Thermal Performance of a Conventional Solar Still with a Built-in Passive Condenser: Experimental studies

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Abstract

Water is a basic human necessity and is the essential source of life on earth .Fresh water demand is growing everyday all over the world. Solar desalination using a still has been regarded as the sustainable solution in particular in rural and arid areas. Investigations and research has focused on exploring methods and finding ways to enhance the efficiency of solar stills and increase the production rates. This work is an experimental investigation on the effect of incorporating a passive built-in condenser into a conventional solar still daily productivity rate. It has been found that solar still with a built-in condenser gives about 16.7% higher production rate as compared to the conventional solar still. Temperature profiles of the glass cover, the condenser galvanized cover, the saline water, and the galvanized basin have been studied and analyzed.

Keywords: **Solar still; passive condensers; built-in condensers; solar distillations**

1. Introduction

Water is the most essential factor for the sustainability of life. Without water life will be impossible and access to potable water is narrowing down day after day all over the world. Most of the human diseases are caused by polluted, contaminated or non-purified water resources. The ground water has been intensively exploited and the problem is escalating by worldwide drought and desertification (Omara et al., 2017: Panchal and Mohan, 2017). The availability of good quality drinking water is a major challenge not only for developed countries and persistent in developing countries. The present situation presents a serious and a big challenge due to the ever-increasing water demands, pollution and salinity (Hassan and Abo-Elfadl, 2017; Gupta et al., 2016). The situation is more critical in rural and arid areas such as North Africa and Middle East. Both these regions have coastal water where access to seawater is abundant but not to water. Therefore, there is an urgent need for clean pure drinking water in many of these areas. The positive outlook is that the majority of the areas that have deficiencies in fresh water supply have huge amounts of solar energy freely available (Ahmed et al., 2014; Kaviti and Shukla 2016). The Solar energy is an abundant and safe source of vitality and therefore is distinguished as one of the most promising alternative energy choices. Solar still distillation systems offer sustainable tools for freshwater production. It is a simple technology which utilizes solar energy an ample source of non-conventional or renewable energy). It is an economical, effective and environment friendly technology. The most simple and least expensive solar stills are passive solar stills (Panchal, 2016; Sahota, 2016).

A conventional solar still was widely exploited over the past decades; the main practical problem and the major defect is that the solar still productivity is very low compared with other desalination systems, such as other thermal or membrane processes (Shadi et al., 2016; Estahbanati, 2016). The solar stills work by the simple concept of evaporation and condensation as a direct simulation of the green house effect. It utilizes the solar thermal energy for the evaporation of the basin water. The vaporized water get condensed on the inclined glass cover and get collected in the condensate channel, from where this distilled water is drained out and collected in a suitable container. The conventional still suffers from the major disadvantage of low efficiency and low productivity. Therefore, researches have focused on studying various parameters affecting the productivity by adopting different techniques and exploring new designs to improve the still's performance and increase productivity. One of these ways is to incorporate the conventional solar still with condensers (Ahmed et al., 2013).

Kabeel et al. (2016) conducted a detailed review of solar stills integrated with external or internal condenser with different design and configuration arrangements. They concluded that the incorporating condensers in conventional solar stills are deemed to be effective. Kabeel et al. (2014) conducted experimental tests in an attempt to enhance the solar still productivity by using nano fluids and also by integrating the still basin with external condenser. The effect of adding external condenser to the still basin is to decrease the heat loss by convection from water to glass as the condenser acts as an additional and effective heat and mass sink. The results show that integrating the solar still with external condenser increases the distillate water yield by about 53.2%. In another study, nanofluids improve the solar still water productivity by about 116%, when the still integrated with the external condenser. Refalo et al. (2015) used a solar chimney and condensers to enhance the productivity of a solar still. It was found that the solar chimney and condensers performed 8.8% better. Madhlopa (2009a) and Madhlopa and Johnstone (2009b) results indicated that the distillate productivity of the passive solar still with internal separate condenser is 62% higher than that of the conventional type. They also reported that the condenser contributed by about 40% of the total distillate. A passive solar still with internal separate condenser was tested, modeled, evaluated, and compared with that of the conventional still under the same meteorological conditions by Ahmed (1988) who used an internal condenser to evaluate its effect on the performance of a single-slope solar still. The still was linked with a double pass internal condenser. The results indicated that joining an internal condenser with solar still caused an enhancement in the still performance by 7.2%. El-Bahi and Inan (1999) studied experimentally the influence of the addition of an outside passive condenser to a single-basin-type solar still with a minimum inclination of 4° for enhancing its efficiency. Incorporating the condenser enhanced the efficiency by 75%. Fath and ELsherbiny (1933) conducted a theoretical and experimental study to investigate the effect of adding a passive condenser on the performance of the single slope, basin type solar still. The experimental results show good agreement with the theoretical predictions and an increase of 50% in the still efficiency. Monowe et al. (2011) made a new design of a portable thermal–electrical solar still with an outside condenser and an external reflecting supporter. The results indicate that the efficiency of such still reached to 77%. El-Samadony et al. (2015) conducted an experimental study of stepped solar still with reflectors (internal and external) and external condenser. They found that the water productivity of stepped still is increased by about 165% over conventional still. Ahmed (2012a) tested three identical simple type solar stills. Two of which, are connected with external passive condensers. The first is a conventional still, and was used as a reference for comparison. In the second still, two passive condensers were connected in parallel, only to the upper part of the back of the still. While in the third still, another two condensers were connected in parallel to, both, upper and lower parts of the back of the solar still. It has been found that the still incorporating condensers connected only to the upper part of the back of the still yielded an increase of 15.1% of the distilled water production rate. The still incorporating condensers connected to the upper and lower parts of the back of the still yielded an increase of 30.54% in the production rate of distilled water. Ahmed (2012b) reported that the enhancement of the condenser-type solar still performance differs greatly for different techniques due to different experimental conditions. Fath and Hosny (2002) presented a theoretical study of the thermal performance of a single-sloped basin still with enhanced evaporation and a built-in additional condenser and found to produce a yield of about 55% over the base case. Khalifa et al. (1999) conducted experimental modifications into the conventional solar still to enhance the distillate water productivity using internal condenser. The condensate water quality was analyzed and was found to be comparable with water quality standards and against rain water and mineral water. Their results indicated that the daily efficiency of solar still with the internal condenser was about 54%.

In the present work, experimental investigations have been carried out to assess the effect of connecting built-in passive condensers to the conventional single slope basin type solar still under the climate of the of the Kingdom of Bahrain.

2. Experimental facilities

A built-in condenser into a single slope conventional basin type solar still was designed and constructed from 1.4 mm thickness galvanized steel. A 4 mm thickness glass sheet was used to cover the upper front side of the solar still. The glass cover slope angle was set at 20.0º with respect to the horizontal. The galvanized backside of the still was extended and tilted by angle of 10.0º to the vertical to form a separate chamber at the back of the solar still. A 20 cm height plate was installed and separated partially the two chambers. The back chamber was used as a built-in condenser with an inclined bare back galvanized plate. The evaporated water from the basin has two ways to condense, either on front upper glass cover or the back galvanized cover plate. Unlike the front glass cover, the back galvanized plate was shaded from sunrays using a polestar board.

The solar still insides, except the back galvanized cover, was painted black using Black Epoxy in order to increase the suns rays' absorptions efficiency and also to eliminate any possible corrosion to the metal surfaces. To prevent or minimize heat loses; the bottom and the two sides of the solar still were insulated with sheets of glass wool of 50 mm thick. The solar still then fitted inside a wooden box of a trapezoidal shape. The net basin horizontal effective area of the solar still will be 1 m² (1m x 1m). In order to keep the whole system of each solar still vapor tight, the glass cover was rubber lined, rested on the basin structure and completely sealed by using superior silicon sealants. The schematic diagram of the solar still is shown in fig.1, and the actual solar still and major parts are shown in fig.2.

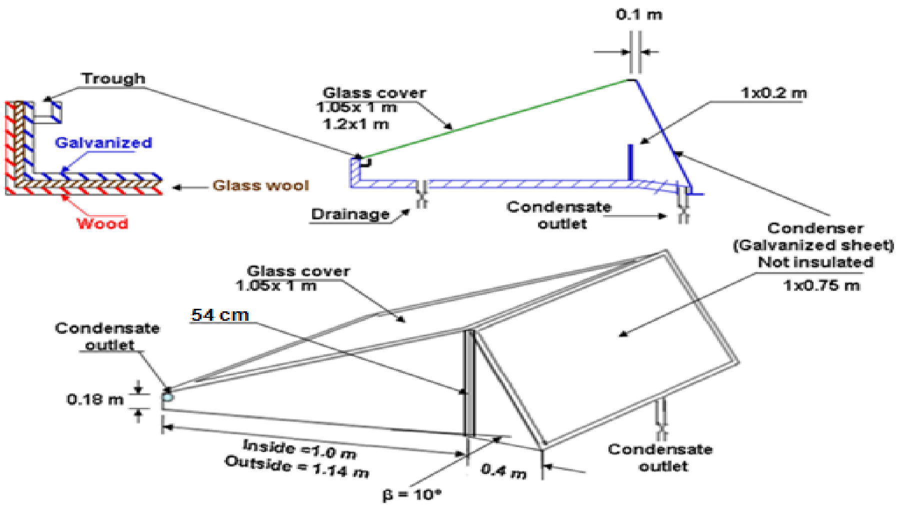

Fig.1. Schematic diagram of the solar still

Fig.2. Solar still with built-in condenser major parts

For comparison purposes, another plate of the size 1 m x 54 cm was installed to separate the two chambers completely. In this case the front chamber with the glass cover was totally separated and isolated the condenser chamber and the front chamber was used as conventional solar still as shown in Fig.3. Superior silicon sealant was used to ensure that the plate sealed completely and the two chambers are completely isolated.

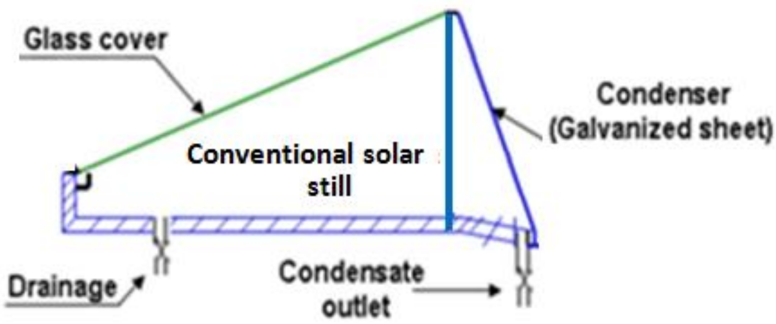

Fig.3. Isolation of conventional solar still schematic diagram

A feed water tank was fixed at higher level of the solar still. A half inch pipe and valves was fixed at the side of the still and connected to the feeding tank. The saline water level inside the solar still was automatically controlled using solenoid valve and water level sensor. The solenoid valve was calibrated to open when saline water level drooped below the set up value of 1 cm. An L shaped trough of 6 cm x 6 cm was used to collect the condensate water running down the inner surface of the inclined glass cover of the solar still. The troughs were fixed at slight slope to ensure that the flow of condensate water is towards the outlet pipe. A half inch diameter pipe and valve were fitted and connected to the lower end of the trough channels to control the collection of the condensate water. Flexible hoses leading to graduated flask was used to collect the distilled water on hourly intervals. Another half inch diameter pipe and a ball valve were fitted and connected to the tilted bottom of the galvanized condenser chamber to collect the condensed water.

Ten K-Type thermocouples and six thermometers was used for temperature measurements at various locations. For redundancy, two thermocouples/thermometers were fixed to measure each temperature parameter. Therefore, two thermocouples was fixed at the outer side of the glass cover, two thermocouples were fixed at the inner side of the glass cover, two thermocouples were fixed at the outer side of the galvanized cover, two thermocouples were fixed at the inner side of the galvanized cover, two thermocouples were fixed at the lower side of the solar still basin, two thermometers were fixed to measure the saline water temperatures, two thermometers were fixed to measure the water vapor (space) temperatures under the glass cover, one thermometers were fixed to measure the vapor (space) temperatures in the condenser chamber, and one thermometers was used to measure ambient temperature. All thermocouples were connected to digital temperature indicators. Care was taken to ensure that the thermocouples and thermometers are not affected by direct sun rays, so they were fixed in ways or in positions to ensure that no direct sun rays could reach their sensing parts. A Styrofoam board was used to protect the condensers from direct sun light as shown in fig.4.

Fig.4. Styrofoam board protecting the condenser from direct sun rays.

Extra care was made to make sure that the thermocouples measured the surface of the inside and outside of the glass cover surface. The main point of concerns related to the fact that the thermocouples may be affected by the sun's direct radiation. In addition the thermocouple sensing part should firmly touch the glass/galvanized surfaces. Therefore, pieces of wood each with a dimension of 2x3 cm were cut and groves of the same diameter as the thermocouples were made to accommodate them so that when the wooden pieces were placed on the glass/galvanized covers, they would hold the thermocouples tight on to the covers' surfaces and at the same time prevent the direct sun's rays to reach the thermocouples. Epoxy glue was used to stick the wooden pieces accommodating the thermocouples sensors firmly on the glass/galvanized covers. Details of these arrangements can be seen in fig.5.

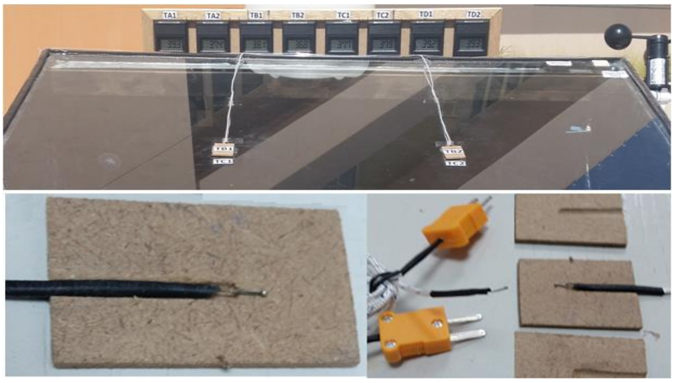

Fig.5. Thermocouple fixing arrangements.

The global solar radiation on the inclined glass cover surfaces was measured using a Daystar type solar meter. This instrument is analog type and can measure solar intensity in the range of 1–1999 W/m² with an accuracy of ±1 W/m². A digital wind anemometer Type LM-8010, with a range of 0-15 m/s and an accuracy of ±0.2 m/s, will be used to measure the wind speed at the solar stills height.

The experiments were conducted on clear days. Preliminary tests were conducted for two days in order to make sure that the system is ready. The experiments were then conducted for another three days for each set of data, and then the average recorded values were taken. All tests started at 7:00 am and carried out till 6:00 pm local time. Measurements of all parameters were recorded on one hour interval.

3. Results and Analysis

In this research, the effect of incorporating built-in passive condenser with conventional, basin type solar still on the solar still productivity was investigated. Outdoor experimental tests were carried out at AMA International University – Bahrain, in the city of Salmabad, in the Kingdom of Bahrain during the month of September 2016. In order to ensure the stability of the solar still and to verify the results obtained, each set of experiments were conducted on three consecutive days.

The first set of experiment was conducted using the solar still as conventional still. This is done by installing a plate completely isolating and separating the two condensing chambers. In this case only the front chamber with glass cover was being used. The second set of experiment was conducted by removing the isolating plate and installing a 20 cm-high plate between the two chambers. In this case the evaporated water from the basin will have two ways to condense, either on front upper glass cover or the back galvanized cover plate (the built-in condenser).

It was found that the reference conventional solar still produced, an accumulated amount of distilled water of 1.325 liters/day. The still that has built in condenser produced a total of 1.540 liters/day. That is an increase of 16.2% in comparison with the conventional solar still. Fig.6 shows the comparison of the accumulated production rate between the two sets of data. Fig.7 shows the comparisons on an hourly basis. The higher rate of productivity of the built-in condenser solar still may be attributed to the increased condensation surface area and better conductivity of the galvanized cover of the built-in condenser.

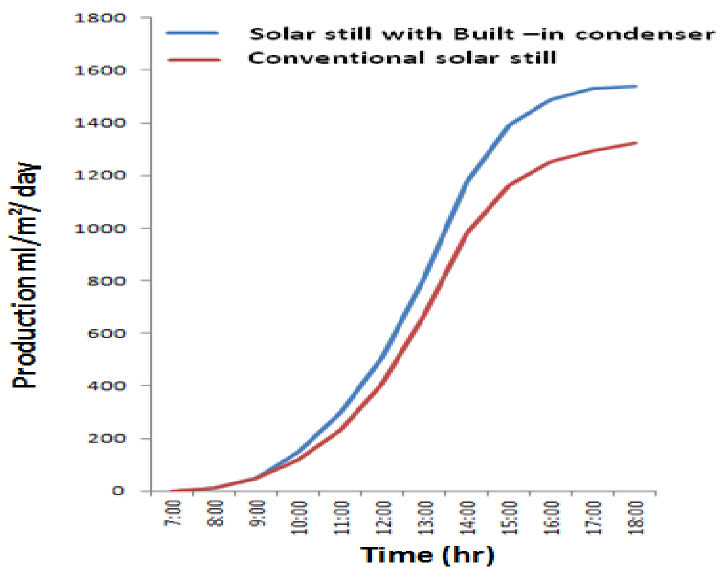

Fig.6. Comparison of production rate between conventional solar still and with built-in condenser solar still on daily basis

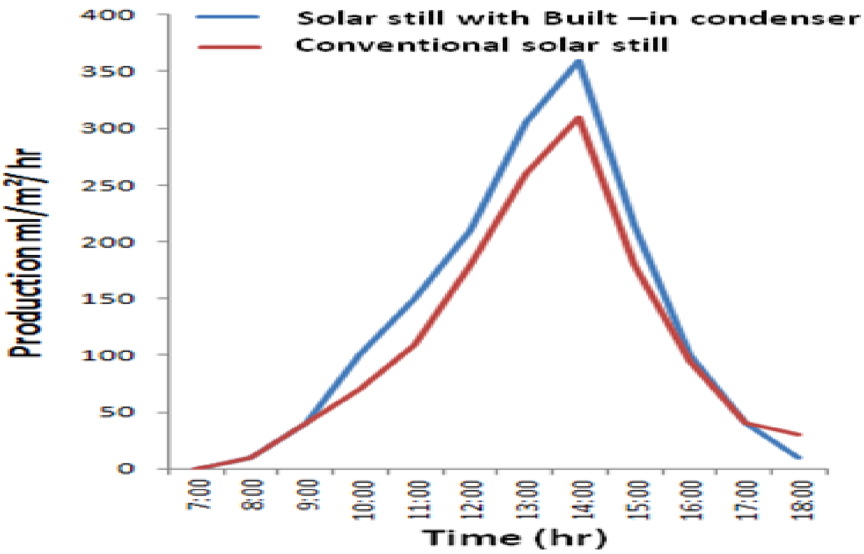

Fig.7. Comparison of production rate between conventional solar still and with built-in condenser solar still on hourly basis.

In the solar still with built-in condenser, the fresh water production through glass' cover condensation was 1.120 litters/days, which represent 72.7% of the total production rate. The fresh water production through galvanized cover condensation of the built in condenser, was 420 litters/days, which represent 27.3% of the total production rate as can be seen in fig. 8.

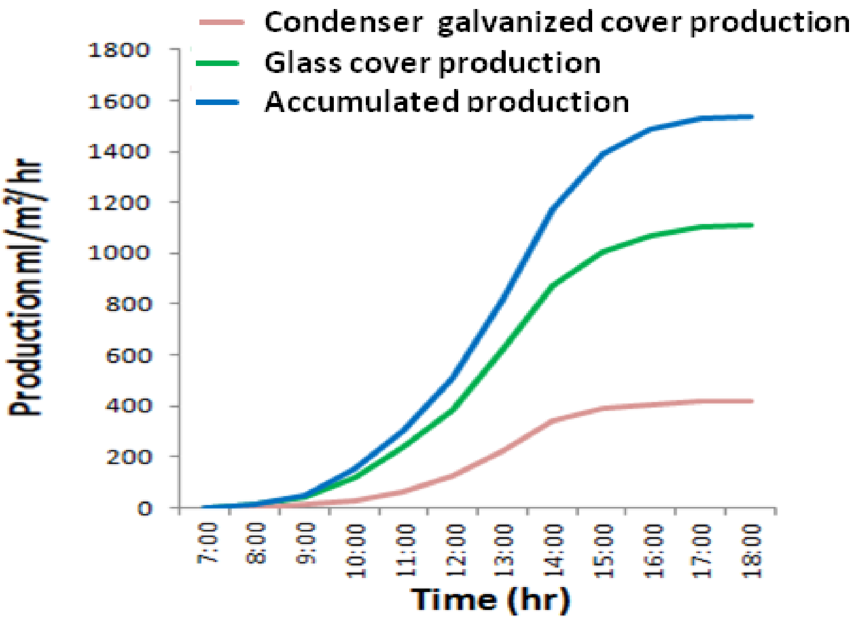

Fig.8. Production rate of built-in condenser solar still.

When comparing the glass cover inside and outside temperatures of the built-in condenser solar still with the inside and outside galvanized cover plate temperatures of the same still, it has been found that the built-in condenser galvanized cover plate have slightly lower temperatures. Both galvanized cove plate and glass cover, inside and outside temperatures are lower than the inside and outside glass cover temperature of the conventional solar still without the built-in condenser. This can be seen if figure 9 and figure 10.

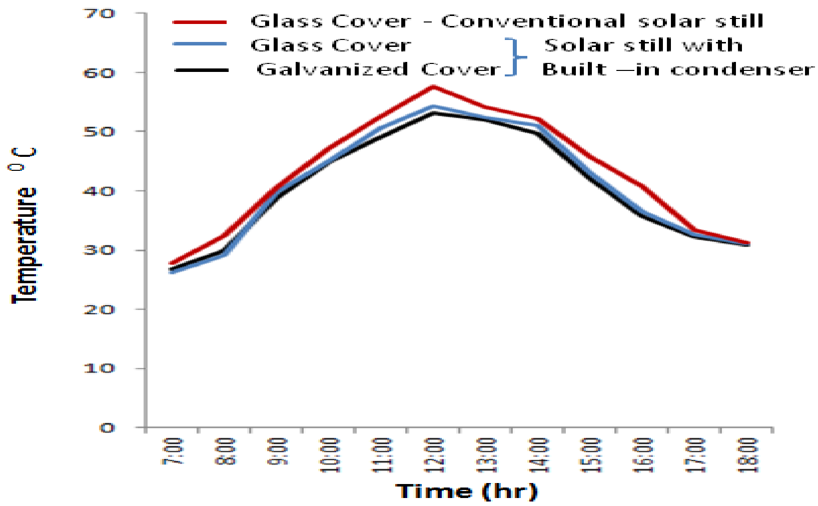

Fig. 9 Comparison between glass inside temperatures, the built-in condenser galvanized cover plate temperatures of the built-in solar still configuration, and with the glass inside temperatures of the conventional solar still configuration.

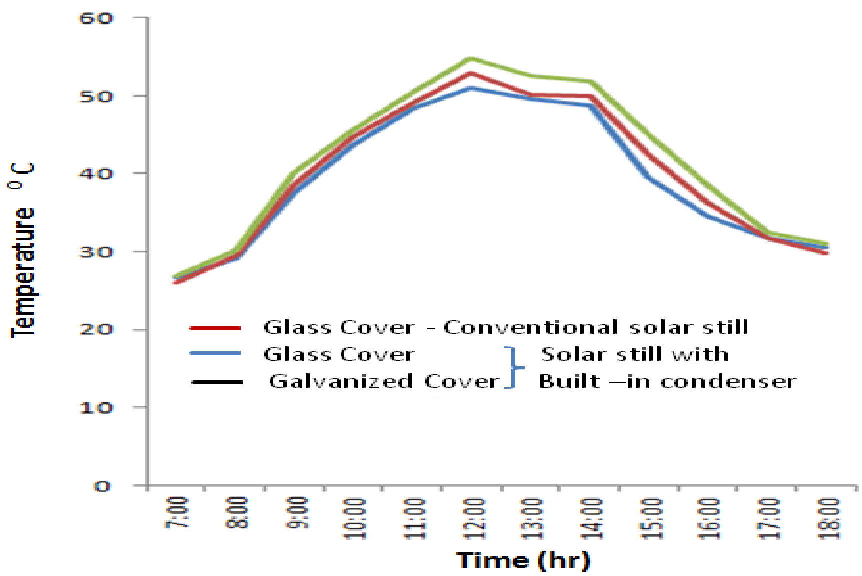

Fig.10. Comparison between glasses outside temperatures, the built-in condenser galvanized cover plate outside temperatures of the built-in solar still configuration, and with the glass outside temperatures of the conventional solar still configuration.

In comparing the temperature of the two configurations, it has been found that the temperatures recorded in conventional solar still are generally higher by 1.0 – 3.0 C than the temperature recorded in the solar still with built-in condenser. This is due to the fact that the presence of the condenser (which is made from galvanized steel) will have the effect of conducting more heat to the atmosphere and consequently reducing the still temperature slightly. Figure 11 shows the comparison between tank basin temperatures of the two stills' configurations, while figure 12 shows the comparison between saline water temperatures of the two configurations.

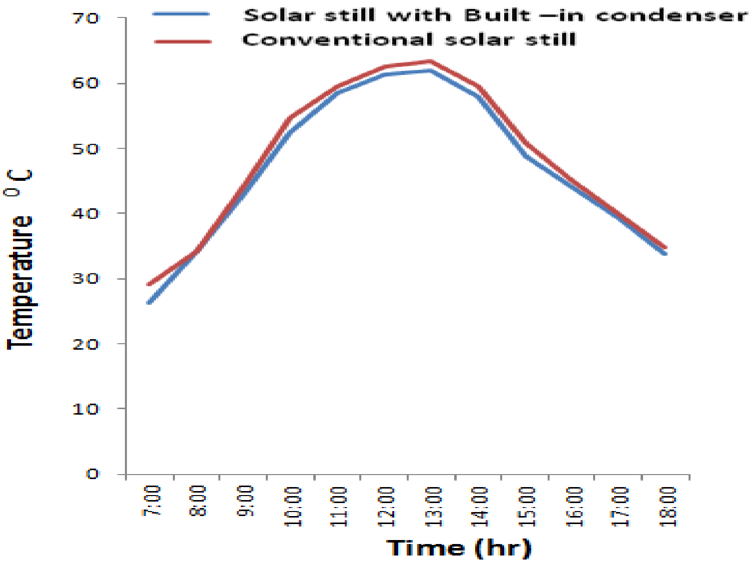

Fig.12. Comparison between tank basin temperatures of conventional solar still and with built-in condenser solar still.

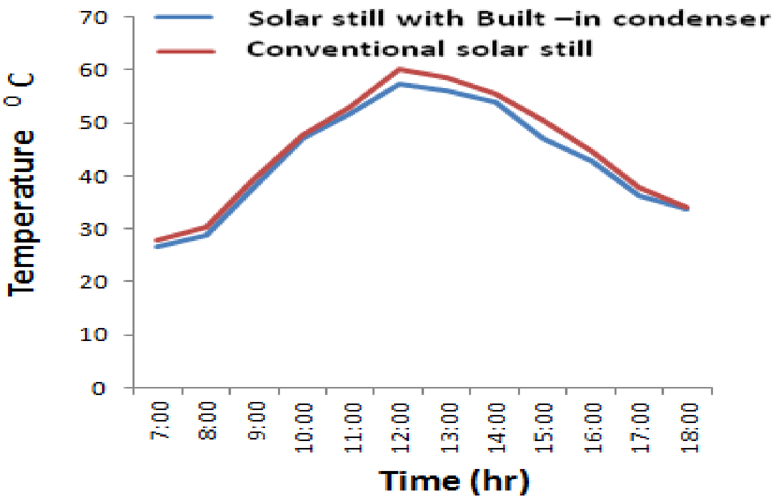

Fig. 12. Comparison between saline water temperatures of conventional solar still and with built-in condenser solar.

4. Conclusions

In this work, It has been found that incorporating a built-in condenser into the conventional solar still enhance its productivity by 16.7% in comparison to the conventional solar still configuration without condenser. The higher production rate may due to the increased condensation surface area and also due to the better conductivity of the galvanized cover of the built-in condenser. It has also been found that 72. 7% of the fresh water was produced through front glass cover while about 27.3% was produced through the galvanized cover of the built in condenser.

The overall temperature profiles in the conventional solar still parameters have found to be higher than temperature profiles of the still with the built-in condenser. This may be as direct results of the higher conductivity rate of the galvanized cover of the built-in condenser.

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