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An Experimental Study on Improving The Performance of A Double Slope Solar Still

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Abstract

Distilled water productivity of the conventional solar stilled is still very limited. This has called for more research to improve efficiency and increase productivity. The present work is an experimental study to improve the productivity of the conventional solar still. This done by three methods which work at the same time. They are: a) modifying conventional design to the proposed design to ensure increase in the condensation surface, b) by coupling of collector/storage solar water heater to solar still. It will heat the water before it is sent to the solar still, and c) using gravel as a suitable storage material to store heat energy to be used when sunlight is not available. For this purpose , two solar stills were made, one conventional designand another made according to the proposed design. The two solar stills were tested during the period from February to July 2014 under varying weather conditions of Baghdad, Iraq (latitude of 33.33 and longitude of 44.43). The results show that integrating the solar still with Internal reflective panels increases the distillate water by 18.5%. And using collector/storage solar water heater and gravel material improves the productivity by 48%.

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Keywords: Distilled water productivity; solar still; productivity; conventional solar still.

1. Introduction

It is commonly known that desalination by using solar energy is a practicable solution to produce potable water especially in remote areas which suffer from scarcity in potable water because the infrastructure is weak and the area is not connected to main water supply network. On the other hand, a small distillation system can be a

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practicable and economical solution for demand for potable water hoth at present and in the future provided enough water sources and sunlight are available in these remote regions. Thus in order to enhance the productivity of solar distillers of water, researchers all over the world have carried out work to define the factors which play a major role in solar distiller productivity and efficiency and to find means to improve their productivity. It is commonly known that desalination by using solar energy is a practicable solution to produce potable water especially in remote areas which suffer from scarcity in potable water because the infrastructure is weak and the area is not connected to main water supply network. On the other hand, a small distillation system can be a small practicable and economical solution for demand for potable water hoth at present and in the future provided enough water sources and sunlight are available in these remote regions. Thus in order to enhance the productivity of solar distillers of water, researchers all over the world have carried out work to define the factors which play a major role in solar distiller productivity and efficiency and to find means to improve their productivity.

(Safwat Nafey et al.,2002) studied the effect of using a bored plate floating on water in the distilling tank on productivity. He achieved 40% increase compared with the conventional solar still. (Badran et al., 2005) studied the effect of connecting a solar water heater operating by forced convection on the performance of a solar still. This method enhanced the performance by 36% . The researcher also investigated the effect of water depth in the basin on the performance of the still. The results show the productivity decreases with increase in water depth. (Velmurugan et al.,2008) studied experimentally the improvement in the productivity of solar still by coupled fins to the still base in order to increase the surface area open to solar radiation. It was found that the productivity increases by 45.5% compared with the conventional solar still. (Panchal et al., 2013) made an experiment with evacuated glass tube collector with solar still in climate conditions of Mehsana,Gujarat. They found 40% increase in distillate output of solar still. (Awad and Agouz studied, 2013) experimentally stepped solar still open loop continuous water flow using humidifi cation–dehumidification processes to improve the solar still performance. The results showed that by increasing the air flow rate, the solar still performance was increased. (Egelioglu et al., 2013) presented experimental results of four different configurations of inclined solar water desalination system with spray jets and open loop continuous water flow. The effect of the spray jets on the economic and thermal performance of the systems was investigated. The results showed that the jets variation, wick material, and solar radiation were the main factors that influence the desalination system performance. (El-Agouz, 2014) presented experimentally performance of stepped solar still with continuous water circulation using a storage tank for sea and salt water in order to enhance the productivity. It was found that the daily efficiency for modified stepped still was higher than that for conventional still approximately by 20%. (Somwansh and Tiwari, 2014) studied the improvement in the productivity of the conventional solar still by using cold air to cool the surface condenser. It was found that the productivity increases by (41.3%). (Gnanadason et al.,2012) reported that using nanofluids in a solar still can increase its productivity. They investigated the effects of adding carbon nanotubes (CNTs) to the water inside a single basin solar still. Their results revealed that adding nanofluids increases the efficiency by 50%. Nevertheless, they have not mentioned the amount of nanofluid added to the water inside the solar still. Regarding the addition of nanofluids to the solar still, the economic viability should be considered. (Rajaseenivasan and Murugavel, 2003) studied experimentally and theoretically the effect of adding extra basin to solar still with single-basin on productivity. the result shows modified solar still gives 85% higher than that of a single basin at same circumstances. (Al Mahdi, 1992) Performed an analysis to investigate the influence basins number of on performance of solar still. he showed that the the double-basin solar still increases productivity. (Al-Hinai et al.,2002) presented the parametric investigation of a double effect solar still and compared with a single-effect solar still. The shallow water basin with asphalt coating of the solar still were used in the study was produced an average annual solar still yield of 4.15 kg/m2/day and 6 kg/m^2/day for single and double effect solar stills, respectively. (Jurban et al., 2000) numerically investigated the multi stage evacuated solar still. The solar still consists of three insulated stages placed on top of each other. There was perfect sealing between the different stages such that the water vapour which evaporated during the boiling can pass only through the small orifice that connects two stages. The still can produce up to 9 kg/m^2/day with a distillation efficiency of 87%.

After reviewing previous literature, it is concluded that there is a variety of methods to improve the performance of solar stills and increase the productivity of distilled water. These methods highly concentrated on modifying the design. One of the points which received much attention is improving solar distiller performance without resorting to highly technology which may require additional energy. Therefore performance improvement requires using simplified designs so that they can be applied in remote areas. For this reason, the present research is a experimental study to improve the performance of conventional solar still by using simple design without resorting to highly advanced technology which may require additional energy such as fans or pumps etc. These means are as follows: i) the modified solar still has been designed in such a way that the distilled basin is larger than distillation basin, thus providing an increase in the condensation surface and speeding up the condensation process. Moreover, increase in the dimensions of the distilled base helps coupling reflective panels to the distilled base to reflect incident solar radiation to the distillation basin, ii) storage solar collector has been used. this collector is simple design and relatively low cost. It does not require most of the main parts found in conventional solar heaters. This design has been studied by many researchers and found very efficient under Baghdad weather conditions, and iii) Gravel in sizes varying from 40-70 mm is used as an energy storing material during daylight. The energy will be utilized when sunlight is not available

2. Experimental set up

In order to validate the results, two solar distillers were made and tested at the same time. The first one is a conventional double slope solar still and the second is the modified design. Fig (1) shows a diagram of the conventional solar still.

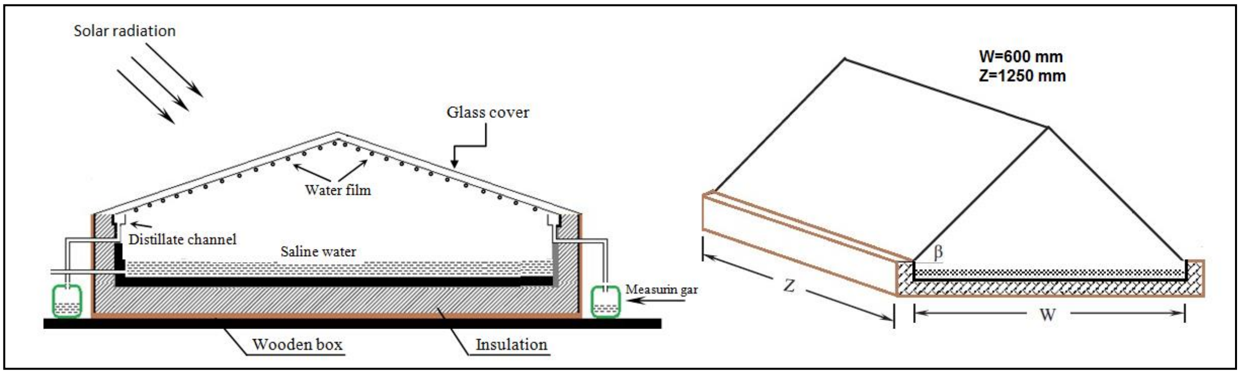

Fig.1. Schematic diagram of the experimental setup for conventional solar still.

It was made of galvanized steel with 1mm in thickness. The dimensions of the distillation basin are 1250 mm x 600 mm and water depth is 10 mm. To collect the solar energy, the surface of the stiller basin was coated with black paint obtained (from Iraqi Modern Paint Co). The paint has absorbency of 0.97 and emissivity of 0.98 [Wissam, 2008]. Ordinary 4mm thick glass panels were used to make the condensation surface. They were inclined by 20° [Radwa et al., 200915]. The glass panels were fixed tightly by using metal tape and a layer of rubber silicon to support the glass panels from the top. From the bottom, they were fixed close to still edge by using a layer of rubber silicon to prevent steam from going out. In order to keep water inside the distiller basin at a constant level and at the required depth, a sensitive float was used .It was specially made for the research. The distillation apparatus was insulated with 5mm glass wool from bottom and sides. The distillation apparatus was covered with 0.3 mm galvanized steel layer and put in 10 mm thick wooden box to keep the distiller and insulation material.. This box will act as an additional insulation material. A storage tank of 40 L was used to provide salty water. In the conventional still, the area of distilled basin is itself the base of the distiller. Therefore the condensation area cannot be increased because it is determined by the dimensions of the distiller base, as shown in **Figure 1**.

In this research, the solar still is designed in such a way that the distilled basin is separated from distiller base and at a height of 30 cm of distiller base. **Figure 2** shows a diagram of the modified solar still. This design achieves two advantages at the same time. The first is condensation surface area larger compared to the conventional solar still, thus providing enough surface area for heat exchange between the glass cover and atmospheric air. The second advantage is the possibility of linked sheets reflective to the distiller base and internal walls to reflect incident sunlight, thus providing additional heating to the distilled basin.

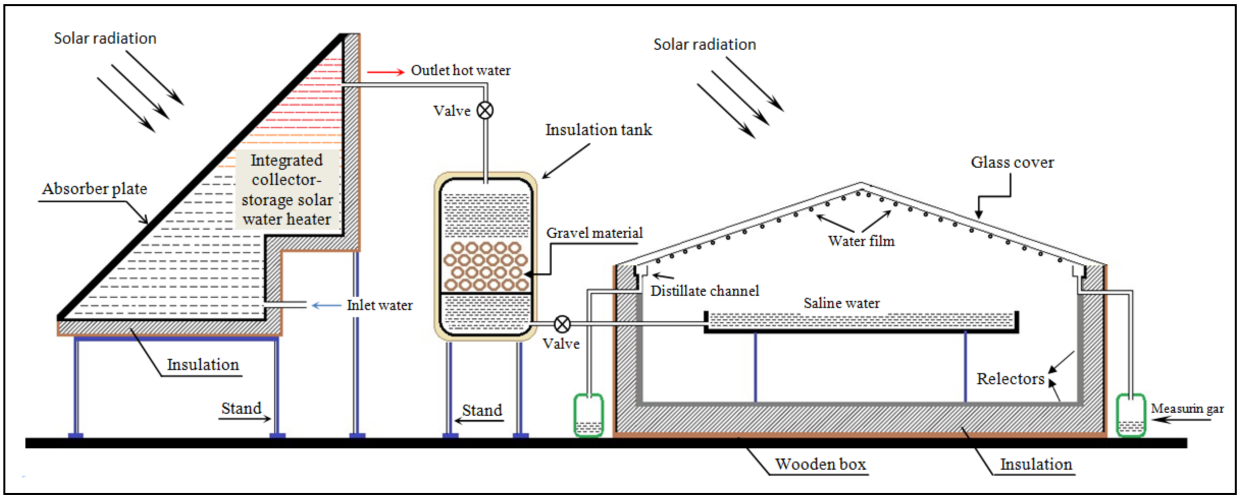

Fig.2. Schematic diagram of the experimental setup for the modified solar still.

The external dimensions of still were 1250 mm x 1100 mm x 400 mm. The surface area of the distilled basin and the depth of water layer were kept the same for conventional and modified solar stills.

The second part of the present study is to increase the productivity of modified solar still by coupling it to a storage solar water heater . This heater is characterized by the fact that it is easy to manufactured and it low cost compared to conventional solar water heaters (natural or forced circulation) that are used by most researchers to improve the distiller performance. This type of a storage solar water heater has been studied by many researcher (Joudi, et al., 2004, Sabah T., 2005, Wissam, 2008,) and has given good efficiency under the various Baghdad weather conditions. This solar system provides 70 liter of warm water at various temperatures The average water temperature ranges from 32°C to 36°C during winter time and from 49°C to 53°C during summer time.

The final part of the present study involves studying the effectiveness of the system used in this research in producing distilled water during the night (when sunlight is not available) by using gravel as heat storage material. An isolated small tank with volume of 0.045 m^3 was used. Part of the tank contains gravel of various sizes ranging from 40 mm-70 mm. It receives warm water from the solar collector and feeds it to the solar still. When warm water passes over the gravel, the gravel gets heated. It keeps the energy during the day. When sunlight is not available, there is a gradual drop in temperature of water coming from solar heater and the gravel provides the water going to distillation tank with the required heat energy so that water continues to be heated when sunlight is not available

To measure temperature inside the solar distillers, thermocouples (type t) was used. They were connected through a 20 point selector switch to a digital thermometer. The ambient temperature was measured with a mercury thermometer which was isolated from sunlight and weather effects. The quantity of collected water was measured by using 2 liter capacity container where the lowest gradation is 100 ml. **Table 1** shows accuracy of various measuring instruments used in the experimental work.

Table 1. Measuring davice with the accuracy and range.

No.	Instrument	Accuracy	Range
1	Copper Constantan Thermocouple	± 0.05 ºC	0 -100 ºC
2	Thermometer	± 2 ºC	0 - 100 ºC
3	Solarimeter	± 2 W/m^2	0-5000 W/m^2
4	Measuring Jar	± 5 ml	0 -1000 ml

3. Test procedure

The experiments are constructed and conducted at Training and Workshops Center, University of Technology, Baghdad, Iraq. The experiments were carried out on solar stills under different weather conditions of Baghdad. The experiments were carried out on both stills at the same time at the period from sunrise to sunset, during February 2014 to July 2014. The experiments were made in three parts: i) modified still by using interenal reflector, ii) modified still by using the collector/storage solar water heater, and iii) modified still by using the collector/storage solar water heater and gravel material.

During all the experiments, the following variables were recorded every hour: solar radiation intensity, average temperature of water in distillation tank, average temperature into distillation tank, average temperature of water coming from solar heater, temperature of glass cover and temperature of the ambient air

4. Results and Discussions

4.1 The effect of present design on the productivity of solar distiller

At first, the depth of water in the distiller basin was maintained at 1 cm. For the two distillers, conventional and modified, the experiments were made at the same time and weather conditions. From all the experiments, it was found that the modified solar still increases the temperature of water in the distiller basin. This is shown in **Figure 3**. The increase in the temperature of water in the basin leads to increase in evaporation rate thus cause increase in hourly productivity. **Figure 4** shows the productivity per hour of distilled water from both distillers under solar radiation intensity of 32 MJ/m^2 during testing hour from (8 am to 6 pm). The results show that integrating the solar still with internal reflectors panels increases the distillate water yield by about 18.5% (without night productivity). **Figure 5** shows the daily productivity with solar radiation intensity for various months of the year for conventional and modified solar still under the same weather conditions.

From the above results, it is found that the present modified design helps in raising water temperature because the internal panels reflect solar radiation, leading to enhancement in the rate of water vaporization. On the other hand, the present design provides enough surface area for condensation, thus increasing the rate of water condensation and productivity.

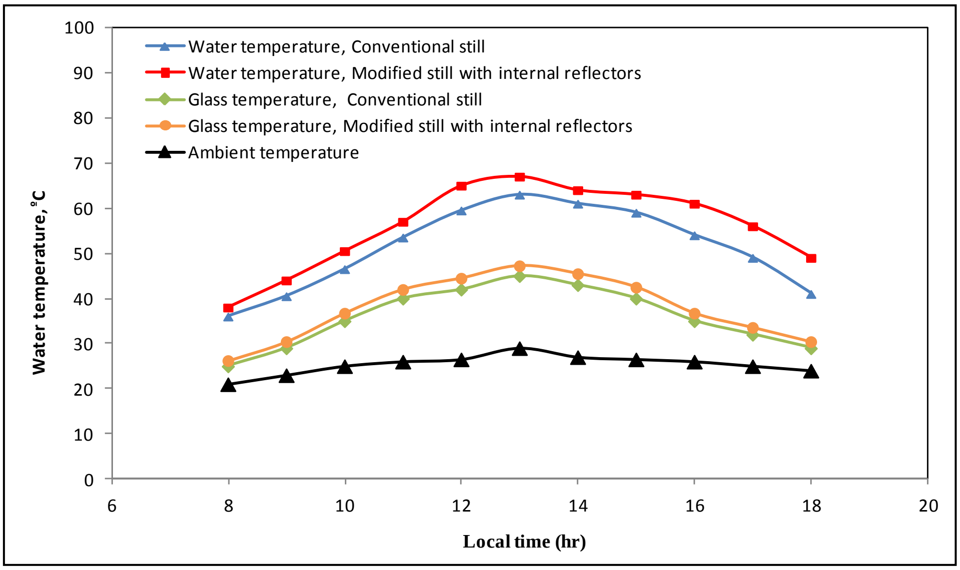

Fig. 3.The hourly temperature variation for the modified and conventional solar still.

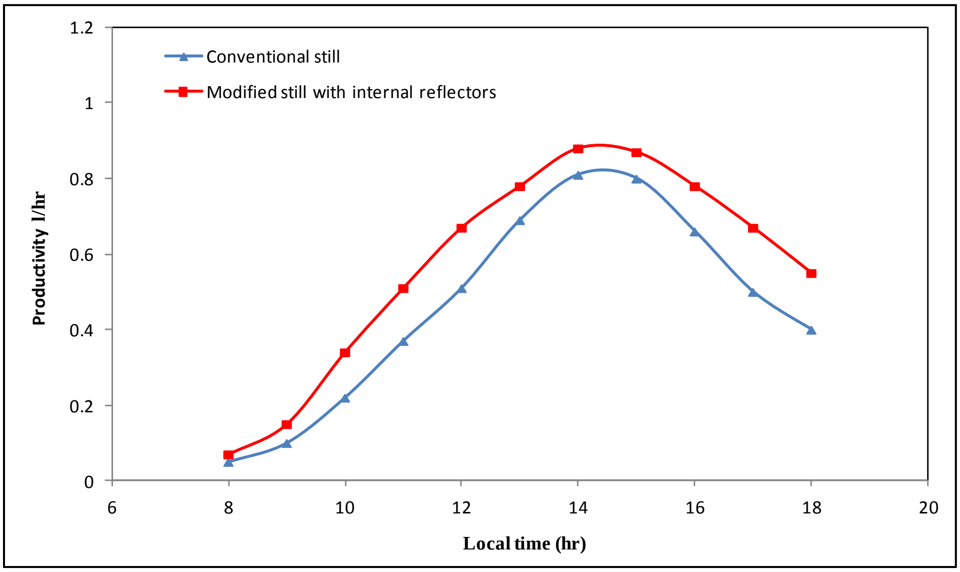

Fig.4. The variation of fresh water productivity for the modified and the conventional still.

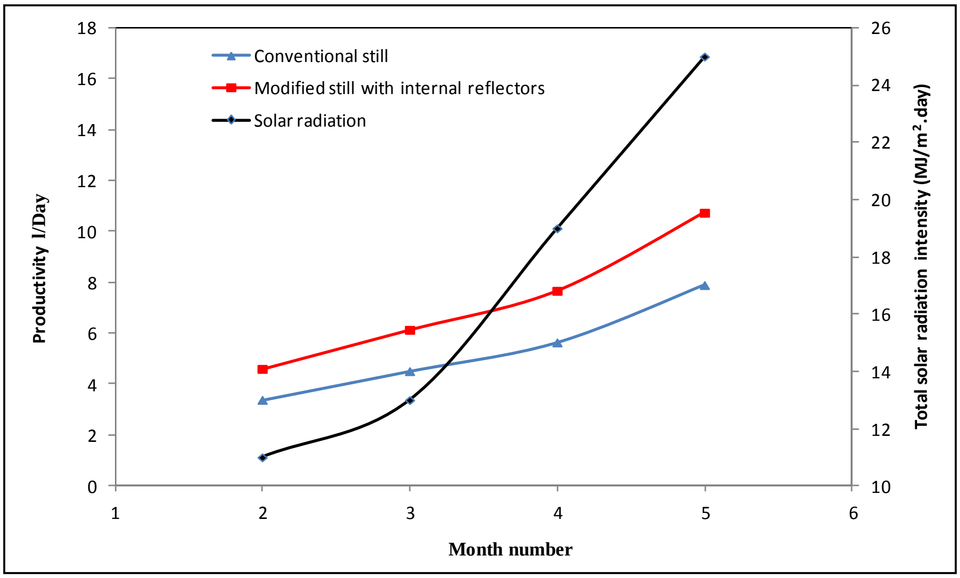

Fig.5. The monthly variation of fresh water productivity and solar radiationfor the modified and the conventional still.

4.2- The effect of the present design on solar distiller productivity

The effect of coupling the storage solar water heater to modified solar still is illustrated in **Figure 6**. It represents change in temperature of water in distiller basin with daytime hours. From **Figure 6** it is found that the temperature of conventional solar still is lower than that of solar still coupling to storage solar water heater. This leads to increase in productivity because the increase in temperature speeds up water evaporation in the distiller basin.

Figure 7 shows a comparison between the hourly accumulative variations of fresh water productivity from 9 am to sunset for the two tested stills. It is found that the amount of accumulated distillate for modified solar still is higher than that of conventional still at all time. The accumulated yield obtained is 34.5% more than the accumulated yield for still without storage solar water heater. The improvement in performance can be explained as follows: the conventional still needs longer time to heat the water while the solar collector heats the water first before it goes to the distiller, thus participating to a great extent in increasing productivity.

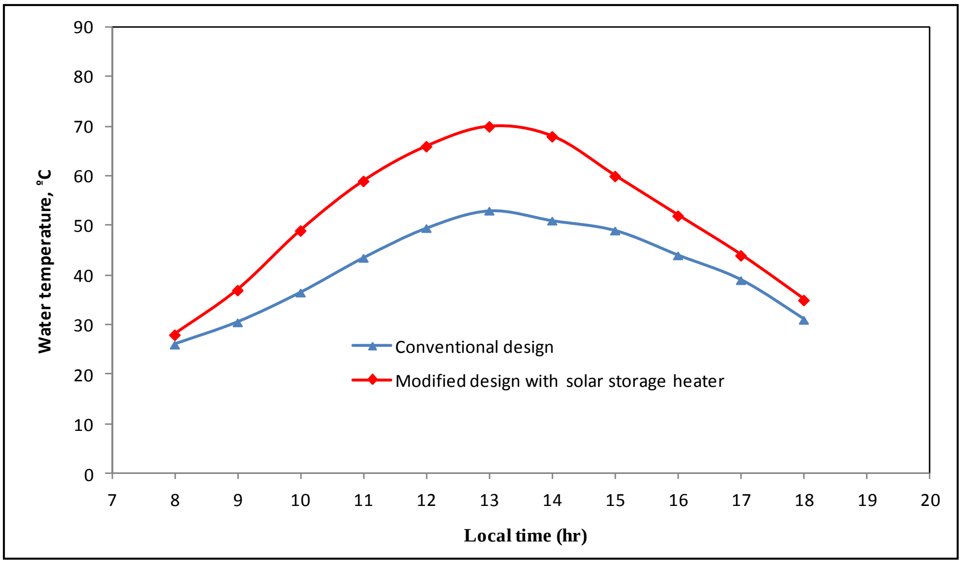

Fig. 6.The hourly temperature variation for the modified and conventional solar still.

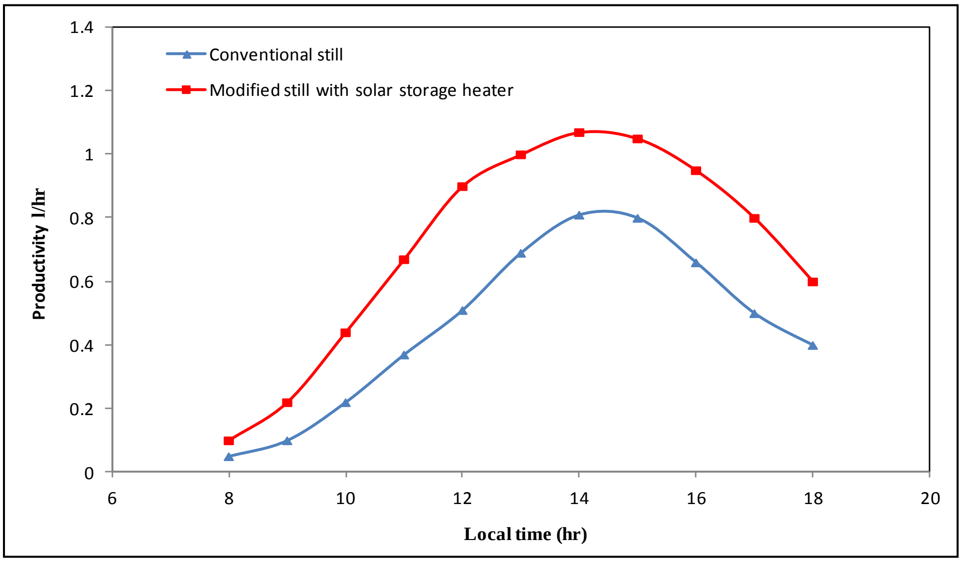

Fig.7. The variation of fresh water productivity for the modified and the conventional

4.3- The effect of adding gravel as heat storing material

The most serious problem facing the conventional solar stills is lack of productivity at night because solar radiation is not available at that time. Researchers have resorted to a variety of techniques to overcome this problem,using phase changing materials [Nafey et al., 2001, Naim and Mervat, 2003, Radwan et al, 2009). In this work, gravel has been used as heat storing material in day time. An insulated tank containing gravel was placed between the solar collector and solar still. The results show that the use of gravel has reduced the decline in productivity in the afternoon. **Figure 8** shows change in temperature with time when gravel was used in the solar collector and shows a comparison with the solar collector without gravel. It is found that when the solar collector is used with the solar still, the temperature rises in a noticeable way but it drops in the afternoon because it follows solar radiation intensity. On the other hand, when gravel is used as heat storing material, it helps to a great extent in preventing sharp drop in temperature of water of the distiller when solar radiation is not available. In addition, the distiller continues to produce distilled water for two hours after solar radiation disappearance. This is shown in **Figure 9** which shows daily production when gravel is used with solar collector and solar distiller. It is found that using the collector/storage solar water heater and gravel material improves the productivity by 48%. **Table 2** shows the comparison between conventional still and three modification data in terms of total daily water production for different days. The comparison of the performance of previous research works and present is depicted in **Table 3**.

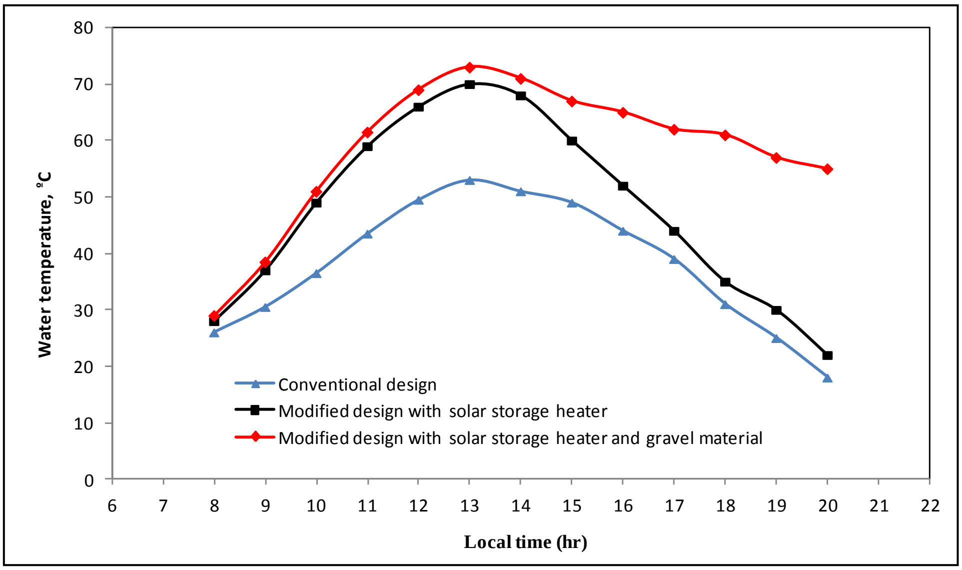

Fig. 8.The hourly temperature variation for the modified and conventional solar still.

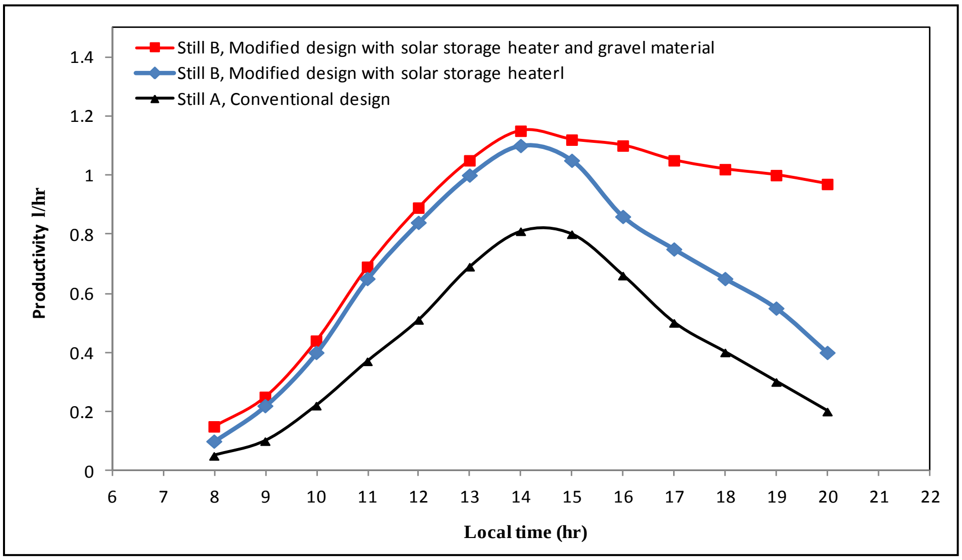

Fig. 9. The variation of fresh water productivity for the modified and the conventional still.

Table 2..Comparison of distillate yield in conventional and different modifications in solar still

No	Modification	Average Solar Radiation W/m^2	Productivity l/m^2/day
1	Conventional still	525	5.61
2	Modified design with internal reflectors	525	6.97
3	Modified still with solar storage heater	540	8.57
4	Modified still with solar storage heater and gravel material	570	10.88

Table 3. Percentage increase in distillate output for various active methods for solar still.

No.	Researcher	Improvement method	% increase In production
1	Nafey, A.S. et al., 2002 [1]	Floating perforated plate	40
2	Badran, et al., 2005 [2]	Solar still integrated with flat plate collector	36
3	Velmurugan et al., 2008 [3].	Solar still with fin	45.5
4	Panchal et al., 2011 [4]	Evacuated glass tube collector	40
5	El-Agouz SA, 2014 [7]	Stepped solar stil	20
6	Aneesh, S. and Anil K. T., 2014 [8]	Air cooler on the cover	41.3
7	In persent work	Solar still with solar storage heater and gravel material	48

5. Conclusion

In this paper, the effect of integrating the still base with internal reflectors and using solar storage water heater and gravel material on the performance of modified solar still was investigated experimentally under outdoors of Baghdad city (capital of Iraq) climatic conditions. Distiller productivity increased by internal reflectors. The maximum improvement reached was 48%. Experimental results showed that the average daily production was higher when solar storage water heater and gravel material were used in the still.

Acknowledgements

In this work, two solar stills system were designed, fabricated and constructed at Training and Workshops Center, University of Technology, Baghdad, Iraq.

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