Enhancement of a Single – Slope Solar Still Productivity for a Different Water Depths

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Abstract

Desalination of brine by solar powered systems is a practical and promising technology for producing potable water in the regions which suffers from water scarcity especially in arid areas. The abundant solar radiation intensity along the year and the available brine resources are two favorable conditions for using the desalination solar technology to produce the fresh water, even for domestic use. Based on these conditions, two small-scale solar powered desalination systems, one with mirrors as interior surface of the walls and the other without mirrors, have been constructed and operated. The present study aims to improve the solar still performance, and to increase its productivity. So it is necessary to evaluate some important parameters affecting the system productivity. The effect of brine depth in the basin on the productivity was evaluated. In the same time, the effect of using reflecting interior fasces (mirrors) and the adding blackened balls, with different materials, on the solar desalination process in the stills were investigated. Different depths of brine (1.5, 3, 5 and 8cm) with TDS of 2000-2050 ppm were tested under the climatic conditions of Kufa city. The obtained results showed that the productivity of the still with reflecting faces was 22.9% higher than that of still without reflecting sides, and that the decreased water depth and the adding blackened balls have a significant effect on the increased still productivity, while the performance characteristics showed that the still productivity was closely related to the incident solar radiation intensity.

Key Words
Single-slope, Solar still, Water productivity, Brine depth

ألخلاصة

تنقية المياه من الملوحة بواسطة أنظمة تعمل بالطاقة الشمسية هي تقنية واعدة وعملية لإنتاج المياه الصالحة للشرب في المناطق التي تعاني من النقص وخصوصا في المناطق القاحلة. غزارة شدة الإشعاع الشمسي طوال السنة وتوفر مصادر المياه المالحة هما أكثر ظرفين مفضلين لإنتاج الماء النقي باستخدام التقنية الشمسية في تنقية المياه. بالاستناد إلى هذه الظروف, تم بناء وتشغيل نظامين صغيرين لتنقية المياه يعملان بالطاقة الشمسية, أحدهما جهز بمرايا كسطوح داخلية على الجدران وترك الأخر على حاله. تهدف هذه الدراسة إلى تحسين أداء المقطر الشمسي وزيادة إنتاجيته. لذلك فمن الضروري تخمين بعض العوامل المهمة والمؤثرة على إنتاجية النظام. تم تخمين تأثير عمق الماء في الحوض على إنتاجية المقطر. وبنفس الوقت تم التحري عن تأثير استخدام سطوح داخلية عاكسة (مرايا) وإضافة كرات من مواد مختلفة طليت باللون الأسود على عملية التنقية الشمسية في المقطر. تم اختبار أعماق مختلفة للماء في حوض المقطر (1.5, 3, 5 and 8 cm) وبنسبة أملاح كلية ذائبة تتراوح بين (2000–2050 ppm) تحت الظروف المناخية لمدينة الكوفة. النتائج المستحصلة أوضحت بان إنتاجية المقطر ذو الأسطح الداخلية العاكسة أعلى بـ 22.9% من إنتاجية المقطر الأخر (بدون أسطح عاكسة) وان نقصان عمق الماء و إضافة الكرات السوداء له تأثير مهم على زيادة إنتاجية المقطر, بينما أوضحت خصائص الأداء بان إنتاجية المقطر لها علاقة كبيرة بشدة الإشعاع الشمسي الساقط.

1. Introduction

The lack of potable water poses a big problem in arid regions of the world where freshwater is becoming very scarce and expensive. Clean drinking water is one of the most important international health issues today. The areas with the severest water shortages are the warm arid countries in the Middle East and North Africa (MENA) region. These areas are characterized by the increase in ground water salinity and infrequent rainfall. The increasing world population growth together with the increasing industrial and agricultural activities all over the world contributes to the depletion and pollution of freshwater resources. **[Qiblawey and Banat, 2008]**.

It has been estimated by **[Kalogirou, 2005]** that the production of 1000 m^3 per day of freshwater requires 10000 tons of oil per year. This is highly significant as it involves a recurrent energy expense which few of the water-short areas of the world can afford. Large commercial desalination plants using fossil fuel are in use in a number of oil-rich countries to supplement the traditional sources of water supply. People in many other areas of the world have neither the money nor oil resources to allow them to develop on a similar manner. Problems relevant to the use of fossil fuels, in part, could be resolved by considering possible utilization of renewable resources such as solar, biomass, wind, or geothermal energy. It often happens that the geographical areas where water is needed are well gifted with renewable energy sources (RES). Thus, the obvious way is to combine those renewable energy sources to a desalination plant, in order to provide water resources as required

Desalination is one of mankind's earliest forms of water treatment, and it is still a popular treatment solution throughout the world today. In nature, solar desalination produces rain when solar radiation is absorbed by the sea and causes water to evaporate. The evaporated water rises above the surface and is moved by the wind. Once this vapor cools down to its dew point, condensation occurs, and the freshwater comes down as rain. This basic process is responsible for the hydrologic cycle. This same principle is used in all man-made distillation systems using alternative sources of heating and cooling **[Qiblawey and Banat, 2008. Al-Hayek and Badran, 2004]**.

Many design variations of solar desalination units exist, and a wide variety of construction materials are used. One of the most suitable solar desalination units is a single-slope solar still (conventional solar still), because of its low initial and maintenance cost, simple construction and operation, high fresh water productivity **[Al-Hayek and Badran, 2004. Aybar and Assefi, 2009]**.

The amount of distilled water that can be produced varies quite dramatically with the geographical position, the sun's position, prevailing meteorological conditions, solar still design and operational technique **[Malik, Tiwari, Kumar and Sodha, 1982]**. Some researches **[Khalifa and Hamood, 2009. Tarawneh, 2007. Badran, 2007. Nijmeh, Odeh and Akash, 2005. Radwan, Hassanain and Abu-Zeid, 2009. Abdenacer and Nafila, 2007. Namprakai and Hirunlabh, 2005]** found that other parameters such as water depth, salinity, black dye, adding different materials to the water, wind speed and direction have an effect on the output of the solar stills.

The productivity of fresh water by solar distillation depends drastically on the daylight time interval **[Al-Hayek and Badran, 2004]**. Considering that, Iraq is a suitable place for making extensive researches on solar distillation.

The aim of this paper is to increase the productivity of fresh water by distillation using two single –slope solar stills: one with mirrors, as inside walls, and the other without. Both solar stills were utilized under the same operational conditions, which represent the climatic condition of Kufa city in Iraq.

2. System Description

Two single – sloped basin – type solar stills (Fig. 1(a and b)) were design from locally available materials and locally manufactured components. Both solar stills with basin areas of $1m^2$ for comparison purpose, are constructed from glazing structure covered with 4mm thick glass (transmissivity of about 0.88, **[Aybar, Egelioglu and Atikol, 2005]**). The bases of the stills made of 6mm thick glass and blackened on their interior surfaces to enable maximum absorption of solar radiation. The bottom and sides of the two stills were insulated from outside with 150mm thick glass wool with thermal conductivity of 0.032 W/m.K to minimize the heat loss with the surrounding. Whole assemblies of both solar stills are made airtight with the help of a rubber gasket and PVC silicon.

Thermocouples were distributed inside and outside the solar stills to measure the ambient air, glass, brine and vapor temperatures.

All experiments were achieved during the month of March of 2010 in Kufa, Iraq (latitude angle 32.2^{o}N). The solar stills glass covers are tilted at an angle of 32^{o} **[Khalifa and Hamood, 2009]** to increase the amount of solar radiation reaching the surface aperture more frequently during the day, and the data which used to compare relative performance of the two stills were at 1.5cm basin-water depth. The distilled water yield is measured by scaled flask every hour. Daily accumulated of fresh water ranging from 2.13 to 4.7 l/m^{2}. One of the present solar stills is made with mirrors, as the interior surface of the walls, to reflect the solar radiation incident on them onto the blackened base.

The brine, with salinity of 2000 to 2050 ppm, is poured into the stills to fill the basins with knowing levels. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the still base. The water beings to heat up and the moisture content of the air is trapped between the water surface and the glass cover, thus the glass cover traps the solar energy inside the still. The base also radiates energy in the infrared region, which is reflected back onto the basin by the interior mirrors which concentrate heat energy at the base **[Al-Hayek and Badran, 2004]**. The water will evaporate from the basin and condenses on the inside of the glass cover. The condensate flows into a collecting channel at the base of the glass cover, which inclined with 5^{o} towards the collecting header in order to speed up the condensate velocity and to avoid the re-evaporation state, and the fresh water eventually delivered to the scaled flask. The stills are filled at the morning and the water production for the day collected in the evening. Brine, making up, was added to the stills through a supply fill port, and the excess water will flow out of an overflow port at the center of the basins.

3. Results and discussion

3.1. Brine depth

3.1.1. Temperature

The temperature of the brine, vapor, inside glass cover and ambient temperature versus time for the two stills, with brine depth of 1.5, 3, 5 and 8cm, are shown in Figs. (2-9). It can be seen from these figures that the same trends of the temperature behavior for the two stills, where the temperature rises during the measuring time up the maximum value at 14:00 hr and then trend to decrease. It is noticed that the temperatures throughout the still decreasing with increasing the brine depth, in turns that the still with mirrors, as interior faces, operates at a higher temperature than the other without mirrors, because the presence of these mirrors will reduce the heat energy losses in the solar still.

3.1.2. Productivity

The effect of brine depth on the still productivity is shown in Figs. (10-13). In general, the productivity increases with the solar intensity increasing until it reaches the maximum value at 14:00 hr, after that the decreasing of temperature will reduce the solar still productivity. For the still without mirrors, the productivity from the lower tested depth has 18.7% higher than that obtained from the depth of 3 cm, which increase of 11.7% higher than that obtained from the depth of 5 cm and an increase of 9.4% in water productivity than that obtained from the tested depth of 8 cm. This is due to increase the heat capacity of the brine when the depth increased, which leads to reduce the evaporation rate and thereby the condensation rate. The presence of mirrors inside the solar still increases the distilled water, due to concentration of the reflected solar radiation incident on them onto the brine.

3.2. Effect of adding balls

Generally, in a solar still most of the incident sunshine absorbed by the base of the still that becomes hotter than the water contained. In turn, adding balls to the still will increase the absorption solar energy to store in these balls and becomes significant with decreasing the solar radiation.

The effect of balls is investigated by adding stainless steel and ceramic blackened balls of 1cm diameter and 75 pieces of each type, for 1.5 cm brine depth test in solar stills with reflecting interior sides, i.e. mirrors. Fig. (14) shows the results of this test, which demonstrate that the productivity from the stills with blackened balls is greater than the other without balls. Thus, the addition of stainless steel blackened balls causes an enhancement in the daily productivity by 15.2% and by 9.6% for the addition of ceramic blackened balls.

Sola still efficiency, η, is defined as the ratio of the heat transfer, q_e (MJ/ m^2/d), in the still by evaporation-condensation to the incident solar radiation, I (MJ/m^2/d), on the still **[Al-Kharabsheh and Goswami, 2004]**, as given by

$$\eta = \frac{q_e}{I}$$

Thus, the calculated efficiency by the above equation for the still without interior reflecting sides is about 35.3%, while the efficiency of the still with mirrors as interior surfaces is about 44.8%. In turn, the productivity increased by 22.9% when the mirrors, which increases the net solar radiation received by the brine due to the reflection rate and minimizing the heat energy loss, are used in the still.

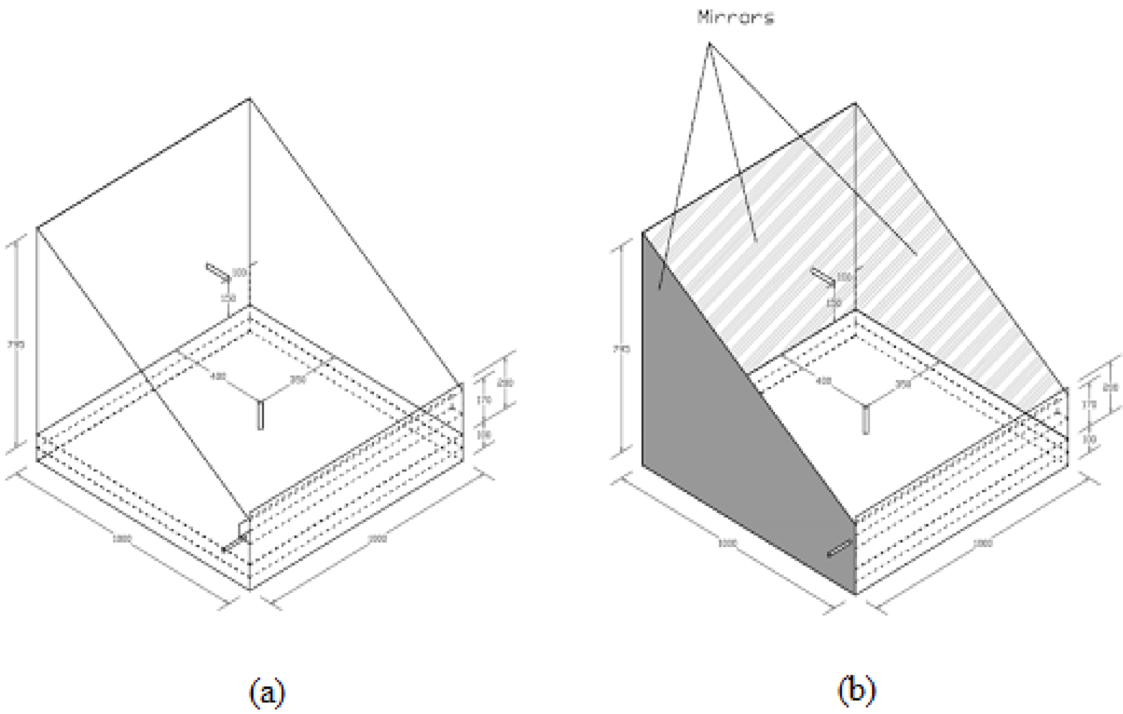

Fig. (1): Schematic diagram of the single-slope solar still with and without interior reflecting surfaces.

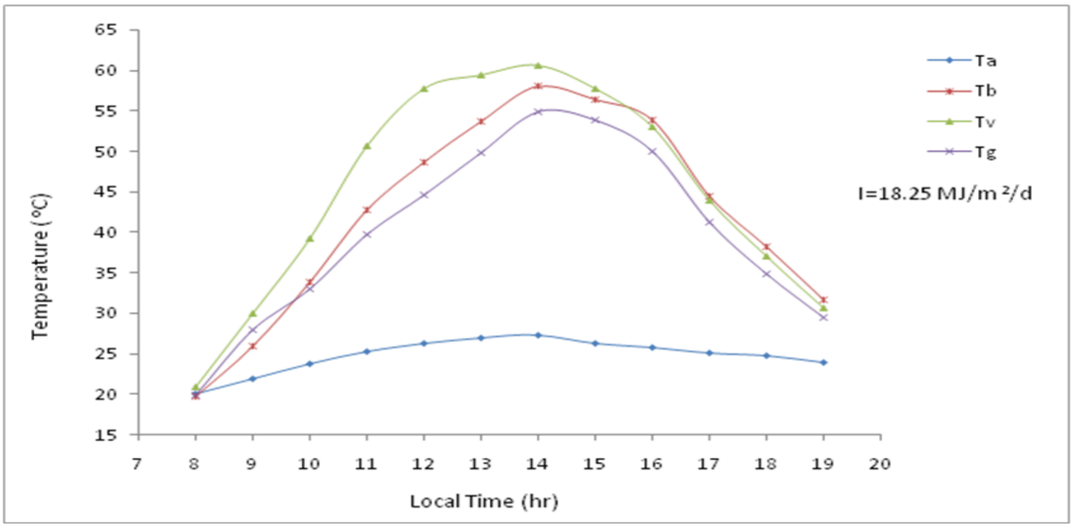

Fig. (2): Hourly variation of temperatures for the still without reflecting interior sides and brine depth of 1.5cm.

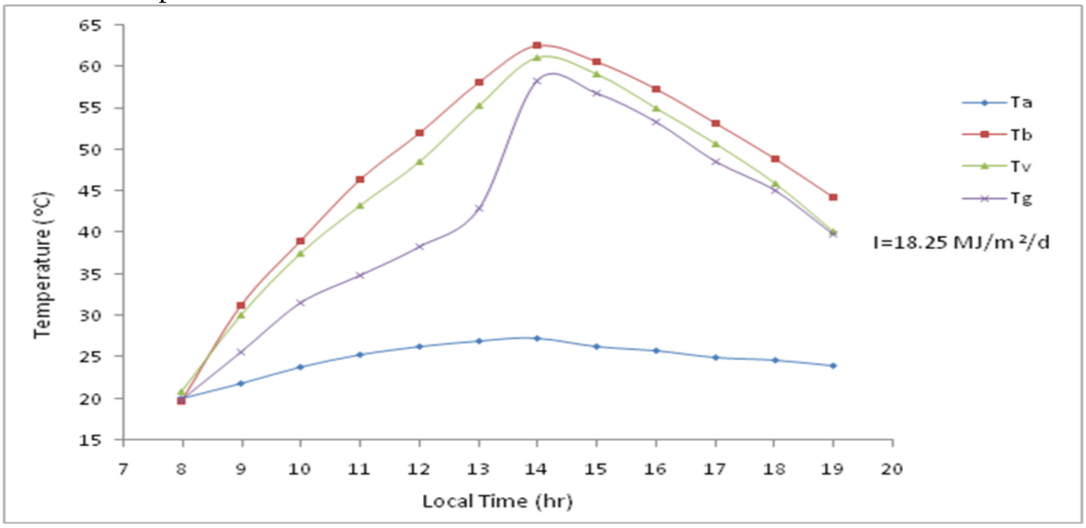

Fig. (3): Hourly variation of temperatures for the still with reflecting interior sides and brine depth of 1.5cm.

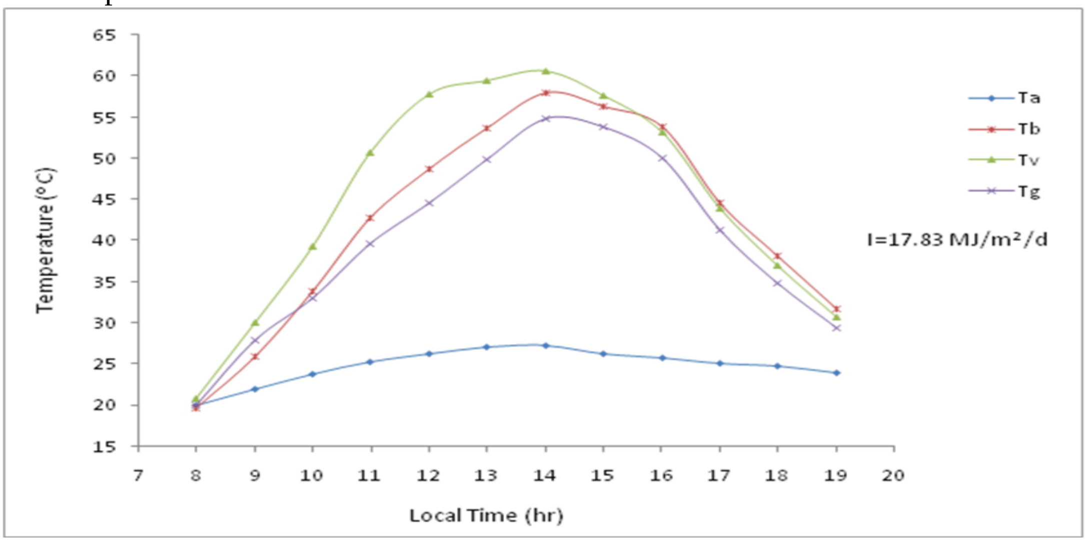

Fig. (4): Hourly variation of temperatures for the still without reflecting interior sides and brine depth of 3cm.

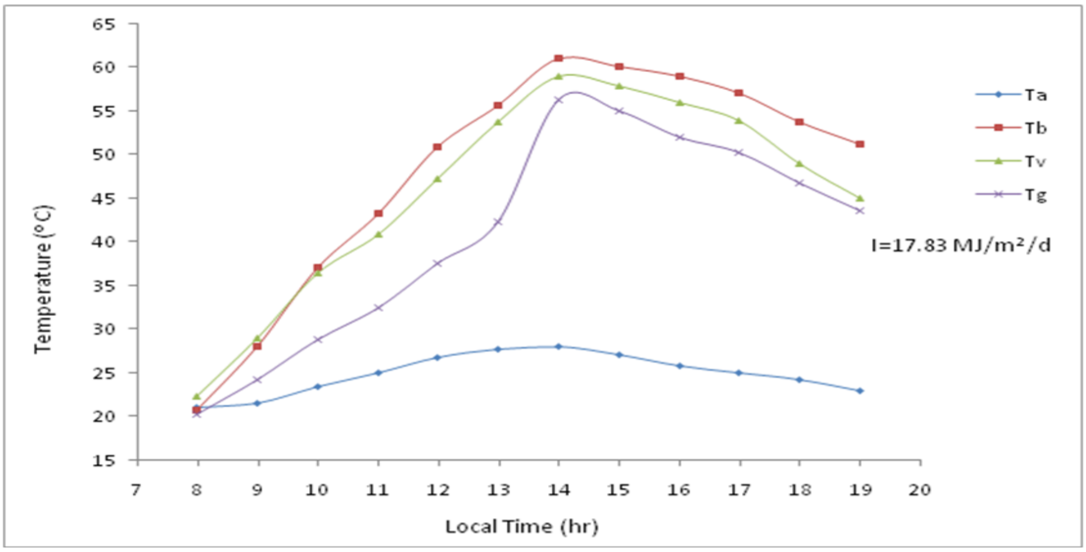

Fig. (5): Hourly variation of temperatures for the still with reflecting interior sides and brine depth of 3cm.

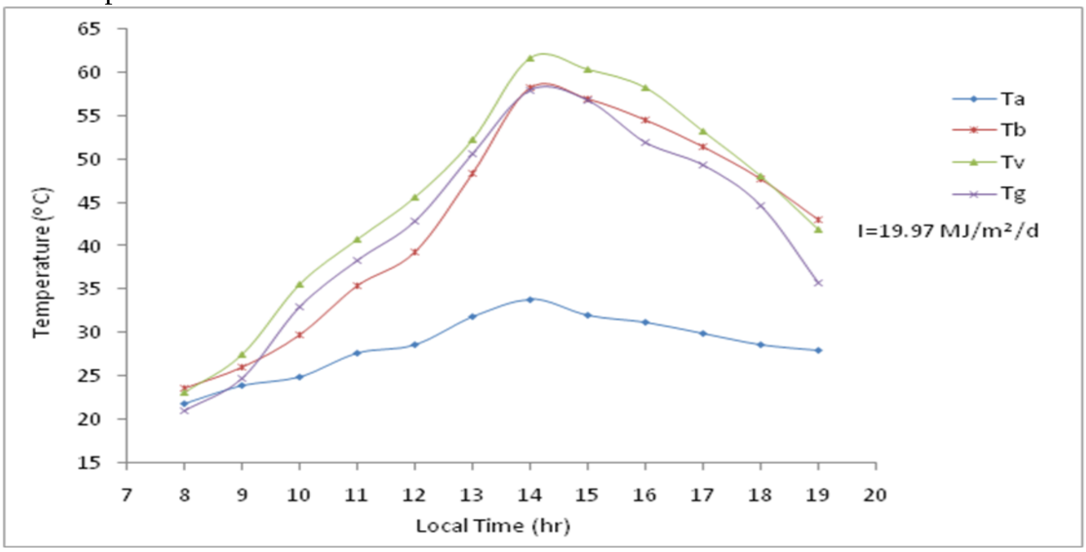

Fig. (6): Hourly variation of temperatures for the still without reflecting interior sides and brine depth of 5cm.

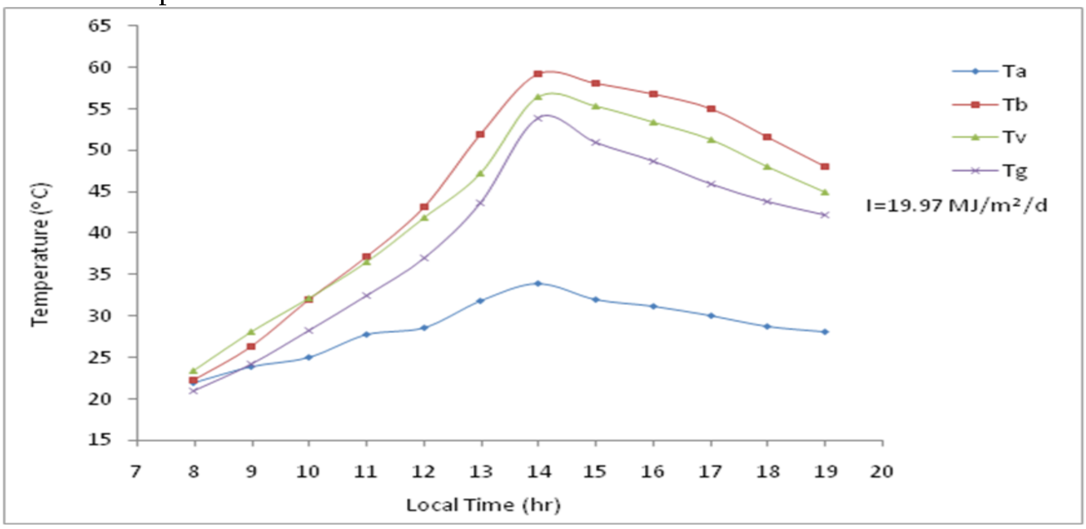

Fig. (7): Hourly variation of temperatures for the still with reflecting interior sides and brine depth of 5cm.

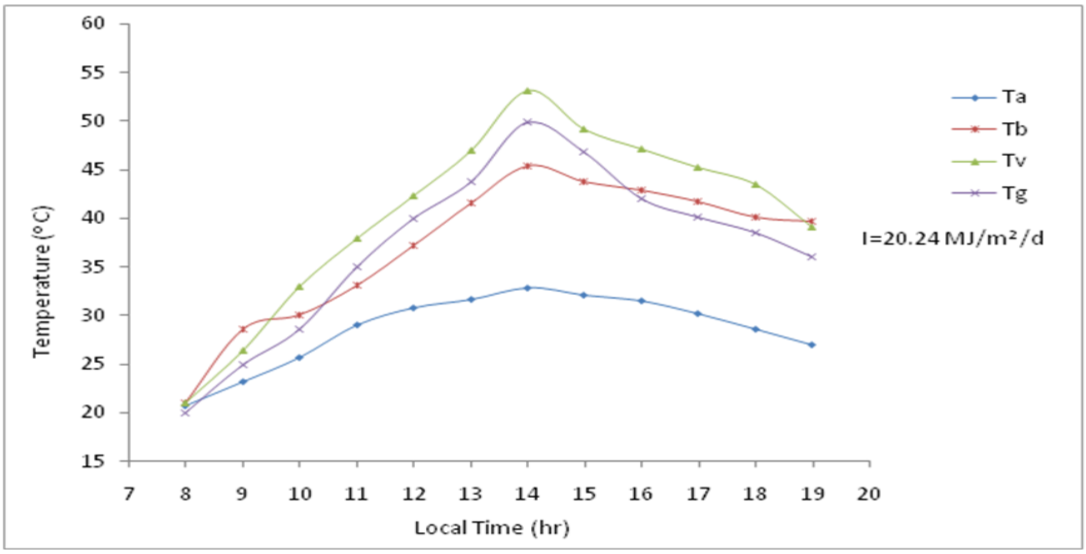

Fig. (8): Hourly variation of temperatures for the still without reflecting interior sides and brine depth of 8cm.

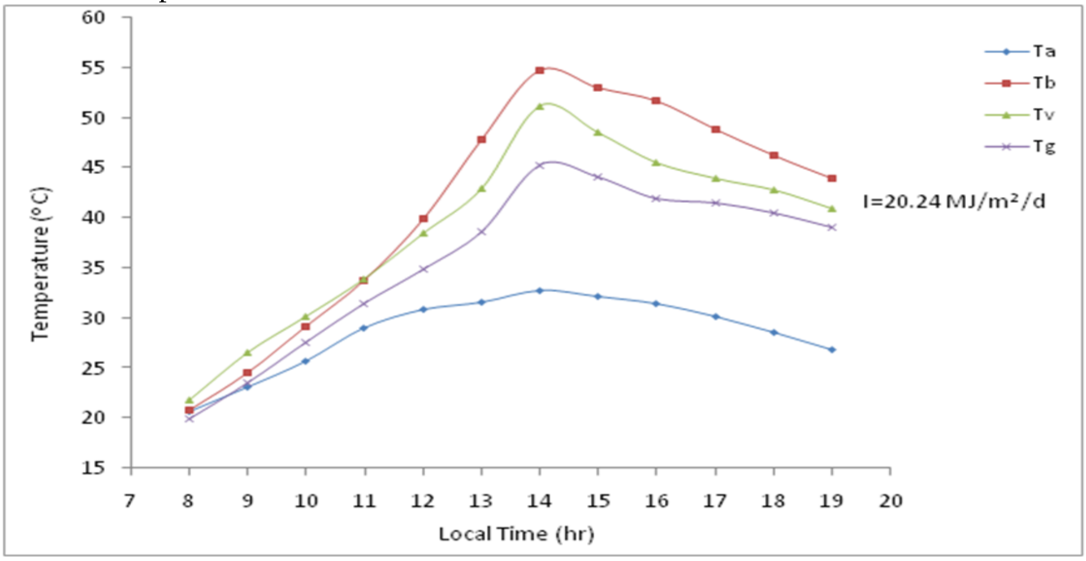

Fig. (9): Hourly variation of temperatures for the still with reflecting interior sides and brine depth of 8cm.

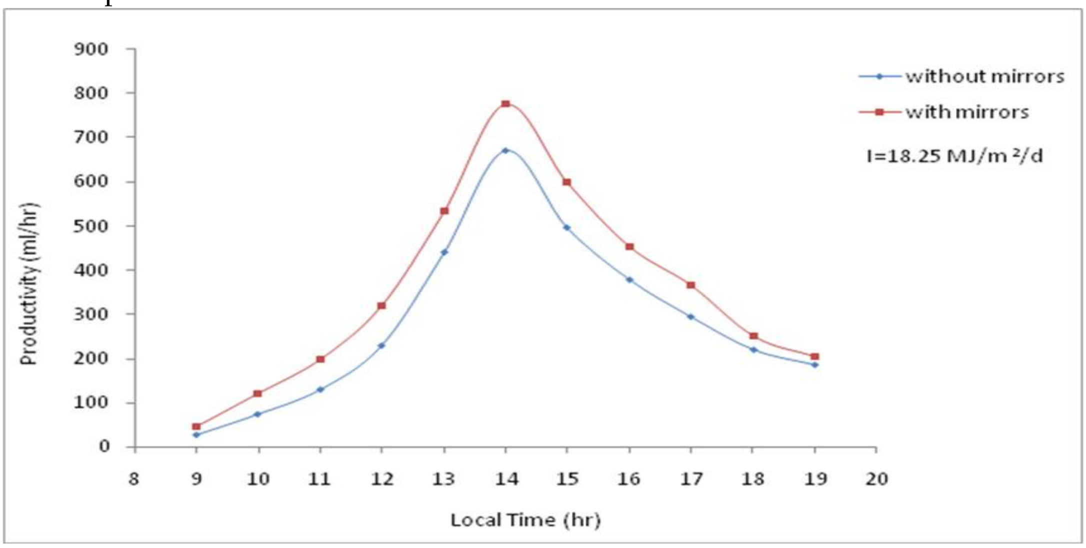

Fig. (10): Hourly variation of the still productivity for brine depth of 1.5cm.

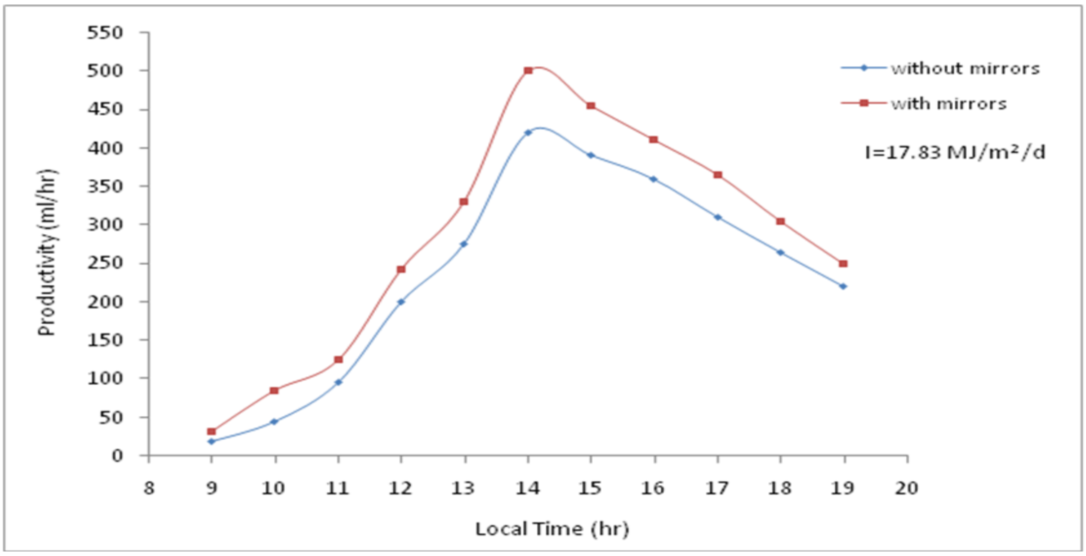

Fig. (11): Hourly variation of the still productivity for brine depth of 3cm.

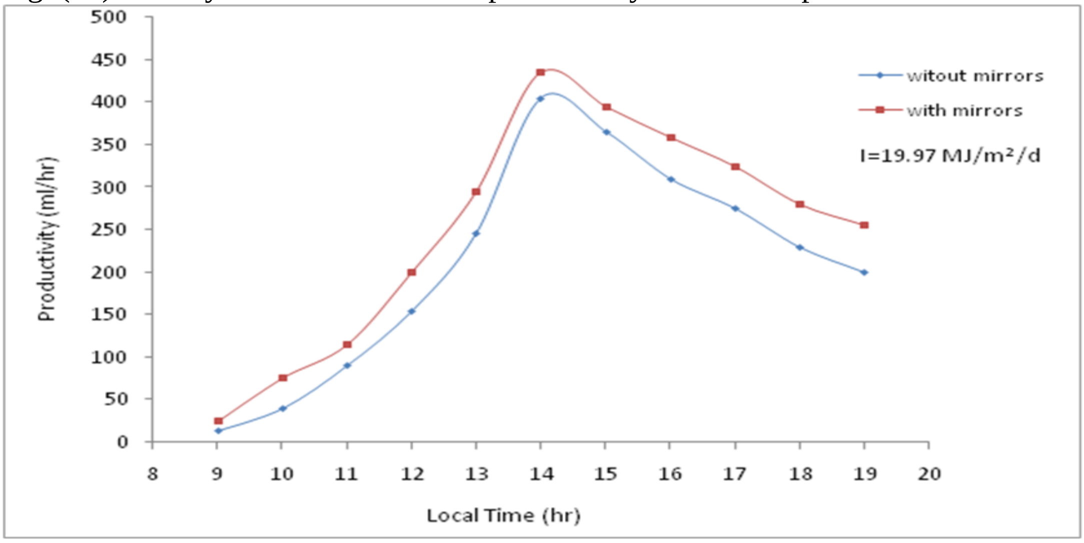

Fig. (12): Hourly variation of the still productivity for brine depth of 5cm.

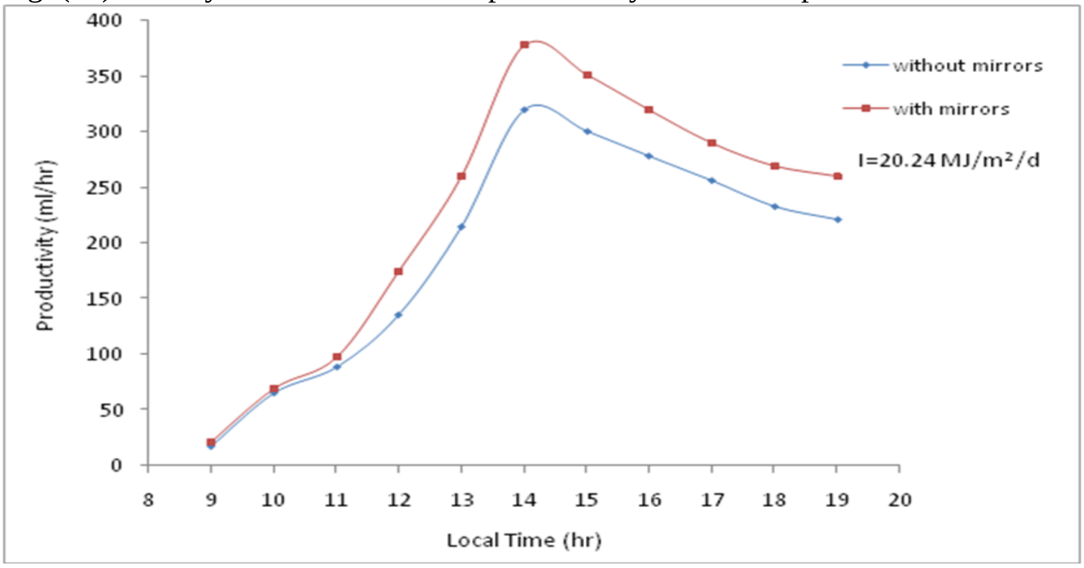

Fig. (13): Hourly variation of the still productivity for brine depth of 8cm.

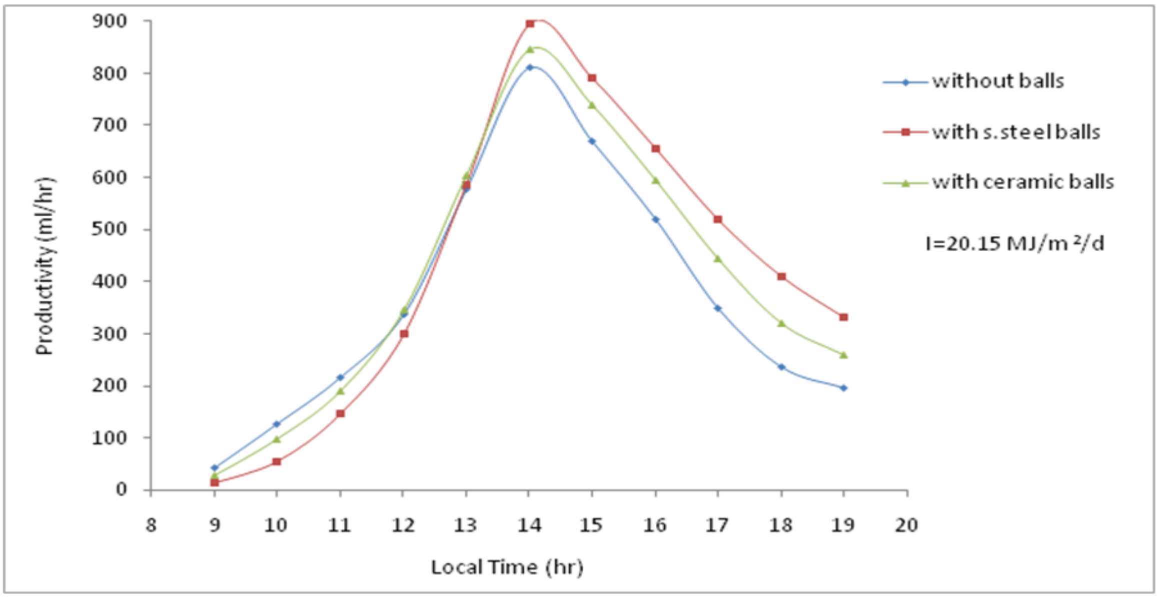

Fig. (14): Hourly variation of the still productivity with adding of balls for brine depth of 1.5cm.

4. Conclusion

An experimental study was carried out, for two single-slope solar stills with and without mirrors on its insides walls and adding blackened balls with deferent materials (stainless steel and ceramic), to enhance the solar still productivity under actual environmental conditions of Kufa city in Iraq.

It is clear from the present study that employment of mirrors on the interior walls of the still enhanced the water productivity more than the other without mirrors, because the presence of mirrors will improves the efficiency by reducing the radiation losses from the still basin. Also, the productivity of the stills improved with decrease of water depth and the addition of balls.

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