DESIGN AND PERFORMANCE ANALYSIS OF A SLANTING-TYPE SOLAR WATER DISTILLATION KIT

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Abstract

Access to safe and pure water to communities is becoming an increasingly difficult issue around the world. The rapid international developments, the industrial growth, agricultural and population explosion all over the world have resulted in a large scale escalation of demand for fresh water. The solar still is the most economical way to accomplish this objective. We fabricated a slanting-type solar water distillation kit which was tested outdoor under the actual meteorological conditions of Imo State University, Owerri, Nigeria. The system includes four major components; a wooden basin of surface area 0.16 m^2, an absorber surface, a slanting glass roof and a condensate channel. Very cheap locally available materials were used to fabricate the solar still. The solar still produced an average of 0.09 m^3 of distilled water per day, and this study was performed in the month of November, 2015. Daily efficiencies of the distillation kit were estimated and the overall efficiency of the kit was found to be 7.7%. We employed correlation analysis to estimate the relationship between such parameters like ambient temperature, internal temperature of the kit, daily distillate yields and daily efficiencies.

Keywords: Pure water, solar energy, water distillation, correlation analysis.

INTRODUCTION

Water is an essential component for life on earth and a precious resource for human civilization. Access to safe and affordable drinking water is considered one of the basic human necessities and remains one of the main challenges of the 21st century (Graziela *et al*, 2021).Water and energy are the two most essential things for sustaining life (Shinde and Tated, 2014). Water is a nature's gift and it plays a key role in the development of an economy and in turn for the welfare of a nation (Gnanadason et al, 2013). Freshwater is an essential requirement of human life. 97.5% of saline water on earth is present in the form of seawater and only 2.5% of water is fresh (Gude et al, 2011). Lack of potable water is one of the major problems faced by both the under developed and developing countries all over the world

(Velmurugan and Srithar 2011; Mehta el al, 2011). Natural surface water bodies are subjected to pollution comprising of organic and inorganic constituents, while the problems of ground water quality are much more acute in the areas which are densely populated and thickly industrialized (Gupta et al, 2013; Ozuomba et al, 2012; Tenthani et al, 2012; Shraddha et al, 2011; Sehar et al, 2011; Unnisa and Khalilullah, 2004). Therefore, researchers are making such devices that can convert impure water to potable water by using renewable resources. Solar still (SS) is a sustainable device that uses solar thermal energy to transform saline and dirty water into freshwater (Kumar et al, 2021; Thakur et al, 2020; Mahian el al, 2015). Solar distillation is the process in which the sun evaporates the water from lakes, rivers, oceans and other surface waters leaving salts and other minerals behind (Diaf, 2015; Medugu and Ndatuwong, 2009). The solar stills are mainly categorised into two parts, passive SS and active SS. Passive SS completely relies on natural resources (Solar Energy) while external devices are used in active SS like flat-plate collectors, PVT, electric water heaters, etc. These are economical and can provide adequate fresh water to remote villages. Passive and active solar stills are further classified as single and double slope SS (Thakur et al, 2020). This classification is shown in Figure 1. A solar still operates similar to the natural hydrologic cycle of evaporation and condensation (Ozuomba et al, 2012; Tenthani et al, 2012). Solar energy has been usefully applied in many other gadgets and devices like concentrating collectors, solar hot water systems, solar pond, solar hot air systems, solar dryers, solar timber kilns, solar photovoltaic systems, power tower, air conditioning, solar collectors, solar cookers, coupled to absorption and refrigeration systems (Salim, 2015). The use of solar distillation method in water purification is a very important method of solving day to day need of isolated villages for clean and healthy water. Distilled water is used for different purposes in institutions for laborotory experiments, health care centers, motor vehicle batteries, industrial and in commercial organisations (Garba et al, 2005).

Conventional distillation processes such as multi-effect fresh evaporation, thin film distillation, reverse osmosis and electrodialysis are energy intensive techniques and are not feasible for large fresh water demands (Medugu and Ndatuwong, 2009). Therefore, solar distillation seems to be a promising method and an alternative method for providing safe drinking water. When water evaporates, only pure water vapour is formed while contaminants are left behind in the still basin and the distillate flows to the collection gutter by gravity. Among the many factors considered in the design and fabrication of a solar water distillation system are cost implication and efficiency.

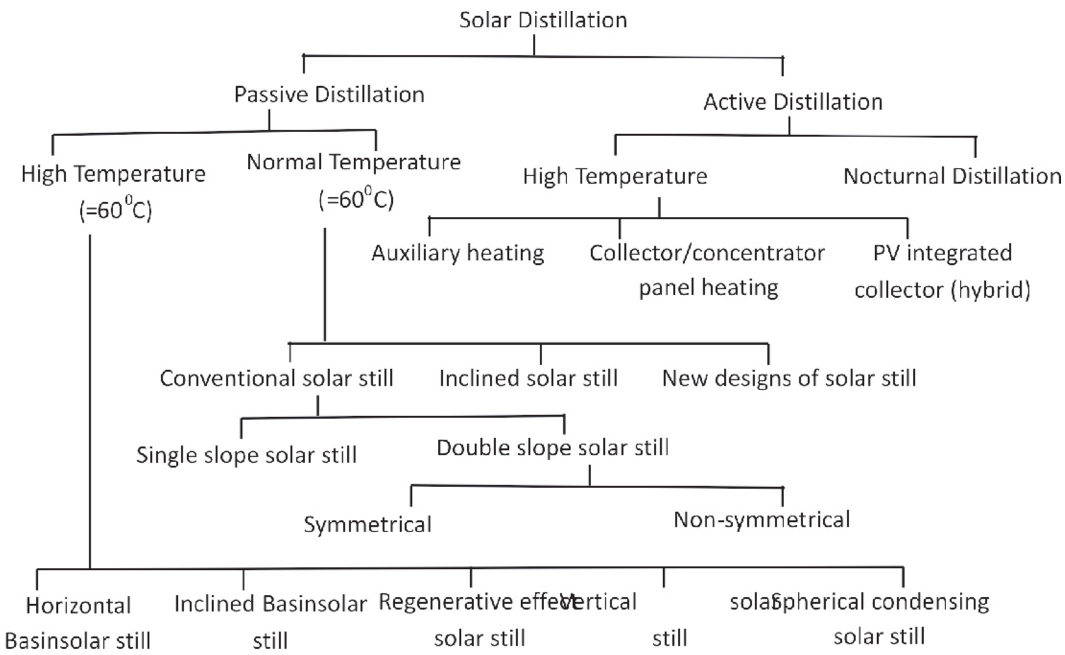

Figure 1. Classification of solar distillation systems (redrawn from Bhattacharyya, 2013)

The present study was undertaken to design and investigate the performance of a slanting-type solar water distillation (SSWD) kit. The SSWD system, which replicates the natural process of evaporation and condensation was fabricated from cheap and local materials.A wooden box covered with black polyethylene absorber surface formed the water heating chamber or water basin. The water basin has a slanting top onto which a glass sheet was gently placed to form the glass roof. Beneath the glass roof was a gutter or condensate channel for driving out distilled water. The heating and evaporation took place on the absorber surface, while condensing process took place on the glass roof. The water sample was collected from Njaba River and the variation of the ambient and internal temperatures of still was studied. The efficiency of the solar distillation kit was estimated and correlation analysis was used to estimate the relationship between such parameters like ambient temperature, internal temperature of the kit, daily distillate yields and daily efficiencies. The characterization of our distillation kit was carried out in the month of November, 2015 under the actual environmental conditions of Imo State University, Owerri, Nigeria.

EXPERIMENTAL SETUP

A schematic diagram of an SSWD system whose interior has been covered with black polyethylene is shown in Figure 2.The water basin or the heating chamber has a surface area of 0.16 m^2. A glass sheet of length 76.0 cm and width 38.2 cm was gently placed on the slanting surface of the water tank to form the glass roof. The water tap can be used to discharge untreated water sample.

Figure 3 shows the inlet for impure water, the outlet for distilled water and the SSWD stand of height 69.5 cm. The condensate channel was made of aluminium sheets, while the wooden frame that formed the water basin also served as thermal insulator. A piece of black leather was used to cover the edges of the glass roof to avoid contaminants like rain water which may drip into the condensation channel. The Top Bond adhesive was used to glue the leather onto the glass and wood surfaces. The parameters of the solar still are given in Table 1.

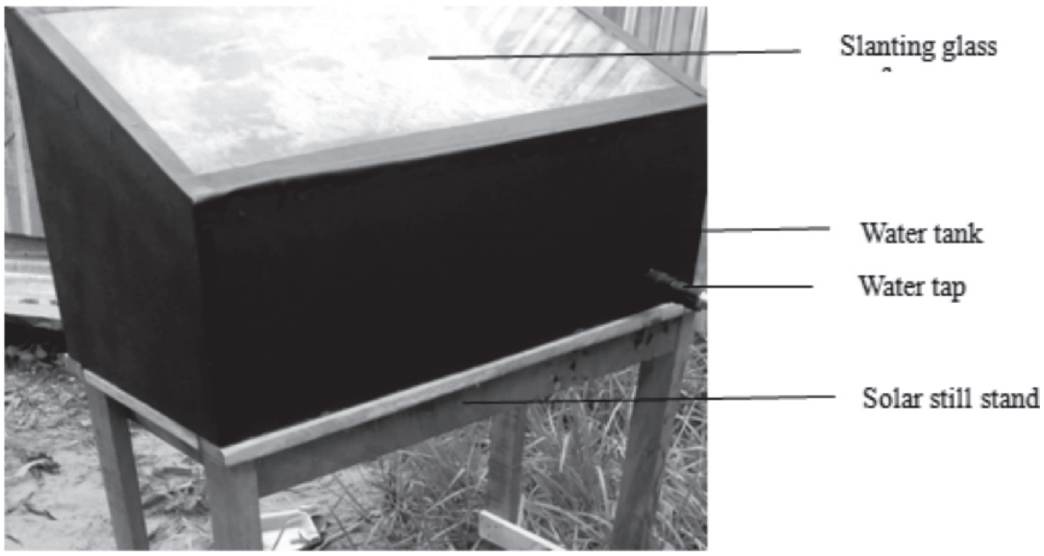

Figure 2. Front view of the slanting-type solar water distillation (SSWD)

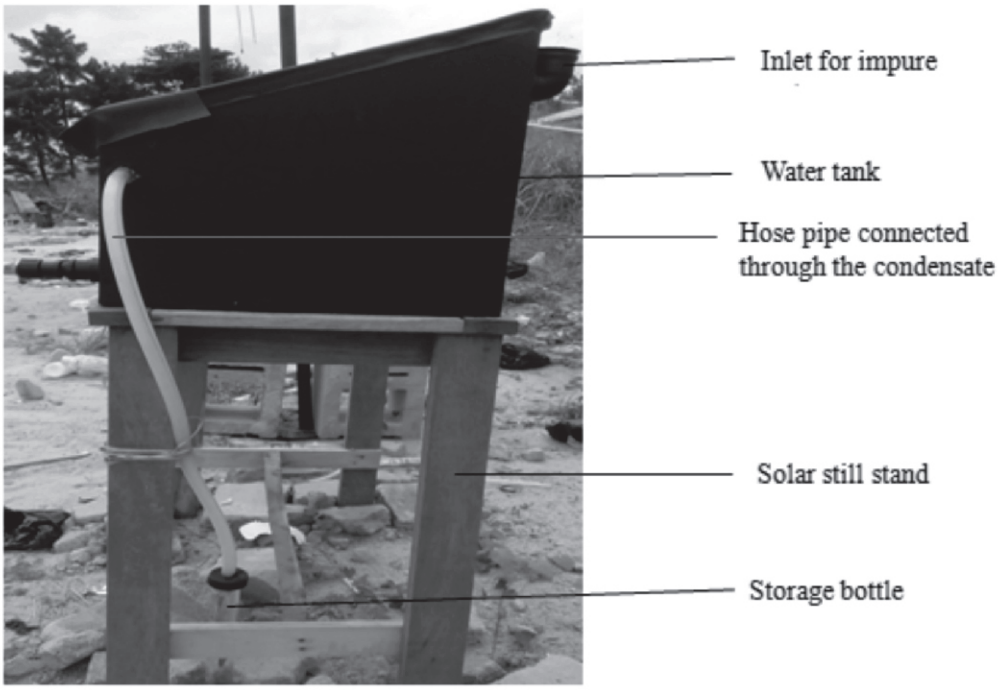

Figure 3. Side view of the slanting-type solar water distillation (SSWD) kit

Table 1. Design parameters of the SSWD kit

Parameter	**Value**
Area of collecting surface	0.16 m^2
Area of basin	0.16 m^2
Tilt angle of glass roof	23^0
Thickness of glass cover	0.003 m
Height of backs wall of basin	0.398 m
Height of front wall of basin	0.245 m
Width of basin	0.360 m
Height of tank stand	0.695 m

Incident solar radiation passes through the glass cover and is mostly absorbed by the blackened liner of the basin. The untreated water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water evaporates from the basin and condenses on the inside of the glass cover. Condensed water trickles down the inclined glass cover to the interior collection trough and out through a hose pipe to a storage bottle.

The volume of distilled water produced hourly by the SSWD kit was measured for seven consecutive days. The water sample was obtained from the Awomamma Station of Njaba River. Njaba River is located in the Eastern part of Nigeria. Hourly measurement of volume and temperature was carried out for seven days at Imo State University, Owerri, Nigeria. The hourly ambient temperature (T_{ext}) was measured using a copper/constantan thermocouple. The corresponding internal temperature (T_{int}) of the SSWD kit was also obtained. The efficiency of the slanting-type solar water distillation kit was estimated using the energy method (Tenthani et al, 2012).

$$\eta = \frac{APH}{3600G} \qquad (1)$$

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. Correlation analysis of some of the solar still parameters like ambient temperature, internal temperature of the kit, daily distillate yields and daily efficiencies was also carried.

RESULTS AND DISCUSSION

The variation of the daily average ambient temperature with the daily average internal temperature of the SSWD is shown in Figure 4 below. The graph shows that the internal temperature is always higher than the ambient temperature. The average temperature difference ranged from 7.09^{0}C on the 2nd day to 14.86^{0}C on the 4th and 6th days. The increased temperature of the water basin should facilitate the purification and the evaporation process.

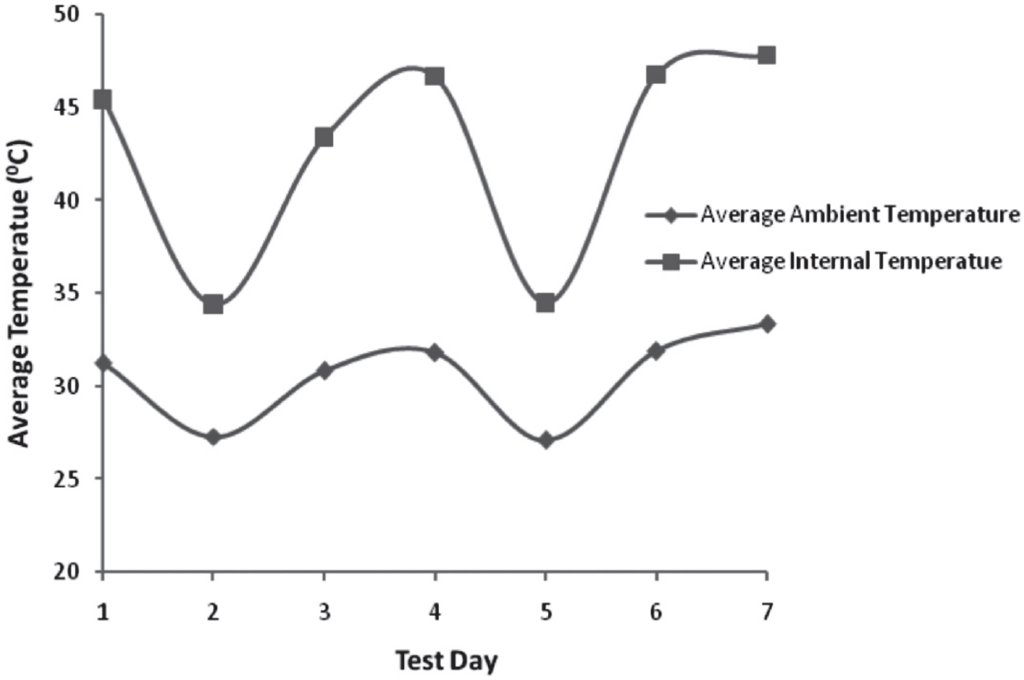

Figure 4. Comparison between the daily average of ambient and internal temperatures

Figure 5 shows the daily distillate yield for the seven days. The maximum volume of potable water produced within the project period was o.115m^3 and this occurred on the 3rd day. Total volume of pure water produced within the seven days was 0.63m^3. Hence our 0.16 m^2 distillation kit was able to produce an average of 0.09 m^3 of potable water per day. It was also observed that a comparable high volume of distilled water usually collects towards evening as ambient temperature decreases.

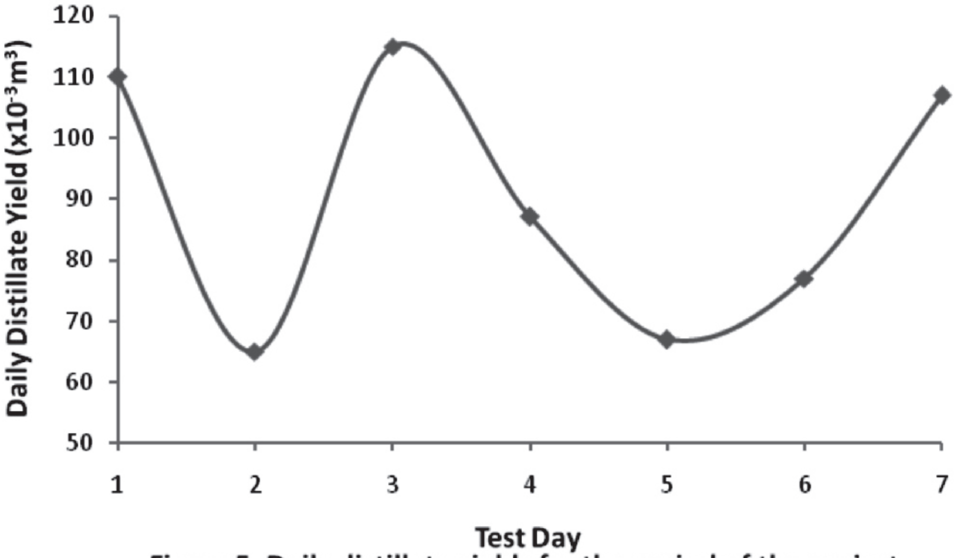

Figure 5. Daily distillate yields for the period of the project

A comparison of daily efficiencies is shown in Figure 6. The highest efficiency of 9.3% was obtained on Day 1, while the least efficiency of 6.3% was recorded on the 2nd day. The overall efficiency of the 0.16 m^{2}slanting-type solar water distillation kit was 7.7%.

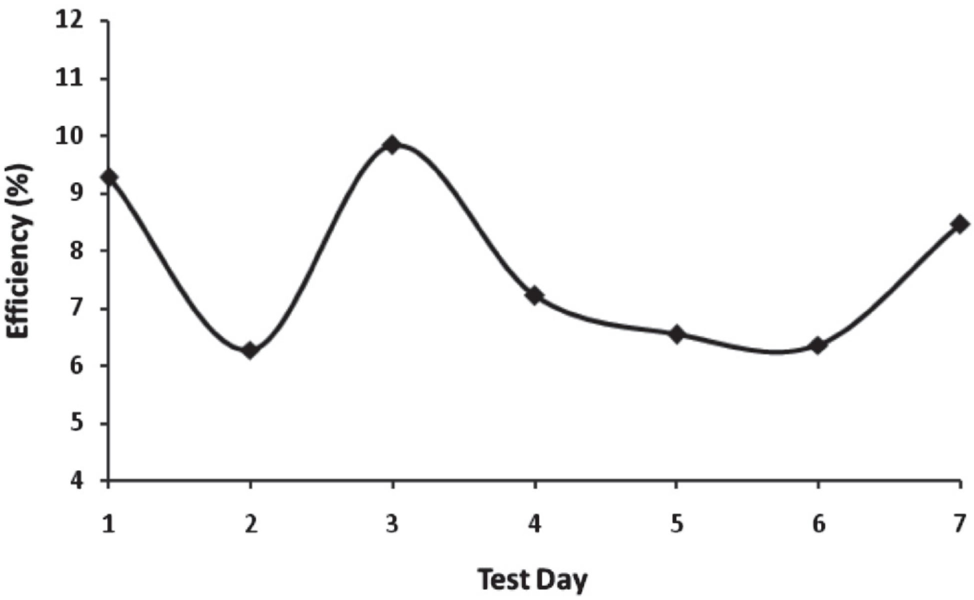

Figure 6. Comparison of daily efficiencies

Correlation analysis of some of the solar still parameters like ambient temperature, internal temperature of the kit, daily distillate yields and daily efficiencies is shown in Table 2. This analysis has thrown more light on the effect of incident solar radiation on the efficiency and the volume of distilled water produced. There exists an almost perfect positive correlation between ambient and internal temperature; and also between daily distillate yield and efficiency. A very strong positive relationship exists between ambient temperature and daily distillate yield while a moderate positive correlation exists between ambient temperature and efficiency

Table 2. The coefficient of correlation for some solar still parameters

Varying Parameters	Correlation Coefficient
Ambient temperature and internal temperature	0.99
Ambient temperature and daily distillate	0.69
Ambient temperature and efficiency	0.48
Daily distillate and efficiency	0.96

CONCLUSION

In developing countries, lack of safe and unreliable drinking water constitutes a major problem. Distillation is one of the many processes of that can be used for water purification. Distilled water is also needful in some industries, hospitals and schools. Solar still is a simple technology and more economical than the other available techniques of water distillation. We successfully fabricated a slanting-type solar water distillation (SSWD) system which was tested under the actual environmental conditions Imo State University, Owerri, Nigeria. The system includes four major components; a wooden basin (heating chamber), an absorber surface (black liner), a slanting glass roof, and a condensate channel. The daily distillate yield ranged from 0.07m^3 to 0.1m^3, while the daily efficiency varied from 6.4% to 9.3%. Actually, the average daily yield (0.09 m^3) is small when compared to daily need of drinking water. The overall efficiency of the 0.16 meter squared SSWD kit was 7.7%, and this is small like many other solar installations. Correlation analysis revealed that there exists an almost perfect positive correlation between ambient and internal temperature; and also between daily distillate yield and efficiency. A very strong positive relationship exists between ambient temperature and daily distillate yield while a moderate positive correlation exists between ambient temperature and efficiency. Like every other solar installation, SSWD system is environment friendly and has low operating and maintenance costs.

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