# Experimental Investigations of Solar Stills Connected to External Passive Condensers

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## ABSTRACT
Solar stills are regarded as one among the foremost promising solutions to solve water scarcity problems, mainly in arid remote areas. Enhancing the solar stills performances and increasing their productivity are the main goals of the investigators in recent years. The aim of this research is to explore ways to increase distillation productivity of conventional, simple basin type solar still. Therefore, three identical simple type solar stills were designed, manufactured, and tested under the actual environment in Bahrain during July, 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.

***Keywords*: Solar still, solar distillation, solar energy, water desalination.**

## 1. Introduction

Historically, there is a strong relationship between the population density and the availability of drinking water. Due to the change in climate, the rapid growth in the population and water pollution, even these areas started to suffer from severe water scarcity. The demand for a fresh water supply is rapidly increasing (El-Zahaby et al., 2011). Therefore the scarcity of a fresh water supply has become one of the major problems in different parts of the world especially in arid and remote areas (Varun, 2010). Tawari (2008) reported that about 40% of the world population will face a shortage of a fresh water supply by the year 2015.

The solar stills are regarded by many researchers as one of the most promising solutions to solve the water scarcity problem, mainly in remote arid areas (Murugavel and Srithar, 2011). Solar stills use a relatively simple technique to produce a small amount of potable water from brackish or sea water in an artificial simulation process based on the green house effect using solar energy (El-Zahaby et al. 2010). The conventional basin-type solar still is simply an airtight shallow basin with side metal frame walls that are very well isolated and with an upper part sloped cover made of a transparent material (usually glass). The transparent material allows the incident solar radiation to enter the solar still and be absorbed as heat by the shallow layer of brackish or saline water and the blackened base. The heated water evaporates, and then condenses on the inner side of the slopped cover and run down to a trough to be collected. They are easy to build and simple to operate and maintain (Ismail, 2009; Kumar and Bai, 2008). Because of its low productivity, this device is not so popular (Murugavel and Srithar, 2011). Recent research has focused on exploring new designs and ideas to enhance the solar stills performance and increase their productivity. Solar still productivity enhancement has become the main goal of investigators in recent years (Dev et al., 2011). Despite all these attempts and proposed ideas by many researchers in the past three decades, the performance of solar stills are still limited (Kabeel and El-Agouz, 2011).

El-Zahaby et al. (2011) tried to enhance solar productivity; by controlling the water depth to a minimum height (minimizing water depth is always regarded as one of the most important key parameter to enhance the performance of solar stills). They feed the saline water into the solar still through a reciprocating spraying system in the form of fine droplets on to the upper part a corrugated surface of steep shaped absorber. They reported that a high efficiency of 77.35% was gained. Boubekri and Chaker (2011) reported that using internal and external reflectors have the effect of increasing the productivity by up to 72.8% in the winter, 40.33% in the spring, and only 7.54% in the summer. They also found that integrating a thermal storage tank with the solar still increases the productivity by 27.5%, 21% and 23.2 % in the winter, spring and summer respectively. They also found that using the thermal storage tank had a significant effect on production rate during the night period. Dev et al. (2011) performed experimental studies using inverted absorbing solar still and a single slope solar still. They reported that inverted absorber solar still yielded 6.302 kg.m$^2$-days in comparison with the simple solar still which yielded only 2.152 kg/m$^2$-day for the same working conditions.

Abdallah et al. (2008) found that the installation of reflecting mirrors on all interior sides of a conventional single slope solar still will enhance its productivity by 30%. They also found that replacing the flat basin of the still by a step wise basin enhanced its performance by 180%. Badran and Al-Tahaineh (2005) found that the coupling of a flat plate solar collector to a single slope solar still with mirrors fixed to its interior sides increased its productivity by 36%. Voropoulos et al. (2003) used Solar stills coupled with flat plate solar collectors and a hot water storage tank. They found that the still productivity was doubled. Nafey et al. (2002) reported that using a floating perforated black plate in a solar still improved the productivity by 15%. Badran (2007) reported that the use of asphalt in the basin of a conventional solar still improved its production rate by 29%. While the use of a sprinkler combined with the asphalt improved the still productivity by 51%.

Ahmed et al. (2010) found that the performance efficiency of conventional solar still decreased by about 4% when they introduced a cooling tube attached to the inner surface of the upper part cover of the still. El-Bahi and Inan (1999a) used direct and reflected solar radiation utilizing a double glass cover and integrated separate condenser. They reported that efficiency was increased by 48% and it exceeded 70% when the condenser cover was cooled down. El-Bahi and Inan (1999b) used a solar still with a minimum inclination of 4$^o$, coupled with an outside passive condenser. They reported that the production efficiency improved by up to 75%. Murugavel and Srithar (2011) used rectangular aluminium fins arranged in different configurations in the basin type double slope solar still, covered with five different wick materials, in order to decrease the volumetric heat capacity of the basin and to enhance the evaporation surface area and consequently increase the production rate. They found that the solar still with a light black cotton cloth is the most effective wick material. They also found that the still with the aluminum fins arranged in a length wise direction and covered with cotton cloth was more effective.

Abu-Hijleh and Rababa'h (2003) used different sizes of sponge, black coal, and black steel cubes placed in the basin of the solar still. They found that the productivity of the solar still increased in the range 18% to 27.3% in comparison with an identical solar still working without cubes under the same conditions. Sakthivel et al. (2010) introduced a medium of jute cloth into the conventional single slop solar still, in an effort to increase the evaporation surface and to utilize the latent heat of condensation. They reported that implementing this technique improved the still efficiency by 8%.

Abdallah et al. (2009) used three different types of absorbing materials in an attempt to improve the thermal performance of the single solar still. They found that using coated metallic wiry sponges improved the productivity by 28%. The uncoated metallic wiry sponges improved the still productivity by 43%. The implementation of black rocks increased the productivity by 60%.

Kabeel (2009) found that using a concave jute wick surface would have the effect of increasing the amount of absorbed solar radiation and consequently enhanced the evaporation surface area. This resulted in an increase in the solar still efficiency by 30%. Arjunan et al. (2009) used a blue metal as a storage medium. They reported an improvement in production efficiency of 5% in comparison with a conventional solar still worked in parallel with the same conditions. Sakthivel and Shanmugasundaram (2008) found that using a black granite gravel material as a thermal energy storage medium enhanced the still yield by 17-20%. Nijmeh et al. (2008) found that using potassium permanganate as an absorbing material increased the single basin solar still by 26%, while using violet dye improved the productivity by 29%. Mahkamov and Akhatov (2008) developed a multistage solar thermal water desalination system. They found that the productivity is about twice as high as that of conventional solar stills. Nassar et al. (2007) found that the introduction of a vacuum system improved the solar still productivity by 303%. Al-Karaghouli and Alnaser (2004) found that using a double basin solar still increased the production efficiency by about 13%.

In the present work, experimental investigations have been carried out to evaluate the effect of connecting two external passive condensers to the conventional single slope basin type solar still using two different ways of connections.

## 2. Experimental facilities

Three identical single slope basin type solar stills were designed and constructed from 1.4 mm galvanized steel with a net basin area of 1 m² (1x1m), and a 4 mm glass cover with a net area of 1 m² (1x1m). The glass cover was fixed at an angle of 20º to the horizontal. In order to prevent or minimize heat lose from the base and the sides of the galvanized basins, each galvanized basin was fixed inside a wooden basin of an identical shape but of a slightly of a larger size. The gaps between each wooden and galvanized basin were packed with 50 mm thick glass wool of 0.045 (W/m² °C) thermal conductivity. In order to maximize the absorption efficiency of solar radiation, the insides of the galvanized basins were painted black. The first still was used as a reference. The schematic diagram of the first still is shown in Fig.1.

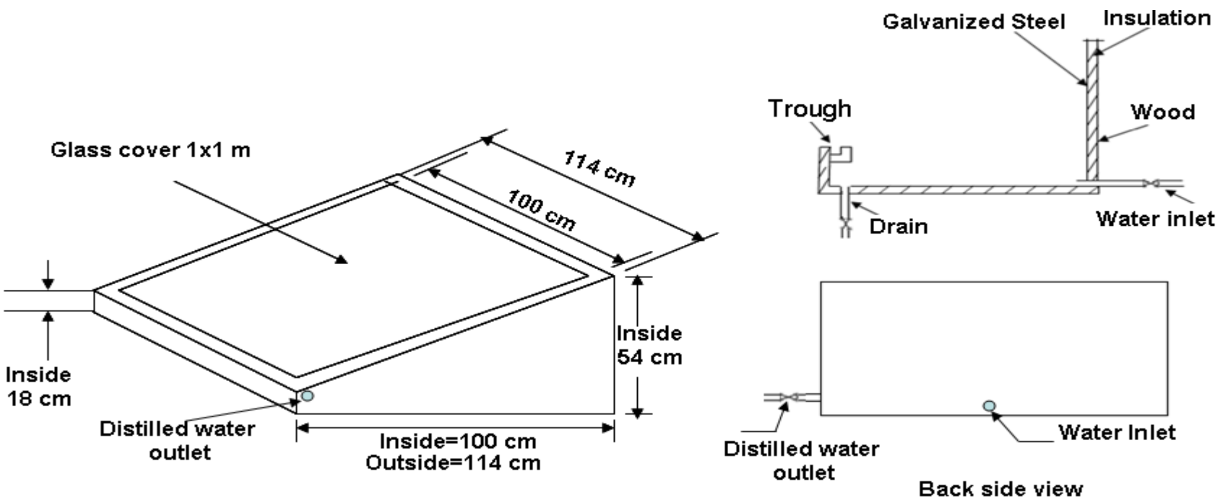


Fig.1. Schematic Diagram of conventional Solar still

Four identical passive cylindrical condensers were designed and manufactured from 1.4 mm galvanized steel. Each has a diameter of 30 cm and a height of 80 cm. The condensers were fixed to the back of the other two solar stills by 10 cm diameter, 20 cm length galvanized pipes using union connections (to facilitate mantling and dismantling the condensers). The first two condensers were fixed in parallel to the upper part of the back of the second solar still as shown in Fig.2.

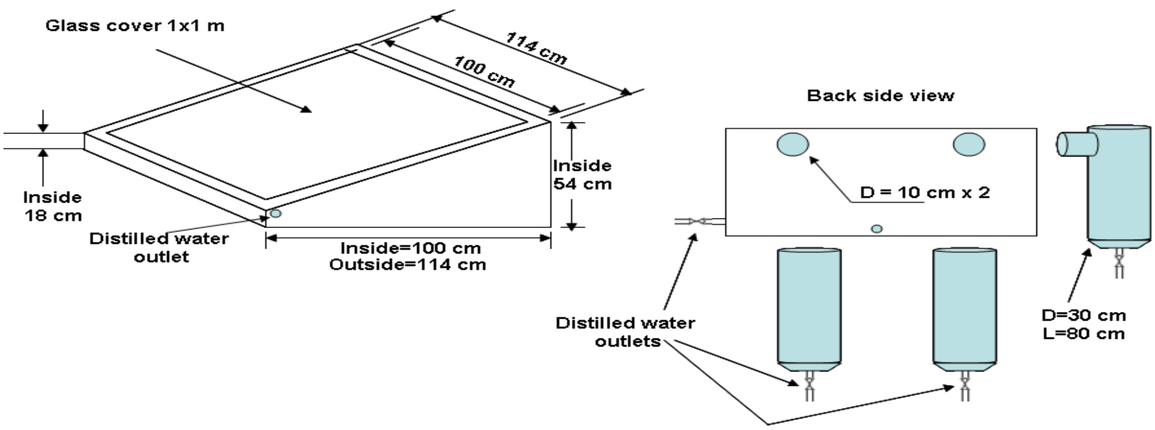


Fig.2. Schematic Diagram of Solar still linked to passive condensers by single connection

The other two condensers were fixed, in parallel, to the back of the third still from both upper and lower parts, as shown in Fig.3. A short pipe fitted to a half inch valve was fixed at the bottom end of each condenser and were used to drain and collect the condensed water.

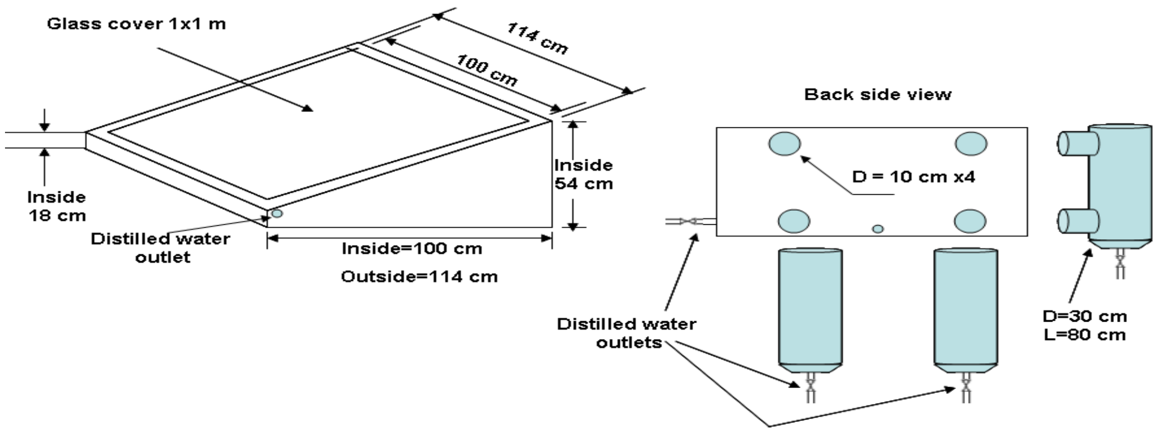


Fig.3. Schematic Diagram of Solar still linked to passive condensers by double connections.

All three stills were mounted on steel structures, shown in Fig.4. A level meter was used to ensure that they were precisely horizontal. A water tank was fixed at the same level as the stills with a float to feed and control the water level inside the still to a fixed value of 1 cm. As an extra measure, to ensure that the water level inside the stills is exactly horizontal, and the brackish water is at the same constant level in all stills, white lines one cm from the bottom of the basin were painted all round the inner side of the basins. The water level was checked before and throughout the tests. An L shape channels (trough) were fitted down stream end of the glass covers and used to collect the distilled water.

Fig.4. Different views of the solar stills

A half inch diameter pipe fitted to a valve was connected to each side of the stills at the bottom side of the trough channel. It was used to collect the distilled water running down the glass cover into the trough. The valves lead, through flexible hoses into plastic bottles, where the collected distilled water can be measured in a graduated flask.

Other sets of half inch pipes and valves were fixed at the lower end of the back of the still and were connected to the feeding tank through a main pipe. All stills have a drainage pipes and valves fitted to the lower part of the stills.

Silicon rubber was used to seal all the stills. The sealant is an essential factor for efficient operation. The three stills were positioned adjacent to each other facing south as shown in Fig.4.

In the present study a solar intensity meter was used to measure the solar radiation intensity in $w/m^2$ (its range was from 0-1.999 $kw/m^2$). An anemometer was used to measure wind speed. Copper-Constantan thermocouples were used to measure the ambient temperature, the galvanized tanks basin temperatures, the water temperatures, the vapor temperatures inside the stills, the glasses inner and outer temperatures, the condensers inside temperatures and the condensers outer surface temperatures.

The experiments were conducted on clear days in the city of Sanad, Bahrain (latitude angle --- EN) during the month of July 2011. Preliminary tests were conducted for two days to make sure that the system was ready. Then the experiments were conducted for another two days and the average values taken.

All experiments were started at 6:00 am and carried out till 6:00 pm local time. The collections taken at 6:00 am represent the overnight condensation. Measurements of all parameters were recorded at two hours intervals.

## 3. Results and Discussions

In order to investigate the effect of incorporating passive condensers, in different ways to the conventional, basin type solar still, outdoor experimental tests were carried out in Bahrain during the month of July 2011, using three simple type solar stills. The first is a conventional still, which was used for comparison with the other two. In the second still, two passive condensers were connected in parallel, to only 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.

The three stills were set up leveled, and adjacent to each other facing south. Measures were taken to ensure that no direct sun light reach the condensers by placing a wooden board on the top of the condensers. The readings of all thermocouples, solar intensity, and wind speed were recorded every two hours from 6:00 am till 6:00 pm. At the same time the distilled condensate from the condensers and that ran down the glass covers, was collected and measured individually. The first collections of distilled water at 6:00 am represented the overnight condensation.

It was found that the, reference, conventional solar still produced, an accumulated amount of distilled water of 3.340 liters/day. The distilled water condensed on the glass cover and ran down into the trough where it was collected. The still that has two condensers connected, in parallel, to only the upper part of its back produced total of 3.845 liters/day. That is an increase of 15.1% in comparison with the conventional solar still. 1.490 Liters of which was collected from the condensers, while the other 2.355 liters were collected from the trough (located down the glass cover). The still that had the condensers connected, in parallel, to, both, the upper and lower parts of its back produced a total amount of distilled water of 4.360 Liters/day. That is an increase of 30.54% in comparison with the conventional distilled solar still. 1.855 Liters of which was collected from the condensers and the other 2.475 Liters was collected from the trough (located down the glass cover). Fig.5 shows the comparison of the accumulated production rate between the three stills. Fig.6 shows the comparisons on an hourly basis.

The incorporation of the condensers has increased the production rates. This may be attributed to the fact that the condensers provided an extra surface area with a lower outside surface temperature in comparison with the glass inner temperate. In addition the condensers have been manufactured from galvanized steel which has better conductivity. Never the less, it can be seen that the amount of condensation running down the glass cover is more than that obtained from the condensers. This may be attributed to the fact that it is harder to drive the vapor from the stills into the condenser spaces. This analysis is supported by the fact that the condensation yield obtained from the still that has the condensers linked to the still by two connections ( at the upper and lower parts of the back) gave a better yield than the still in which the condensers were connected only to the upper part of the back. The two connections set up, increased vapor circulation and consequently, gave a better condensation yield.

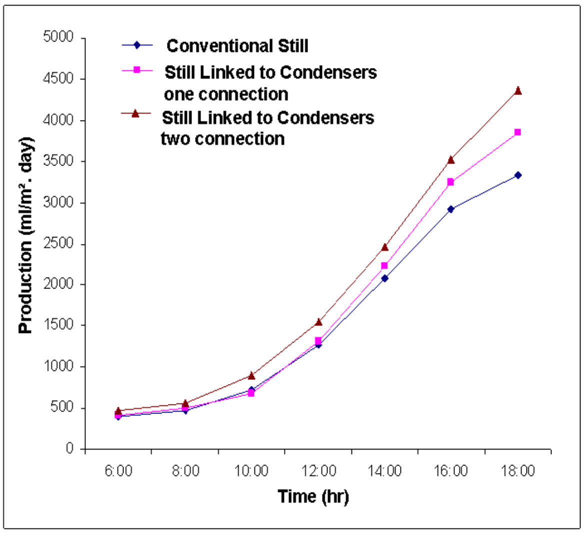


Fig.5. Comparison between Accumulated productivity of the three stills

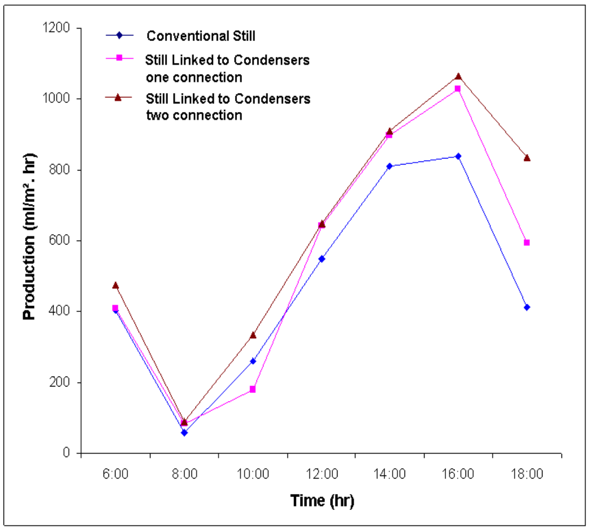


Fig.6. Comparisons between productivity of the three stills on hourly basis

A comparison between the production rates obtained from the condensers and the glass covers are shown in Fig.7. For the same reasons, it has been found that the vapor temperatures inside the still are linked to the condensers by two connections is, slightly, lower than the vapor temperatures inside the other two stills, while the vapor temperatures inside the conventional (reference) still is , in general higher than the other two stills connected to external condensers. This can be seen in Fig.8, which shows the vapor temperature distribution inside the three stills.

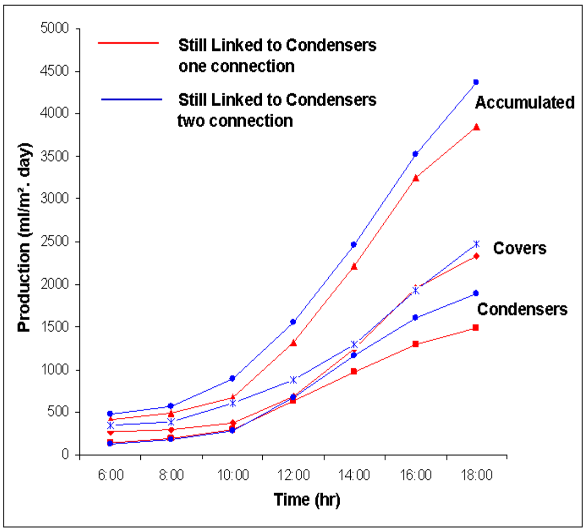


Fig.7. Comparison between distilled water obtained by stills covers and condensers

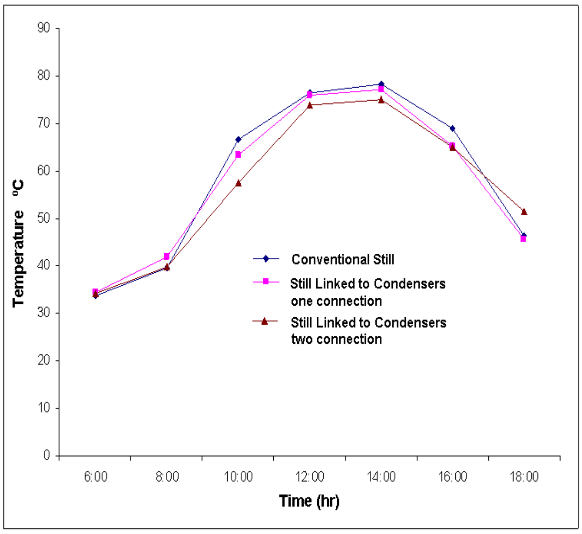


Fig.8. Vapor temperature distributions

The same trend can be observed comparing the glass covers inside and outside temperatures as shown in Fig.9 and Fig.10 respectively, and also the basin and water temperatures which are shown in Fig.11 and Fig.12 respectively.

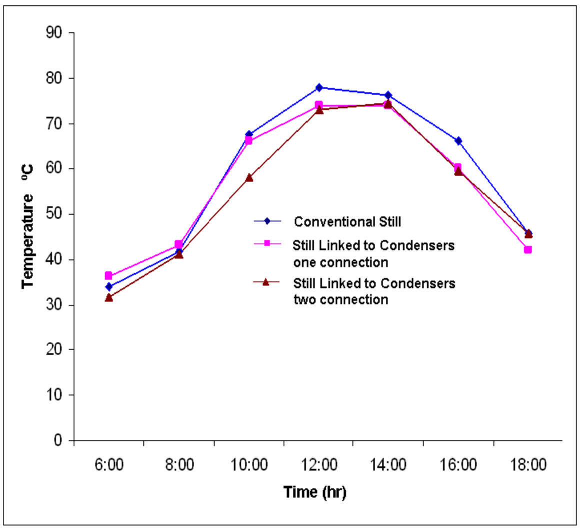


Fig.9. Glass covers inside temperature Distribution

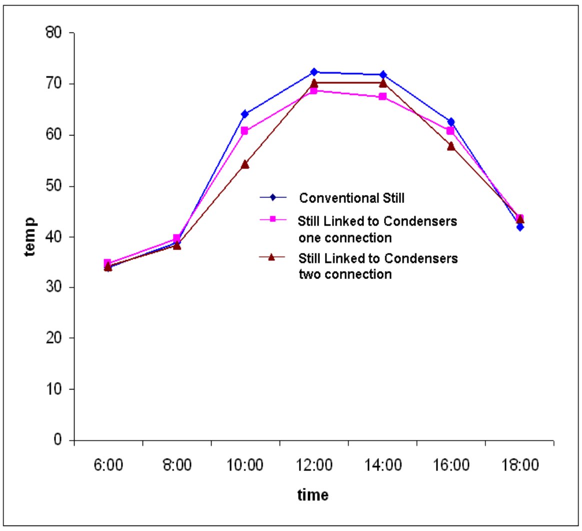


Fig.10. Glass covers outside temperature distribution

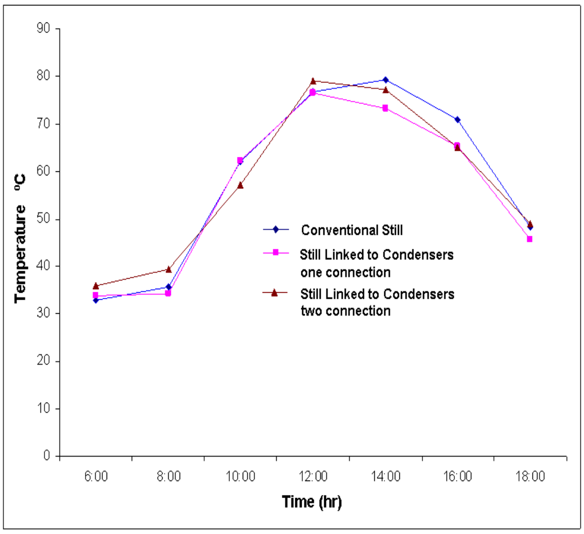


Fig.11. Basin water temperature distributions

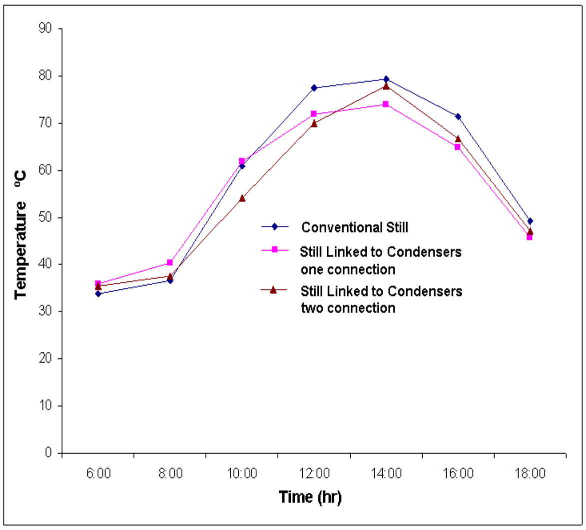


Fig.12. Basin temperature distributions

## 4. Conclusions and Recommendations

Experimental tests have been carried out to investigate the effect of incorporating and connecting external passive condensers to the conventional, basin type, solar still. It can be concluded that:

a- Incorporating outside passive condensers will enhance production yields of the conventional, basin type solar still.

b- The methods of incorporating and connecting the condensers to the conventional solar still have a significant effect on enhancing the production of distilled water

c- Incorporating external condensers linked to the solar still by only a single connection, enhanced the production of distilled water by 15.1%.

d- Incorporating external condensers liked to the solar still by two connections, enhanced production yields of distilled water by 30.54%.

Based on the results of this investigation, it is recommended that new stills should be built with the condensers connected directly to the still with no obstacles in between.

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