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Research Article

Evaluation of Modified Conventional Still Distiller Using Coupled External Passive Condenser: An Experimental Study

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Abstract

Solar radiation plays an important part in the desalination of saline water owing to its abundance in areas with potable water shortage and it also occupies a paramount place in green energy generation due to its simplicity of application. Still distiller is viewed by researchers as a suitable source of potable water because of low cost of fabrication, easy operation and zero emission technology. Studies by researchers are geared towards exploring new models to improve the productivity of solar stills and enhance its production rate is ongoing. The main aspiration of this work is to experiment the consequence of introducing a passive condenser to a modified conventional solar still to enhance its productivity yield. It was observed that the modified passive still distiller coupled with the external condenser gave about 11.85% higher production yield in comparison with the modified conventional still distiller. Daily and accumulated distillate yield for the still distillers have been studied and analyzed. The result of the findings revealed that sawdust padding around the still distillers is recommended to maximize productivity leading to efficient water distillation in regions where that require still distiller usage. This recommendation has been seen to produce the desired result in accessing to potable water within areas where water scarcity prevails. This is suggested to contribute effectively bearing the cost ineffective water desalination technique.

Keywords

Modified Passive Still Distiller, Modified Conventional Still Distiller, Potable Water, Solar Radiation, Sawdust, Distillate

1. Introduction

The access to 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 as the sustainable development goal of the 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. [1-4]. Remote settlements arid regions, especially in the sub-Saharan are characterized by below the poverty line populations that live with poor geographical accessibility [5, 6] Although demand for potable water in such areas is paramount to sustain population growth

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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 [7]. 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 [8, 9]. 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 [10-13]. Desalination of saline water with still distillers represents a practical way of solving potable water scarcity problem in regions where solar radiation is readily available. Researcher have presented several modifications to solar still in a bid to better its performance on daily yield such as single slope, single slope with solar collector, pyramid shaped, double slope with condenser, tubular shaped, hemispherical shaped, multi-slopes, vertical inclined stills, heat storage with different phase change material (PCM), amongst others [14-17]. According to Tuly *et al*. [18], the improvement in potable water production using double slope modified still distiller coupled with external condenser, fin and wick with PCM in a comparative assessment of modified, and traditional still distillers. The authors investigated the mutual contribution of the solid rectangular fin coated with paraffin wax as the thermal storage of the system while the wick material was black cotton cloth. Their results showed daily potable water productivity rate of 3.07 for modified still distiller, 2.70 for finned, and 2.46 L/m^2 for traditional solar still. They opined that with the inclusion of an external condenser, the productivity rate was boosted with about 10%. Researchers have tried to improve the unpredictable pattern of solar radiation as regards the still distiller by involving several thermal storage systems with coupled PCM for improved still distiller performance. The study by Abdullah *et al*. [19], experimented the daily output for conventional absorber still distiller against convex still absorber distiller using nano black paint, different wick materials, and nano PCM. Their work suggested a linear relationship between the convex height and daily productivity implying that by increasing convex height, productivity increases till an optimum height of 15 cm after which a decline was observed. They proposed that the wick material had a superior performance than the jute while the jute had better function than the cotton. Result obtained from their study revealed convex height of about 15 cm with jute wick recorded a 54% improved performance than conventional still distiller.

Benhammou and Y. Sahli [20], 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 proposed that increasing the PCM mass, the solar radiation absorption is negatively affected even at optimum tilt angle of 15^o for stills distillers. Eltawil and Omara [21] investigated the performance of still distillers fabricated with flat plate solar collectors, solar air collector, external condenser, and perforated tubes. They suggested that the increased production yield of 51% was attained because the external condenser gave more surface area for condensation while the still distiller installed with water solar collector and condenser showed greater performance of a 104% increase. However, still distillers installed with external sources of heat generation such as with hot water spray and hot air better increased their performance coupled with a condenser recorded high performance over conventional solar still by 148%.

Abdullaha *et al*., [22], researched the effect of installing internal reflectors and the impacts of different surface coating materials like a mixture of black paint and copper oxide nanoparticles (CuO Np) on tray distiller productivity. Their work proposed that heat transfer mechanism could enhance in the still distiller if appropriate surface coating material is used. They evaluated the influence on still distiller performance when paraffin wax is mixed with CuO Np as a PCM with obtained results revealing daily productivity yield of 57% for reflectors, 14% for CuO Np in paint, 70.7% for reflectors and nano-coating, and 108% nano coating and PCM with CuO Np when compared with the conventional still distiller. A study by Sharshira *et al*. [23], on the use of linen wicks and carbon black nanoparticle to improve the still distiller performance by varying evaporation surface area and improved heat transfer for stepped double slope solar still. Both the exergy and energy calculation for the convection and evaporation efficiency for each different still distiller modification was analyzed and found to increase daily efficiency proficiency. The experimental work by Abdel-Aziz *et al*. [24], investigated the effect of introducing an electric heater powered by solar radiation to traditional solar still using paraffin wax as PCM positioned beneath the still distillers' basin. Their work reports enhanced productivity of the modified still distiller at 252.4% using electric heater regulated at temperature of 65 ℃ during spring season while 214.5% greater performance during the summer at same conditions. They further elaborated their study to incorporate economic importance of the proposed still distiller using the knowledge of cost per litre of the produced potable water and resolved that the still distiller using an electric heater 65 ℃ exhibited higher exergoeconomic value compared to the traditional one. Kabeel and Abdelgaied [25], 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 the solar still design exhibited 140.4% superior efficiency than normal traditional still distiller. One of the factors affecting still distiller performance is the top glass cover thickness and Khechekhouche *et al*. [26], studied the impact of glass cover thickness on the performance of traditional still distiller using three (3) different glass thickness. They proposed that solar radiation passes through the top glass cover of the still distiller in form of heat energy hence, the thinner the glass cover, the better the performance while the greater the thickness, the lower still distiller's productivity. The results obtained in their study revealed glass thickness of 3 mm as optimum still distiller top glass thickness as it yielded better productivity in the traditional still distiller as recorded efficiency were 30.71% for 3 mm thickness, 19.02% for 5 mm, and 11.44% 6 mm.

Several solar still modification have been studied in recent years in a bid to improve its performance in service. The research work in view involves a systematic approach in designing a still distiller with cost ineffectiveness modifications in order to mitigate heat dissipation and improve productivity yield. The present research evaluates modified conventional single slope still distiller as a yardstick for which the productivity of modified passive single slope still distiller installed with an external condenser is evaluated. Among the features included to the modified conventional still distiller in a bid to reduce heat loss involve suspending its water basin within the still distiller using sawdust of a few inches depth as an insulator and an outer wooden frame around the still distiller also filled 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 redelivering same to elevate the systems' temperature. The experiments were conducted within the months of March and April 2024 in the northern parts of Nigeria using the modified still distillers. The graphic representation of the constructed stills distiller used for experiments is shown in Figure 1 below.

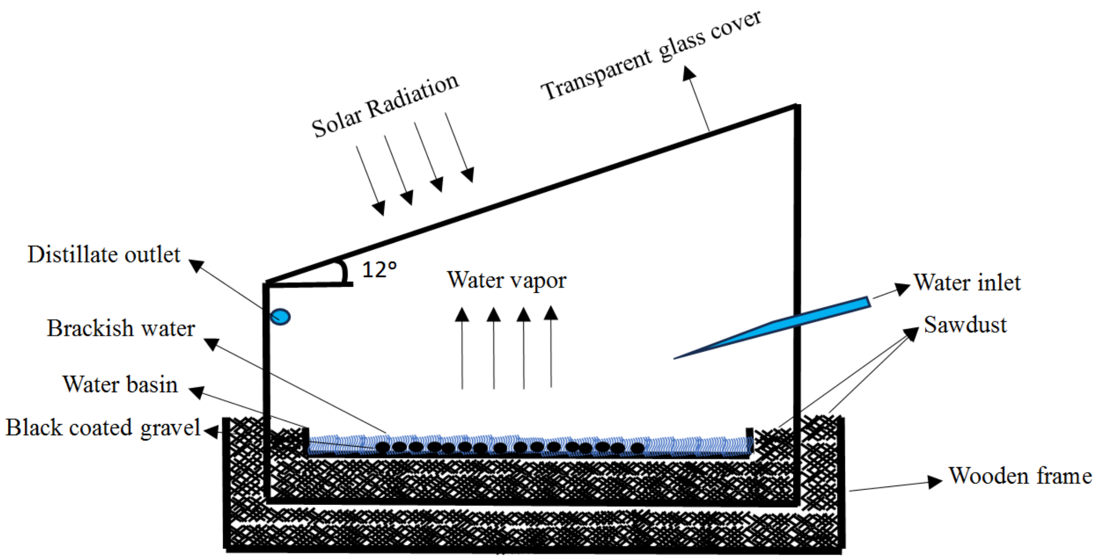

Figure 1. *Graphic representation of the constructed stills distiller.*

2. Experimental Methodology

2.1. Working Principle

Still distillers engage solar energy to produce clean water using heat energy acquired through suns' radiation to propagate evaporation and subsequent condensation process [7]. The two core working principal forms of still distiller is active and passive solar still depending on the heat generation source used to evaporate the water in the basin. Heat generation can be accessed directly from the suns radiation (passive) and/ or generation of heat energy by some mechanical techniques (active) [9]. 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 [1]. The simplicity of its operation involves the sun's incident rays transmitted through the upper transparent glass top in a bid to increase temperature of 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 condensation process in form of heat released through latent heats and heat lost by convection.

2.2. Design of the Experimental

The object of the experimental work here is to suggest a novel design for still distiller in order to overcome the prevalent heat losses 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 recorded in Table 1. As seen in Table 1, the design geared towards containment of heat within the system. Improvement to the solar radiation absorption within the still distiller was achieved by painting the base and sides with glossy black and also black gravels were placed at the base to retain heat within the basin. 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 7:30 a.m. to 7:30 p.m. on a daily basis. On March 30, 2024, experiments commenced with MPSD and MCSD with total distillate volume measured for each day. A snapshot of the experimental still distiller is shown in Figure 2.

A B

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

Table 1. *Design specification of modified conventional still distiller (MCSD) and modified passive still distiller (MPSD).*

Parameter	MCSD	MPSD
Solar still outer dimensions	1.0 m x 0.9 m	1.0 m x 0.9 m
Inside water basin dimensions	0.8 m x 0.7 m	0.8 m x 0.7 m
Depth of the still distiller	45 cm	45 cm
Water depth within the basin	8 cm	8 cm
The thickness of glass cover	0.4 cm	0.4 cm
Glass angle of inclination with the horizontal	12^{o}	12^{o}
Depth of the sawdust beneath the water basin	35 cm	35 cm
Thickness of the sawdust around the water basin	9 cm	9 cm
Distance of the water basin from top cover	25 cm	25 cm
Thickness of the sawdust around the still distiller	20 cm	20 cm
Thickness of the sawdust beneath the still distiller	30 cm	30 cm

3. Results and Analysis

Purification of saline and/ or brackish or contaminated water using still distiller is seen as an effective technique to provide sufficient potable water for household usage and reduce greenhouse gas emission involved in other techniques of water purification [27]. Factors considered in increasing evaporation and condensation process of the passive still distiller are low-cost fabrication and design that will enhance overall yield [28]. 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*. [2], enhancement of solar still performance is seen as a future potable water solution in regions with saline or brackish water due to its Eco-friendliness 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*. [29], 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 [13]. 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 a total distillate volume of about 1.5 L/day. MCSD had the 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 [30].

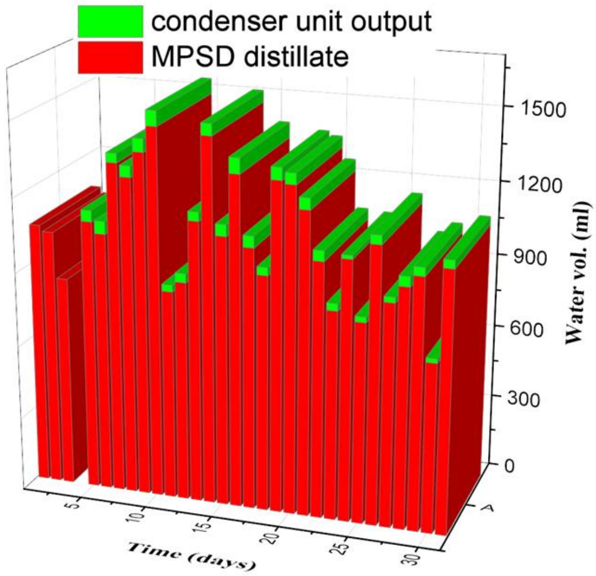

Figure 3. *Comparison of production rate of daily distillate yield for modified passive solar distiller and condenser distillate output.*

Figure 4. *Snapshot of the coupled condenser.*

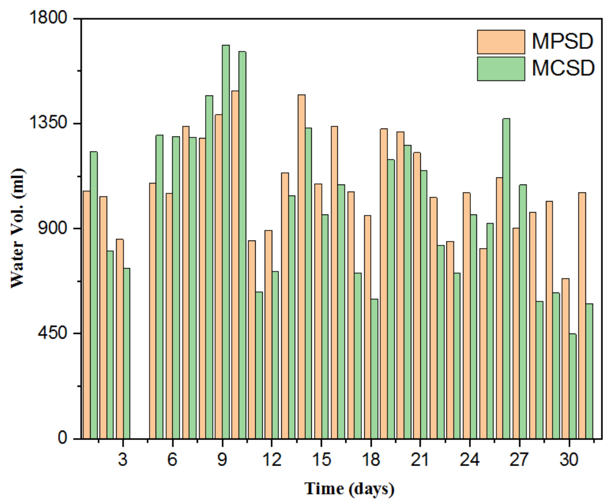

Figure 5. *Comparison of production rate between modified conventional still distiller and modified passive still distiller with external condenser on daily basis.*

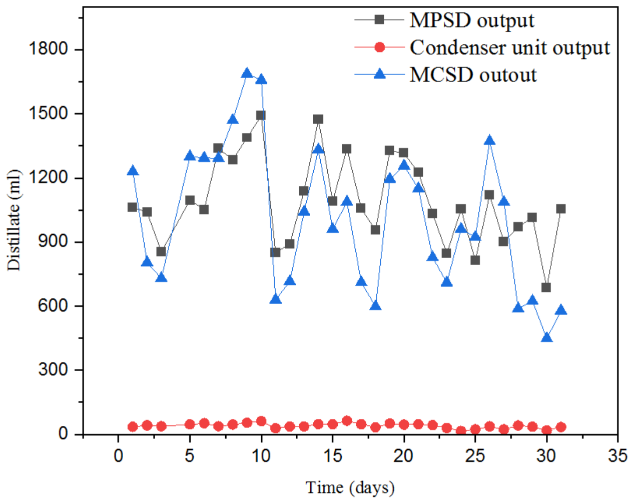

Figure 6. *Comparison of production rate between modified conventional still distiller, modified passive still distiller and the passive condenser on a daily basis.*

4. Conclusion

The present work experimented on coupling a passive condenser to a modified passive still distiller with an improved productivity of 11.85% better than that of the modified conventional still distiller under the same experimental conditions. The higher accumulated yield could be attributed to the passive condenser which provided increased condensation area and enhanced heat dissipation containment within the system. 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. The use of cost un-effectiveness 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 a higher conductivity rate of the corrugated iron design of the coupled condenser.

Abbreviations

CDS	Convectional Still Distiller
MCSD	Modified Conventional Still Distiller
MPSD	Modified Passive Still Distiller

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Conflicts of Interest

The authors declare no conflicts of interest.

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