1. Introduction

Availability of potable water to meet global demand has been on the decline despite the earth's abundant water bodies and is among global challenges. Scarcity of potable water is listed the sustainable development goal of United Nations (UN) which pose a threat to millions of people around the world today due to urbanization, growing population, industrial demand and contamination of water resources, meteorological conditions, etc (Kalidasan et al., 2021; Kabeel et al.,2023; Oni et al., 2020; United Nations Educational, 2020. The remote settlements, especially in the sub-Saharan regions are characterized by below the poverty line populations that live with poor geographical accessibility (Zhang et al., 2021; Alkilani et al., 2023). Although demand for potable water in such areas is paramount to sustain population growth which drives the agricultural activity. In such areas, the water resource is limited to seawater, deep groundwater and blackish water which cannot be directly used for potable water because of contaminants (Ayoobi & Ramezanizadeh, 2021). Therefore, purification of the contaminated water is in lockstep with freshwater and drinkable water availability for the populace in such regions. Several techniques known for water purification systems such as reverse osmosis, electro-dialysis, vacuum distillation, Nano-filtration, multi effect distillation, solar distillation etc. are engaged around the globe (Misdan et al., 2012; Darre & Toor, 2018). Most techniques' reliance on fossil fuels with attendant emission of greenhouse gases pose a challenge to the environment.

Desalination is a reliable approach to generate potable water for societal usage considering the abundance of non-potable water and solar desalination technology with ecofriendly benefits including minimal maintenance requirements, insignificant environmental impact, zero emission of greenhouse gases, powered by solar energy which improves process sustainability and ease of fabrication have a promising future (Abdelgaied et al., 2022a; Abdelgaied et al., 2022b; Abdelgaied et al., 2021; Abdelgaied & Kabeel, 2021). The desalination of water using solar still represents a viable method to solve potable water scarcity in regions where the solar energy is abundant and water resources are limited and modifications on solar still have been investigated in search of better performance such as single slope, single slope with solar collector, pyramid shaped, wicked, finned, triangular, tubular, hemispherical, concave, multi-slopes, vertical stills, inclined, stepped, heat storage and those having external devices such as reflectors and condensers (Alnaimat et al., 2018; Abu-Arabi et al., 2020; Taamneh & Taamneh, 2012; Sampathkumar et al., 2010). Tuly et al. (2021) reported an enhanced potable water productivity using double slope modified solar still coupled with fin, phase change material, wick and external condenser in a comparative assessment of modified, finned, and traditional solar stills. They used the combined effect of solid rectangular fin with paraffin wax as the thermal storage medium and black cotton cloth as a wick material. Their results showed potable water productivity rate of 3.07, 2.70, and 2.46 L/m^2 for modified, finned and traditional solar still while the inclusion of external condenser boosted productivity with about 10%. Researchers have tried to improve the intermittent nature of solar power by using various thermal energy storage system that integrates phase change material for improved performance of solar stills. Abdullah et al. (2022) investigated the performance of conventional absorber solar still and convex absorber solar still with different wick materials, nano black paint and nano phase change materials. They proposed that increasing the convex height of the solar still increases daily productivity till reaching the peak at 15 cm after which a decline was observed while for the wick material, the jute had superior performance than cotton. Their results presented that a 15 cm convex height and jute wick convex solar still showed a 54% superior productivity than conventional solar still.

Benhammou & Sahli (2021) studied the efficiency of heat storage system that is coupled with double glazing solar collector which provided stored latent heat to single slope solar still. This setup is modelled to work autonomously and continuously throughout the day with results indicating increased productivity for daily and nocturnal yield to be at 63% and 635% respectively as compared to the conventional systems. They opined that useful energy is strongly influenced negatively by the increase of phase change material mass and an optimum tilt angle of 15^o for solar stills. Eltawil and Omara (2014) investigated the performance of solar still equipped with flat plate solar collector, solar air collector, spraying unit, perforated tubes and external condenser. They suggested that an increased production yield of 51% was achieved by the use of external condenser while the solar still coupled with water solar collector and condenser showed better performance of 104% increase. However, the solar still coupled with hot water-spray, hot air and condenser exhibited better performance over conventional solar still by 148% with daily efficiency is about 29%.

Abdullaha et al. (2020) investigated the effect of internal reflectors on tray distiller performance alongside the influence of coating the solar still surface with the mixture of black paint and copper oxide (CuO) nanoparticles. They suggested that it could enhance the heat transfer characteristics within the solar still. Their study evaluated the impact of mixing paraffin wax with CuO nanoparticles as a phase change material for the tray distiller. Results they obtained revealed a total freshwater yield for the tray distiller to improve by 57, 14, 70.7, and 108% when using reflectors, CuO nanoparticles in paint, reflectors and nano-coating, nano coating and PCM with CuO nanoparticles respectively. Sharshira et al. (2020) studied the use of linen wicks and carbon black nanoparticles to enhance the solar stills' evaporation surface area via improved heat transfer with increased performance for stepped double slope solar still. The energy and exergy for convection and evaporation and exergy efficiency for each different modification was analyzed and found to increase the productivity and energy efficiency by 80.57 and 110.5%. Abdel-Aziz et al. (2023) carried out an experiment on the effect of introducing a solar powered electric heater to a conventional single-slope solar still with paraffin wax as phase change material situated under the solar still basin. Their work reports that the accumulated productivity of the modified solar still is enhanced by 252.4% and 214.5% with heater at control temperature of 65 °C at spring and summer, respectively. They further evaluated the economic mode of the proposed solar still with the aid of cost per litre and solved that the solar still with heater operating at 65 °C had higher exergoeconomic value than the conventional one. Abdelgaied (2018) assessed the effectiveness of parabolic trough concentrator attached to a solar still which was controlled by oil heat exchanger and phase change material. Their report concluded that its solar still design has 140.4% greater efficiency than normal conventional solar still. Khechekhouche et al. (2021) investigated the effect of glass cover thickness on efficiency of a solar still considering three different glass thicknesses. They stated that the solar energy flows through the glass cover as heat; therefore, the higher glass cover's temperature, the lower solar still's productivity. Their results showed that the glass thickness of 3 mm yields better efficiency for the conventional solar still. The measured energy efficiency was 30.71, 19.02, and 11.44% for different cover thicknesses of 3, 5, and 6 mm, respectively.

Several solar still modifications have been studied in recent years in a bid to improve its performance in service. In this present work a methodical process has been adopted to design a solar still with low capital cost and modifications in order to reduce heat losses and enhance productivity yield. The study investigates modified conventional single slope solar still as a reference against which the performance of modified passive single solar still coupled with external condenser was evaluated. The features included to the modified conventional still distiller in a bid to reduce heat loss involves suspending the water basin inside the solar still with sawdust as an insulator and an outer wooden frame which also the still distiller with sawdust. However, to enhance productivity, the research adopted a low-cost feature to increase condensation rate process through the attached passive hollow condenser as a concentrated effort geared towards containing dissipation of heat and redeliver same to elevate the systems' temperature. All trials were conducted in the distiller basin within the months of March and April 2024 in the northern parts of Nigeria. The schematic diagram of the experimentally constructed stills distiller is shown in Figure 1.

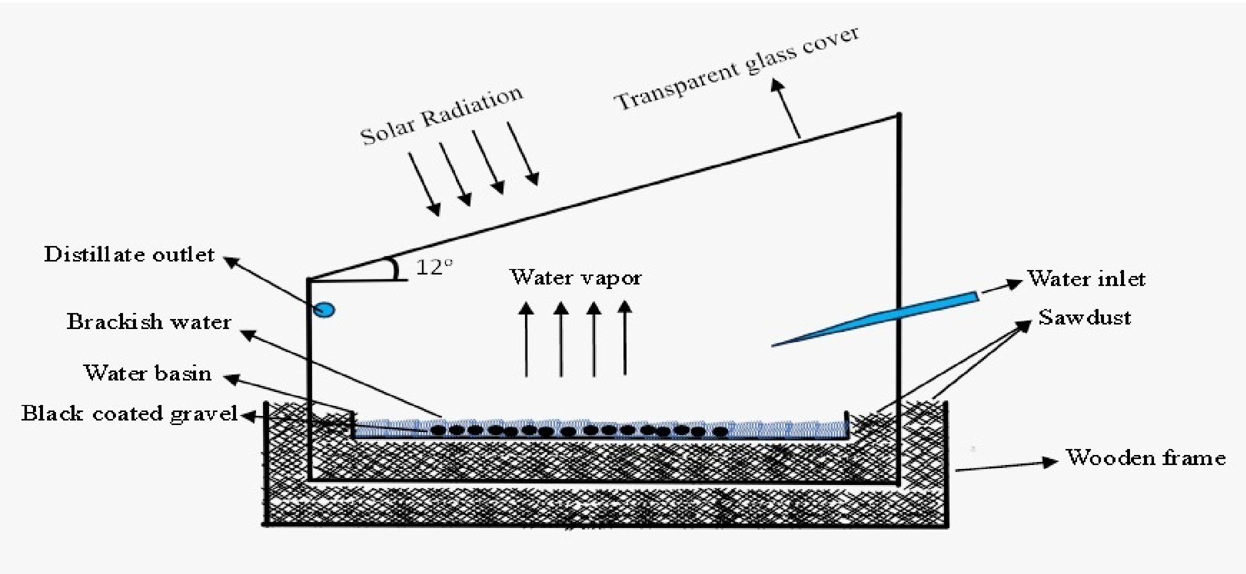

Figure 1. Schematic diagram of the experimentally constructed stills distiller

2. Research Procedures

Working principle

Solar stills engage solar energy to produce clean water through the heat acquired from the suns' radiation to initiate evaporation and subsequent condensation process (Ayoobi & Ramezanizadeh, 2021). The two core working principal types of solar stills are active and passive solar still which depends on the source of heat generation to evaporate the water in its basin. Heat generation can be accessed directly from the suns radiation (passive) and/ or generation of heat energy by some mechanical techniques (active) (Darre & Toor, 2018). Convectional still distiller (CSD) grouped under the passive solar stills basically comprises of a water basin, transparent glass cover and a distillate collector.

Several modifications have been added to CSD by researchers to improve its performance in terms of hourly yield and aesthetic design (Kalidasan et al., 2021). The simplicity of its operation involves incident solar radiation transmitted via the top transparent glass cover to heat up the basin containing either saline or brackish water within the still distiller. The heated water then evaporates towards the top glass cover where condensation takes place to water droplets collected by the distillate collector. However, heat losses are known to occur during the process such as heat released through latent heat of condensation and heat lost to the environment.

Experimental setup

The present experimental work aims to propose a novel design for still distillers to overcome the prevalent heat loss of associated with its operation in service. To realize this aim, the system is fabricated with corrugated iron sheets and partly imbedded with sawdust as an insulator to mitigate heat losses. In addition, the surface area available for condensation process is increased by coupling passive external condenser to the still that might recycle latent heat of condensation within the system. Condensation process is enhanced by using 4 mm thick transparent glass cover which also offer maximum access of solar radiation. For optimal yield, the gas cover is inclined at angle of 12^{o} to achieve enhanced water droplet slide under gravity. Overall dimensions and specifications for MPSD and MCSD are presented in Table 1. To improve solar radiation absorption, inside of the solar still; base and sides are painted black and black gravels are placed at the base to retain heat within the system. However, the passive condenser is painted white within and outside as a reflector to external radiations with an aluminum roof placed over the condenser to shade direct sunrays. The distillate is collected through an inclined conduit connected to 4L volumetric flask on a frame base. The experiments were conducted in Abubakar Tafawa Balewa University Bauchi between the months of March and April 2024 from 8 a.m. to 8 p.m. On March 30, 2024, experiments commenced with MPSD and MCSD with total distillate volume measured for each day. A snapshot of the solar stills is shown in Figure 2.

Table 1. Design specification of modified conventional still distiller and modified passive still distiller

Parameter	MCSS	MPSS
Solar still outer dimensions (cm)	100 x 90	100 x 90 m
Inside water basin dimensions (cm)	80 x 70	80 x 70
Depth of the still distiller (cm)	45	45
Depth of the water basin (cm)	8	8
The thickness of glass cover (cm)	0.4	0.4
Angle of inclination with the horizontal	12^{o}	12^{o}
Depth of the sawdust beneath the water basin (cm)	35	35
Thickness of the sawdust around the water basin (cm)	9	9
Distance of the water basin from top cover (cm)	25	25
Thickness of the sawdust around the still distiller (cm)	20	20
Thickness of the sawdust beneath the still distiller (cm)	30	30

Figure 2. Snapshot of the Solar Stills (a) Modified Passive Still Distiller (b) Modified Convectional Still Distiller

3. Results and Discussion

Purification of saline and/ or brackish water using solar still is an efficient means to meet potable water demands and reduce greenhouse gas emission involved in other techniques of water purification (Srithar et al., 2023). Factors considered in increasing evaporation and condensation process of the passive still distiller are low cost fabrication and design that will enhance overall yield (Samuel et al., 2022). Data obtained from the study revealed that MCSD which is the reference still distiller produced an accumulated distillate totaling 30263.3 ml for the period of the study while MPSD recorded total distillate yield of 33850.4 ml in the same period and conditions. The calculated average showed that MPSD had better average percentage yield of 11.85% for the period of experiments indicating that modified still distillers using cost effective materials can serve effectively as potable water source. According to Kabeel et al. (2023), modified solar still are seen as future potable resource for regions with saline or brackish water due to its zero emission and ease of operation. As can be clearly seen from Figure 3, MPSD had high rate of distillate yield that fluctuated with weather conditions. The enhanced productivity is attributed to attached passive condenser which provided more condensation surface area and volume that contained dissipated latent heat within the system. However, as observed from the graph, the passive condenser compartment had low yield of the distillate. The accumulated distillate from the condenser totaled 1173.4 ml that is 3.5% of MPSD output. Similarly, Ahmed et al (2017) in a study reported an output of 27.4% from condenser compartment which reveals that the design in this study did not produce at optimal condenser efficiency. The low output is attributed mainly to the design pattern and weather conditions during the period of experiments. As seen in Figure 4, design of the condenser got heated up with the sun's radiation despite the white paint that was intended to repel the radiations and its overhead aluminum shade. The passive condenser however did contribute to the overall total distillate yield for MPSD. Figure 5 shows the comparison of the stills' daily distillate yield which clearly revealed fluctuations in daily distillate yield from both MPSD and MCSD. This fluctuation could be ascribed to environmental factors such as sun's radiation, wind velocity and weather conditions which is in agreement with the work by Abdelgaied and Kabeel (2021). Perusal of Figure 6 reveals highest daily distillate yield for MPSD was obtained on day nine of the experimental study with a total distillate volume of about 1.6 L/day with the second peak recorded on the thirteenth day with total distillate volume of about 1.5 L/day. MCSD had highest daily distillate yield on day eight with about 1.7 L/day of the distillate collected. This suggests that MCSD had higher distillate yield than MPSD on few days a phenomenon that we ascribed to environmental factors and weather conditions (Chamsaard et al., 2020).

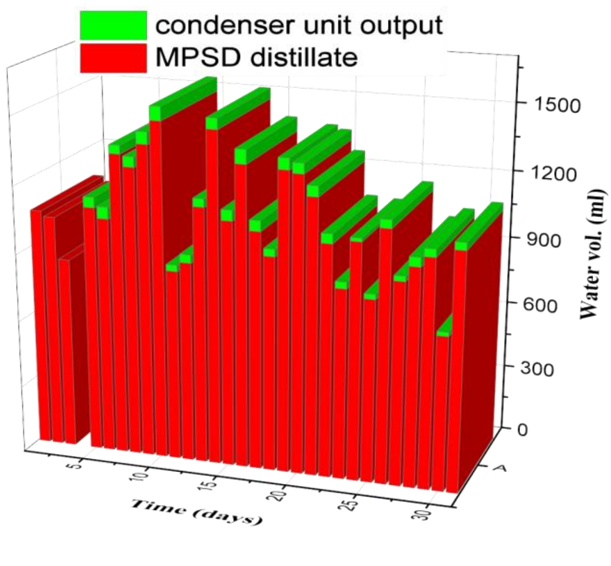

Figure 3. Comparison of production rate of daily distillate yield for modified passive solar distiller and condenser distillate output

Figure 4. snapshot of the coupled condenser

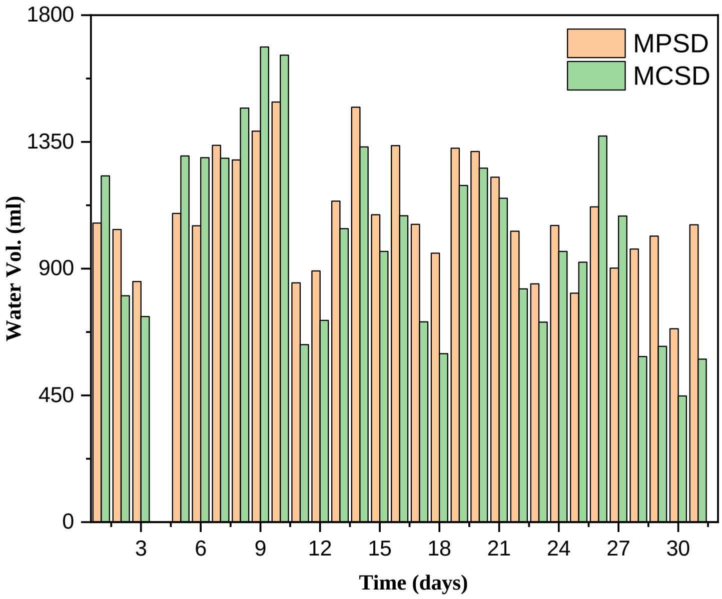

Figure 5. Comparison of production rate between modified conventional still distiller and modified passive still distiller with external condenser on daily basis.

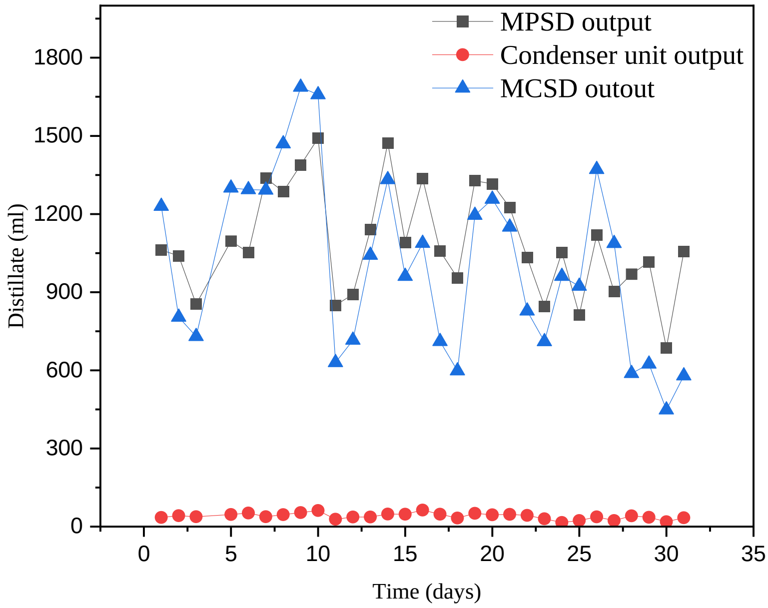

Figure 6. Comparison of production rate between modified conventional still distiller, modified passive still distiller and the passive condenser on daily basis.

4. Conclusion

The present work experimented on coupling a passive condenser to modified passive still distiller whose productivity was enhanced by 11.85% in comparison to the modified conventional still distiller under same conditions. The higher accumulated yield may be attributed to the passive condenser providing increased surface area for condensation. The accumulated high yield could also be that the coupled condenser contained the dissipated latent heat and redelivered same to the system. The padded still distiller was found to have good daily yield as the sawdust reduced loss of heat within the system. Use of low cost materials for still distiller fabrication to produce potable water is seen to demonstrate objective of improving solar stills productivity. The overall low yield (3.5%) from the condenser compartment in the modified passive still distiller may be as a direct result of higher conductivity rate of the corrugated iron design of the coupled condenser.

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