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Temperature Analysis of Conventional Solar Still linked to Passive Cylindrical Condensers

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ABSTRACT

In recent years, solar distillation has gained momentum and is regarded as one of the most promising methods of utilizing solar energy to produce fresh water from brackish and sea water, mainly on a small production scale and in remote regions. The enhancement of solar stills performances and improving their productivity has been the main goals of the investigators. This experimental work has been conducted to explore ways of increasing distillation productivity of a conventional, simple basin type solar still. Therefore two identical simple type solar stills were designed, manufactured, and tested under the actual environment of the Kingdom of Bahrain at Gulf University, during the month of March 2013, one of which was linked to external passive cylindrical condensers. The two stills glass cover's tilt angle was fixed at 20º to the horizontal, the water depth was controlled and fixed at 1 cm, and each still basin effective area was 1 m². It has been found that the daily production rate of the solar still connected to the cylindrical condensers produced 26.9%, more fresh water compared to that of a conventional solar still. The temperatures of the solar stills linked to condensers was found (in general) to be lower than that of the conventional solar still due to the extra cooling surface provided by the existence of the external condensers and better thermal conductivity

***Keywords*: Solar still; solar distillation; solar energy; Water desalination.**

1. Introduction

Fresh water is a basic human necessity. It is the most essential thing is sustaining life. Due to the rapid growth of population and increasing pollution, the demand is growing all over the world for various purposes as water scarcity around the world is increasingly becoming a very serious problem, especially for the developing countries (Rajaseenivasan et al., 2013). Fresh water is therefore, the key to man’s prosperity; and is intimately associated with the evolution of civilization (Zala et al 2013). About 97% of the world's water is saline, and more than 2% of this water is frozen at the Polar Regions. Hence, less than 1% of the earth's water is available for the requirements of plants, animals and human life in rivers, lakes and ground water (Xiao et al., 2013). Even this small fraction of fresh water is believed to be adequate to support life and vegetation on the earth, but unfortunately, it is not evenly distributed. The problem has been aggravated, in many parts of the world, due to pollution and contamination of fresh water resources. In addition; the ground water has been intensively exploited (Agboola and Egelioglu 2011). The present situation represents a major and serious challenge due to the ever-increasing water demand, pollution and salinity. Worldwide drought and desertification are increasing and complicating the problem (Arunkumar et al., 2012). The situation is more critical in rural and arid areas. The Gulf region and North African regions have large coastal locations where seawater is abundant but fresh water is not available. Therefore there is an urgent need for clean and pure drinking water in many of these areas, (Ahmed 2012a). To overcome these problems, seawater desalination has been shown to be the best alternative to provide fresh water for human consumption for many regions in the world such as the Arabian Gulf, Middle East and Australia (Yousef and Kassem 2011). For the time being, 50% of the world's desalinated water is being produced by Saudi Arabia (Alramadan 2012). The majority of areas that have deficiencies in a fresh water supply have huge amounts of solar energy freely available (Ahmed 2012b). In recent years producing pure water by using solar energy has gained momentum, and solar stills are regarded by many researchers to be one of the most promising solutions to solve the water scarcity problem, mainly in remote arid areas (Murugavel and Srithar 2011).

Solar stills represent the foremost attractive and simple technique among all the distillation processes. It can very easily be fabricated by the unskilled local people, using locally available materials. 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 water vapors get condensed on the inclined glass cover and get collected at the condensate channel, from where this distilled water is drained out and is collected in a suitable container (Srivastava and Agrawal 2013). A number of solar still units are installed for domestic utilities in the West-Indian Islands, Australia and the US/Mexico border (Patel et al 2011; Foster et al 2005). Studies showed that the practically installed solar stills efficiently removed all salts, heavy metals, biological contaminations (E. coli, Cryptosporidium) and water borne pathogens from contaminated water sources due to UV rays and high temperatures (Rays and Jain 2011). Having such simple, economical and attractive features, 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 (Dev et al., 2011). Despite all these attempts and proposed ideas by many researchers in the past three decades, the solar still's performance is still limited (Kabeel and El-Agouz, 2011).

Therefore the aim of present work is to study experimentally the performance of two solar stills in order to evaluate the effect of connecting external passive condensers to the conventional single still on its performance and analyze its impact on temperature distributions.

2. Experimental facilities

Two identical single slope basin type solar stills were designed and fabricated from 1.4 mm galvanized steel with a net basin area of 1 m² (1x1m). A 4 mm thickness glass cover was fixed at an angle of 20º to the horizontal. The bottom and the sides of the galvanized basins were fitted 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 to minimize and prevent heat lose from the stills. The galvanized basins were painted black to maximize the absorption efficiency of the solar radiation. Two identical passive cylindrical condensers were designed and fabricated from 1.4 mm galvanized steel. Each had a diameter of 30 cm and a height of 80 cm. The condensers were fixed to the back of the second solar stills by 10 cm diameter, 20 cm length galvanized pipes using union connections (to facilitate the mantling and dismantling of the condensers). An L shape channel (trough) was fitted to the down stream end of the glass covers and used to collect the distilled water. 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. A short pipe fitted to a half inch ball valve was fixed at the bottom end of each condenser and was used to drain and collect the condensed water. Silicon rubber was used to fix the glass cover and to seal the two stills. The sealant is an essential factor for efficient operation. The schematic diagrams of the two solar stills are shown in Fig.1 and Fig. 2, respectively. 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 depth of 1 cm. A wooden board was used to protect the condensers from direct sun light. The two solar stills were positioned adjacent to each other facing south. Two photos of the stills in situ are shown in Fig.3.

In the present study a solar intensity meter was used to measure the solar radiation intensity in w/m² (its range was from 0-1.999 kw/m²). An anemometer was used to measure wind speed. Copper-Constantan thermocouples were used to measure the glasses covers and the condensers inner and outer surface temperatures and the galvanized tanks basin temperatures. RTD thermometers were used to measure the ambient temperature, the water temperatures, the vapor (space) temperatures inside the stills, and the condensers inside temperatures. 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. Therefore, four pieces of wood each with a dimension of 2x3 cm were cut and groves with the same diameter as the thermocouples were made to accommodate them so that when the wooden pieces were placed on the glass covers, they would hold the thermocouples tight on to the glass cover surfaces and at the same time prevent the direct sun's rays to reach the thermocouples. The RTD thermometers were fixed in positions so that no direct sun ray could reach them.

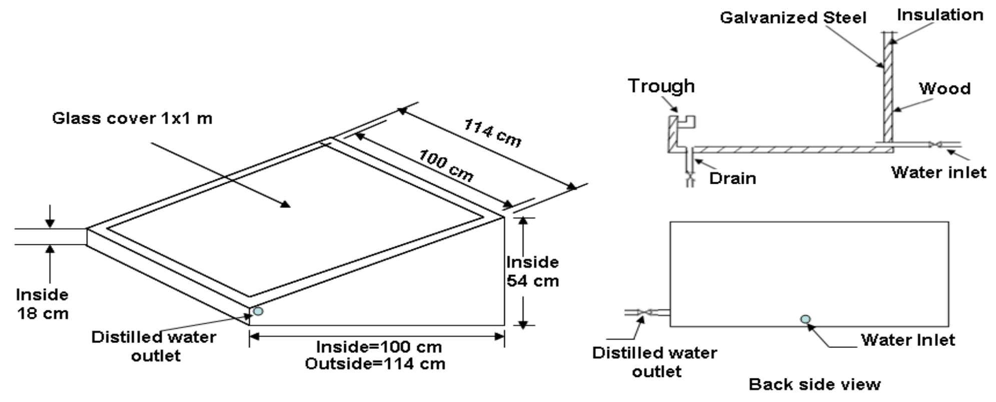

Fig.1 Schematic Diagram of conventional Solar still

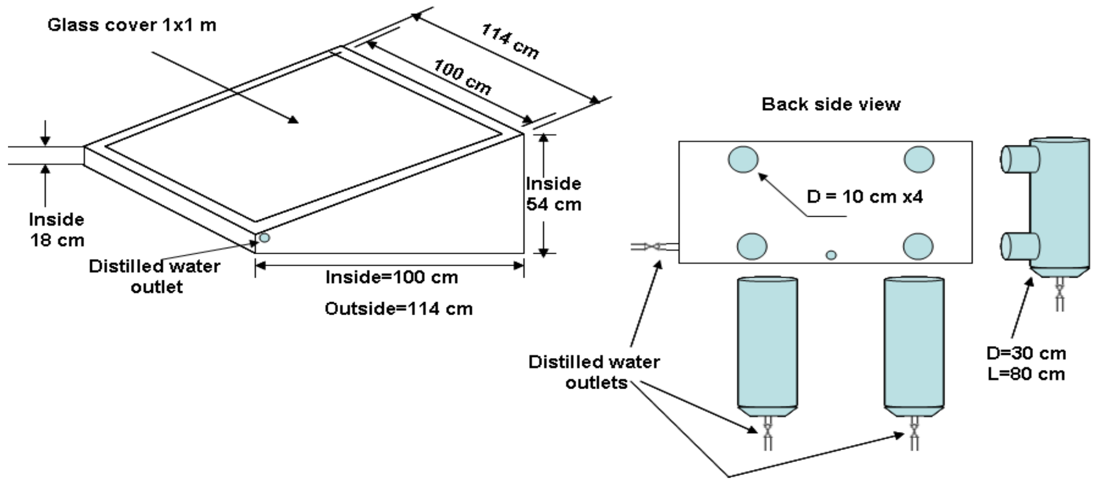

Fig.2 Modified conventional solar still schematic diagram fitted with cylindrical condensers

Fig.3 The two solar stills in Situ

3. Results and Discussions

Two simple type solar stills were used to investigate the effect of incorporating passive condensers on production rates. The experiments were conducted on clear days at Gulf University in the city of Sanad, (32.4º E 26.1º N), Kingdom of Bahrain, during the month of March 2013. The experiments were conducted for two days and the average values were taken. The two stills were set up level and adjacent to each other facing south. The readings of all the thermocouples, solar intensity, and wind speed were recorded every hour from 7:00 am till 6:00 pm. Fig. 4 shows the measured solar radiation intensity when the solar meter was directed (focused) perpendicularly towards the sun's rays (sun direction) and when the meter was fixed at the surface of the solar still directed south at an angle of 20º to the horizontal (still direction). It can bee seen that the difference between the two situations is substantial which dies out during mid day period. The maximum intensity was recorded at 12:00 noon. The total of 10251 Watts was recorded when the solar meter was directed towards the sun, while a total of 7750 Watts was recorded when the meter mimics the stills direction. In other words only 74% of the sun's rays were effective on the solar still and the use of a sun tracking system will defiantly increase the efficiency by about 26%. These results agreed with the findings of Abdallah and Badran (2008) who used a sun tracking system and reported an increase in productivity of 22%.

In comparing the production rates, it was found that the conventional solar still produced an accumulated amount of distilled water of 3.160 liters/day. The still that has two condensers connected to its back produced 4.010 liters/day. That is an increase of 26.9% in comparison with the conventional solar still. Fig.5 shows the comparison of the accumulated production rate between the two stills. Fig.6 shows the comparison on an hourly basis. Incorporation the condensers 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 temperature of the conventional solar still. The condensers have been manufactured from galvanized steel which has a much better thermal conductivity. This leads to a decrease in the inside still temperature, and in consequence, a reduction in the still's inside temperature and also the glass cover's inside and out side temperatures in the still connected to the condensers. This is evident when the vapor (space) temperature and the glass covers inside and outside temperatures were compared as can be seen in Figs. 7 and 8. respectively.

Figs 9 and 10 show the temperature distributions of the two solar stills respectively. It was found that the maximum basin water temperature of the conventional still was 73.8 ºC and the average was 52.7 ºC, which was higher than that of the still linked to the condensers (maximum was 67.6 ºC and the average was 49.7 ºC). Therefore, the evaporation should be better in the conventional still than that linked to the condensers. This is true, but there is another factor that affects the condensation process of the vapor. This is the temperature difference between the basin water temperature (T_w) and the condenser/glass cover inside surface temperature (T_{ci} / T_{gi}). This is demonstrated in Fig. 11, which shows the previous results obtained for the two stills.

It can be seen that the highest temperature difference was between the water temperature and the condensers inside surface (maximum was 16.4 ºC and the average was 9.6 ºC). The temperature difference inside the still linked to condensers (maximum was 11.8 ºC and the average was 6.96 ºC) which was higher than that of the conventional still (maximum was 7.6 ºC and the average was 3.9 ºC). It is obvious that the effect of condensation driving temperature difference is higher than the effect of the basin water temperature. This is also evident when the amount of condensation in the still linked to the condensers was analyzed. It was found that 2.530 liters/day was collected from the condensers, while only 1480 liters/day was collected from the trough, running down the glass cover inside surface. This represented 71% more yield from the condensers than the glass cover.

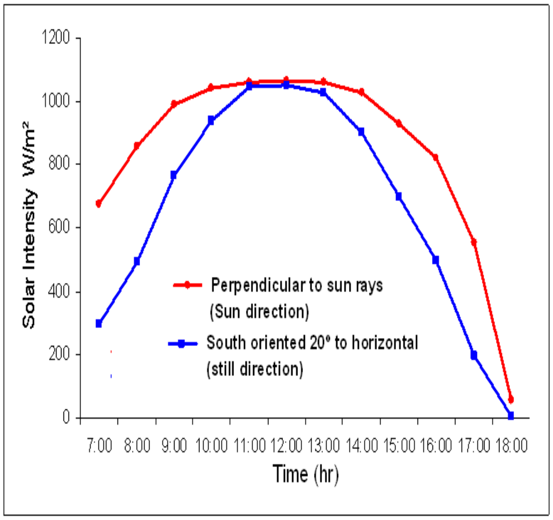

Fig. 4 Solar radiation intensity measurements

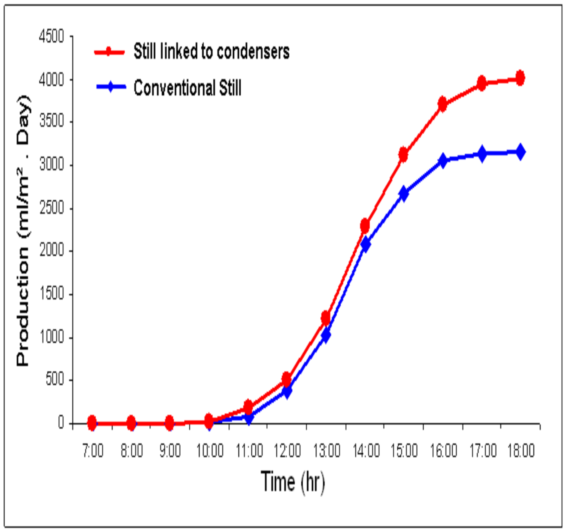

Fig. 5 Comparison between Accumulated productivity of the two stills

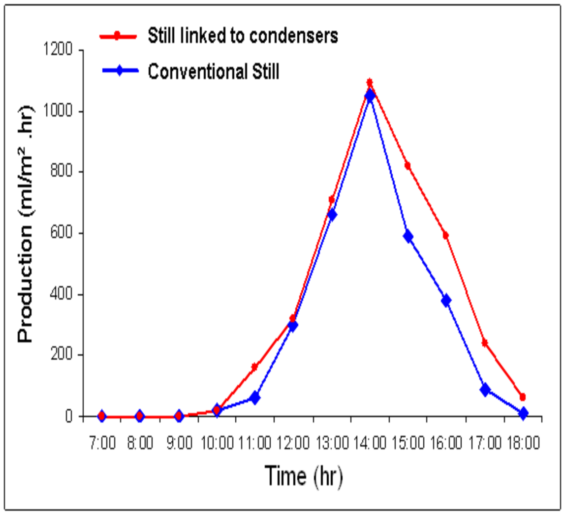

Fig. 6 Comparisons between productivity of the two stills on hourly basis

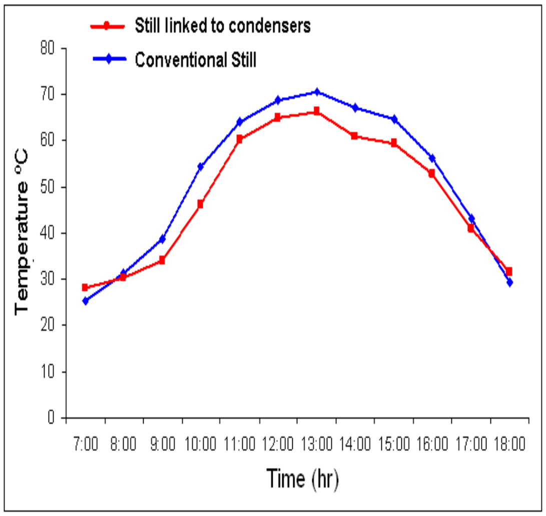

Fig. 7 Comparisons between space temperatures of the two stills

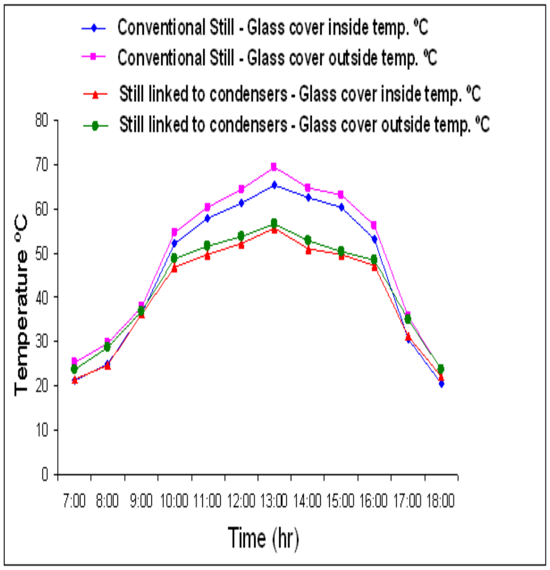

Fig. 8 Comparisons between glass cover temperatures of the two stills

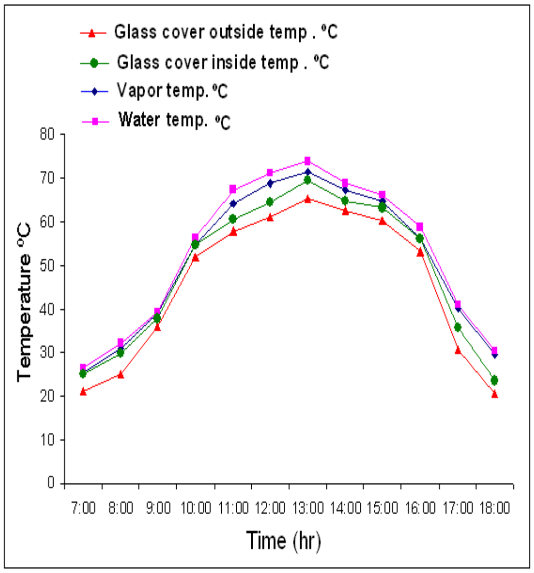

Fig. 9 Conventional solar still temp distribution

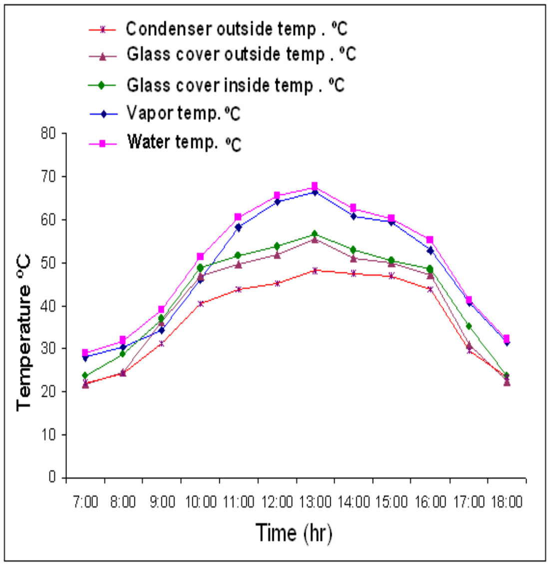

Fig. 10 Still linked to condenser temp distribution

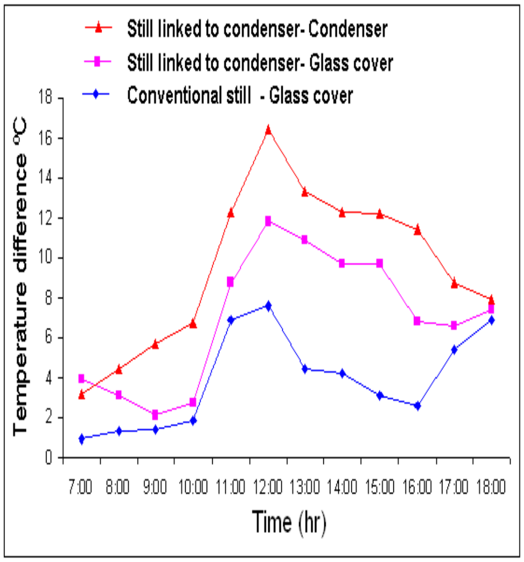

Fig. 11 Temperature difference variation between water and inside surface temperatures

5. Conclusions

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

a- Incorporating outside passive condensers will enhance the production yield of the conventional solar still.

b- The temperature inside the solar still connected to the condensers is lower in comparison to that of the conventional solar still due to the extra cooling surface and better thermal conductivity provided by the existence of the external condensers.

c- The difference between the basin water temperature and the condenser/glass inside surface temperature has the major effect on condensation rate.

6. Acknowledgements

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