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EXPERIMENTAL INVESTIGATION ON AN ELEVATED BASIN SOLAR STILL WITH INTEGRATED INTERNAL REFLECTORS AND INCLINED FINS

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Abstract

Many developing countries are increasingly involved in desalination of seawater. The usage of solar still for freshwater production in rural area is an ideal solution where there are no water and electrical supplies. Worldwide, there were many trials for increasing solar stills efficiencies. This study is an experimental work to assess the productivity of modified conventional solar stills. The modification includes redesigning and converting the conventional solar still to a solar still with an elevated basin where the internal reflectors and inclined fins were combination. In the modified design, the distillation basin has become higher than the still base by 30 cm and the condensation area increased by 82.4%. In addition, internal reflectors installed at the walls and base of the still in order to increase the solar radiation. Furthermore, inclined fins fixed with an angle of 45° to the distillation basin, which helps to increase heat transfer area and acting as heat absorbent surfaces. The performance of the modified solar still was evaluated and compared with that of the traditional solar still by considering the effect of elevated basin still only, elevated basin solar still with reflectors and elevated basin solar still with the combination of internal reflector and inclined finned absorber. Results indicate an increase in the productivity by 28% when the elevated basin type solar still was used, 43% increase when the elevated basin with internal reflectors type of solar still were used and 59% increase when the elevated basin with the combination of internal reflector and inclined finned absorber were used.

Keywords: Desalination, Enhancement productivity, Finned still, Inclined fins, Solar still.

1. Introduction

Solar energy was actively promoted in recent years as a viable source of energy. Solar still remain one of the easiest and most straightforward applications of solar energy [1]. Many developing countries show increasing interests in the sea water and brackish water desalinations by using solar distillation. This heat treatment is an effective solution to the worldwide scarcity of fresh water. The solar still can be effectively used to generate sufficient quantities of fresh water from salt water where a square meter of still area can produce approximately (0.5-2.5) litter per meter square of pure water [2]. This solution is ideal in rural area where there is no water and electrical supplies. Up to date, there were many trials undertaken to modify the configurations of solar still in order to increase freshwater productivity.

To improve the performance of solar stills, researchers had conducted intensive studies on the improvement of still productivity and efficiency [2]. The productivity of solar stills is affected by various factors including solar radiation intensity, wind speed, air temperature and the difference between water and glass temperatures. The glass temperatures and water temperatures are uncontrollable, this is because they depend on meteorological information of the geographical area [3]. By contrast, other factors, such as the design type, area of absorber plate, water temperature, glass inclination angle and water depth inside the distillation basin, can be controlled to increase the efficiency and performance of solar stills [3].

Many researchers had developed several solar desalination units over the years by studying the factors mentioned above. Moreover, they have used various solar collector designs for water heating before entering the solar stills to enhance the efficiency of a simple solar still. Badran et al. [4] and Dwiviedi and Tiwari [5] examined the effects of coupling a flat type of solar heater to single and double slope solar stills and they obtained an increase of 51% in the efficiency compared with the traditional solar stills. Rajaseenivasan et al. [6] studied solar still with a flat plate solar collector and obtained an increment of 60% in the yield of distilled water compared with traditional solar stills. In 2013, before it reaches the solar system, Panchal [7] used evacuated tubes to heat the water, which increased of 56% in the productivity compared with the conventional design.

To upgrade the production of traditional solar stills, several researchers have tested the coupling of external or internal reflectors in solar stills. Minasian et al. [8] experimentally examined a new shape of solar still, which integrated a curvy reflector that allows the concentration of solar radiation in the distillation basin. The findings showed that productivity improved by 25%-35% compared to simple solar stills.

Tanaka [9] performed an experimental test to determine the integration of inside and outside reflectors to the distillation basin in terms of improving productivity. An increase in productivity of 70%-100% was observe when the proposed new design was comparing with the traditional design of solar still. Tanaka and Nakatake [10] studied the influence of adding reflector with vertical design to increase solar radiation and enhance the productivity of a simple solar still. Their findings showed that the solar still performance was enhanced by 15%-27% when a vertical external reflector with the same dimension was increased.

Omara et al. [11] achieved an increase of 125% in the productivity of distilled water when inside and outside reflectors were utilized in the graded solar stills compared with the traditional still.

Another team of researchers tested the enhancement of the performance of solar distillates using various heat-conserving substances to store heat during daytime and then use it in the evening. In 2003, Naim and El Kawi [12] carried out an experimental evaluation of a single slope still that uses a PCM to store energy. The substance was dumped into the distillation basin, and a special mixture of emulsion consisting of paraffin wax, water and aluminium was used to enhance heat transfer. The output respectively improved by 26%, 47% and 300% when a combination of wax, oil and water were used.

Chaichan and Kazem [13] conducted experiments to enhance the productivity of a conventional solar system by using wax of paraffin as a PCM. Their findings showed that when paraffin wax was used, the solar distillery continued to operate for an additional three hour and output improved by 180 percent. The black rubber and black gravel were used as solar storage for simple solar shades by Nafey et al. [14]. Their experimental findings showed that black gravel and black rubber, respectively, increased productivity by 19% and 20%. El-Sebaii at el. [15] studied the improvement of the daily yield of a simple solar tube by coupling it to a saline solar pool at high temperature.

Several researchers studied how to enhance the thermal performance between water and the absorber plate by adding different nanomaterials. Koilraj et al. [16] tested the influence of using carbonic nanomaterials in a copper still basin and found that nanomaterials increase the daily yield by 50% compared with a traditional solar system. Panitapu et al. [17] studied the influence of including titanium oxide nanoparticles (Titania, TiO_2) to the distilled water in the distillation basin based on the temperature change of water, steam, and glass in the traditional solar still. They concluded that using nanoparticles increases production by 40%.

Kabeel et al. [18] experimentally examined the impact of including aluminium oxide (Al_2O_3) to increase water production of the conventional solar stills. The researchers observed that by adding Al_2O_3 the production increased by 76%. Gupta et al. [19] tested the influences of adding CuO nanoparticles to a single slope still system. Compared to conventional stills, they inferred that by utilizing CuO nanoparticles, the production of distilled water was increased by 22.4%. Many other studies were conducted on heat and nanofluids in buffaloed channels [20-22].

Akash et al. [23] studied the impact on the efficiency of a still with different absorbing materials experimentally. Ghoneyem [24] explored the impact of the distance between the waterline and the Condensing surface on the productivity of a simple solar still. He found that by reducing the gap from 13 cm to 8 cm, productivity improved by 11 percent. For the best daily productivity of multibasin solar stills, Al-Mahdi [25] has carried out an analytical study to determine the optimum basins number of solar still. The outcomes indicated that the solar distiller with double basins achieves the highest performance. Malaeb et al [26] updated a study concerning the influence of glass geometry on solar still system productivity.

Arunkumar et al. [27] experimentally researched the presentation of seven solar still designs (spherical, pyramid, hemispherical, double basin glass, concentrator, and tubular stills) and their outcomes indicated that the tubular still coupled with a pyramid solar still demonstrated the maximum productivity. Alawee [28] and Alawee at al. [29] conducted an experimental analysis to increase the productivity of a traditional still. They modified the traditional still by increasing the condensation surface and coupling the reflective panels. With same basin condition, the results indicated that the performance was improved by approximately 18%-48% over traditional still.

Velmurugan et al. [30] showed in his study that when fins were combined with basin, the solar still yield was increased by approximately 53% over traditional solar still. In another study, Velmurugan et al. [31] compared the yield of a solar still with ordinary basin with other solar stills of different basins. The first basin was contained wicks while the second and third basins contained sponge fins, respectively. The increase in the productivity were found to be 29.6%, 15.3% and 45.4% for solar tills with wick basin, sponge basin and fined basin, respectively.

Omara et al. [32] examined the productivity of the solar still integrated with the basin of water of the gilled and corrugated distilled base under Egyptian weather conditions. The results indicated that the outcome of this type of solar still was approximately 21%-40% over the conventional absorption plate. Ayuthaya et al. [33] analysed the thermal efficiency of a solar still integrated with a gilled absorption plate and found that yield was increase by approximately 15.5% over traditional solar still. Other researchers studied the thermal transfer in solar air channel with L-shaped, R-shaped, S-shaped, V-shaped, and different baffles and fins [34-49].

To increase the efficiency of a hot box type solar system of a traditional still, it was systematically compared with solar still with a cover of different inclination angles, solar still with inside and outside reflectors, solar system with various materials such as fins, sponge, wick, solar still modified by using nanofluid, and solar still with different designs. As mentioned above, many trials worldwide have undertaken to enhance the configurations of the conventional solar still in order to improve the efficiency. Nevertheless, more innovative ideas needed to improve the design of the traditional solar still such as a combined design with elevated basin, internal reflector, and inclined fins.

The objective of this study is to examine the productivity of fresh water by distillation when three different modifications are made on the traditional system (i.e., solar still with elevated basin, elevated basin with the combination of internal reflector and elevated basin with the combination of internal reflector and inclined fins) under the climatic conditions of Iraq. However, the modified design of the conventional solar still which includes elevated basin, internal reflector and inclined fins is the main novelty of the present study.

2. Experimental Setup and Procedure

The experiments of the present study were designed, installed, and tested at the training and workshop centre of the University of Technology, Baghdad, Iraq (latitude: 33° 18’ N, longitude: 44° 21’ E). Two solar stills were manufactured and examined under the weather conditions of Baghdad, Iraq. The first tested system was a conventional dual slope solar still, and the second was a modified type with three improvements.

The traditional solar still was made of 1 mm galvanised steel, whereas the distillation basin was 1250 mm long, 600 mm wide and 10 mm deep. The surface of the basin was black to absorb the bulk of incident solar radiation. Glass panels with an inclination of 30° and a thickness of 4 mm were used as condensation surfaces. To close the solar still tightly, the glass panels were fixed using a metal tape and two layers of rubber silicon. The solar still was insulated with 5 mm of glass wool from the bottom and sides and then covered with 0.3 mm galvanised steel layer and fixed in a 5 mm-thick wooden box. The source of salty water was a tank with a capacity of 40L.

Figure 1 shows a diagrammatic sketch of the traditional double slope still system. In a traditional still, the distillation basin has limited in size. Therefore, the condensation area is limited and restricted by the dimensions of still basin (Fig. 1**)**. In this analysis, the productivity of modified traditional solar was evaluated using experimental research. The traditional double-slope solar still was modified to an elevated basin double-slope solar still. In the elevated basin still, the distillation basin was higher than the still basin by 30 cm as shown in Fig. 2. This modification increased the condensation surface area by (84%) compared with that of the conventional design (see Appendix A).

The external dimensions of the elevated base solar still were 1250 mm long, 1100 mm wide and 400 mm depth. The distillation basin was separated from the still base at a height of 300 mm. For comparison, the areas of the distillation basin of the traditional solar still and for the elevated basin solar still were kept constant and equal to 0.75 m^2 in all experiments.

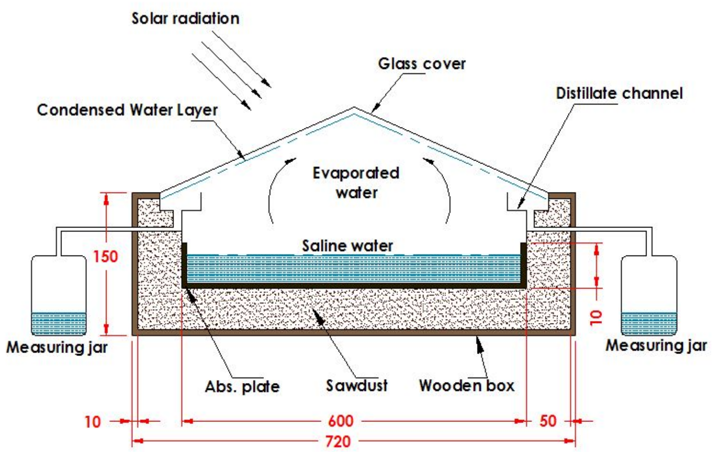

Fig. 1. Schematic diagram of a conventional solar still (all dimensions are in mm).

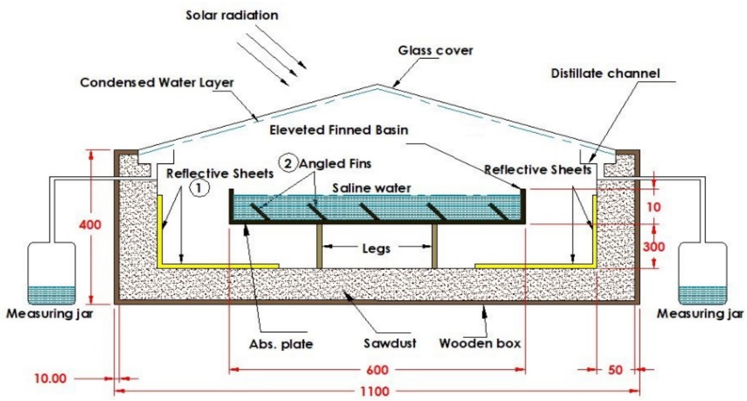

Fig. 2. Schematic diagram of the elevated basin solar still with the combination of internal reflector and inclined finned absorber (all dimensions are in mm).

The elevated basin still provides space between the still base and the distillation basin exposed to solar radiation but untapped. Therefore, internal reflectors were placed on the walls and base of the still to reflect the solar radiation to the distillation basin, thus accelerating the process of water heating in the distillation basin.

Furthermore, inclined fins were coupled with the distillation basin. Forty fins with an inclined angle of 45˚ were attached to the elevated basin. Inclined fins not only increase the surface area but also act as extra absorbent surfaces for solar radiation because they provide the best inclination angle in winter in Iraq [50]. Figure 2 shows a diagrammatic sketch of the modified still (elevated basin still) tested in the present study with two improvements, i.e., internal reflective and inclined fins. The fins were 14, 10 and 2 mm respectively in weight, width, and thickness. The distance between neighbouring fins, the dimensions and other details of the finned basin is shown in Fig. 3**.**

The water temperature inside the distillation region was measured with a copper-constant thermocouple. However, a mercury thermometer was used for calculating the air temperature. The quantity of collected water was measured using a 2 L-capacity measuring beaker.

The yield of the elevated basin still was verified and compared with the traditional still under three cases, i.e., elevated basin still only, elevated basin still with internal reflectors, and elevated basin still with internal reflectors and inclined finned absorber. During all the experiments, the hourly recorded variables were solar radiation intensity, average water temperature in the distillation basin, temperature of glass cover and ambient air temperature.

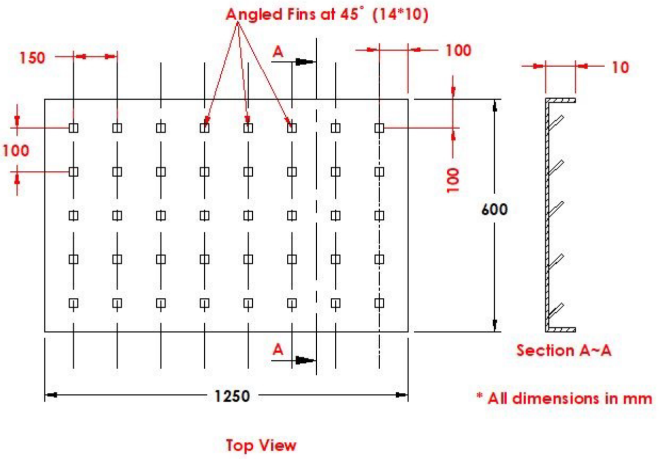

Fig. 3. Top view and sectional side view for the elevated finned basin.

3. Analysis of Experimental Error

Several parameters have been calculated to assess the solar stills performance. The temperature of the basin water was measured using a T-type thermocouple (copper constantan) (± 0.2 °C) that is linked to a digital thermometer. The solar radiation was measure by a solar meter (0-2500 W/m^2) with a precision of ± 2 W/m^2. Temperature of ambient was manually estimated with a mercury thermometer. A distillate output was measured using a 2000 mL-capacity beaker (with an accuracy of 3 mL). The total uncertainty in the experimental measurements was checked by the methodology proposed by Kline and McClintock [51] and found it to be within ± 8%. Table 1 shows the accuracies of these instruments.

Table 1. Measuring device with the accuracy and range.

No.	Instrument	Range	Accuracy	Error
1	**Thermocouples**	(0 -100) ˚C	± 0.2 ˚C	0.25%
2	**Thermometer**	(0 -100) ˚C	± 1 ˚C	0.5%
3	**Solar meter**	(0 -2500)W/m^2	± 2 W/m^2	2%
4	**Measuring beaker**	mL	± 3 mL	1%

4. Results and Discussion

The time allocated for each experiment was 10 hours (from 8:00 a.m. to 6:00 pm) and the tests were conducted 3 times per month from February-May 2018 and the experiments were done during sunny days of the year. The measurements were selected to cover the maximum and minimum solar radiation hours (the solar radiation ranges from 80 to 1000 W/m^2).

4.1. Variation of solar radiation, basin water temperature and air temperature

Figures 4, 5 and 6 depict the hourly variations of solar radiation, the basin water temperature and ambient temperature of the conventional and modified solar stills. The trend of temperatures for all solar stills found similar. The temperature rises during the daytime up to the maximum from 2 p.m. to 3 p.m. These results were found similar to that obtained by other researchers [10, 12, 17, 52, 53].

It was noticed that the lowest measured temperature in the water basin was observed in the traditional solar still while the higher temperature was found in the modified solar still in which a combination of internal reflector and inclined fins were used.

The increase in the water temperature can be attributed to improvement made to the thermal performance of the modified still system. The use of reflective panels increases the absorbed energy which made the distillation basin to heat up and this eventually increases the rate of evaporation. However, the fins reduced the water volume in the distillation basin and increased the thermal performance between base still and saline water.

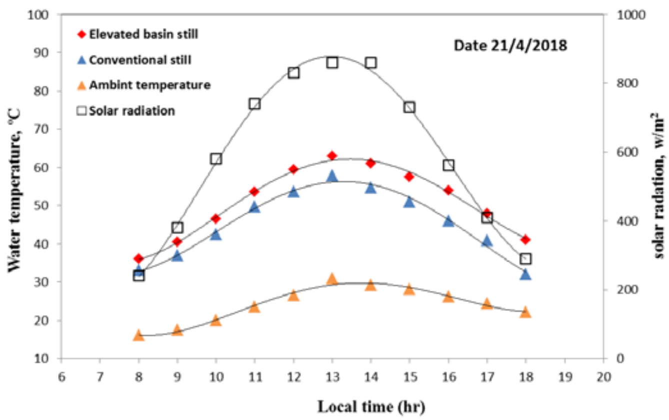

Fig. 4. Variation of various hourly temperatures for traditional solar still.

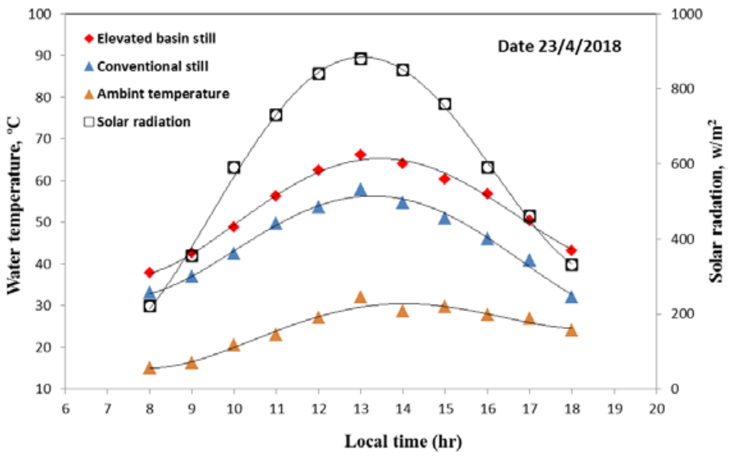

Fig. 5. Variation of different hourly temperatures for the elevated basin solar still with the internal reflector.

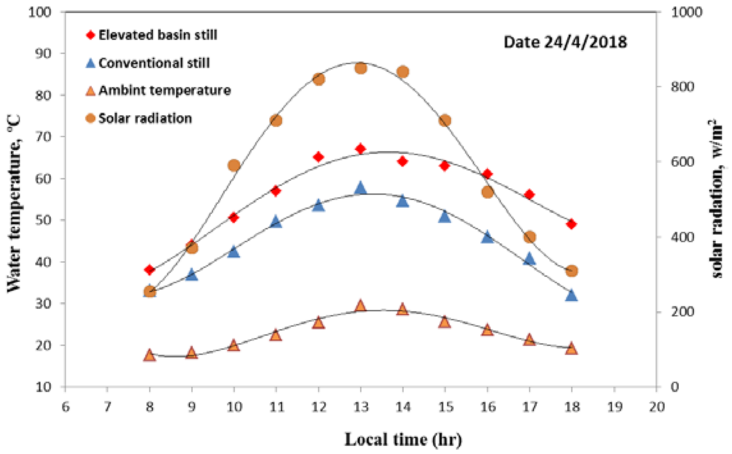

Fig. 6. Variation of various hourly temperatures for the elevated basin solar still with the combination of internal reflector and inclined finned absorber.

4.1.1. Elevated basin still only

Figure 7 shows the comparison between the productivity of the traditional and elevated basin solar stills. The average productivity of the conventional still was 2910 mL/m^2/day and that from the elevated basin solar still was 3732 mL/m^2/day on 21ST April 2018. The maximum hourly productivity per unit area found to be 0.449 kg/m^2 and 0.533 kg/m^2 for the conventional still and the still with elevated basin, respectively at 3 p.m.

These findings indicate that redesign of traditional solar still enhances hourly productivity. This is because the condensation area of the elevated basin solar still is greater than that in the traditional still. Hence, the rate of condensation was increased. In addition, the elevated basin decreases the walls and bottom heat loss due to space left between the water basin and the walls. This confirms that the modified design overcome the shortcomings of the conventional solar still.

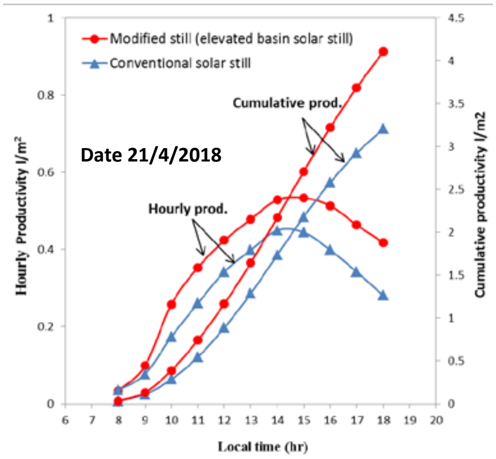

Fig. 7. Hourly and cumulative yields for the conventional and the elevated basin solar stills.

4.1.2. Elevated basin still with internal reflective plates

In this segment, the yield output of the elevated basin still with reflectors installed on the side walls was investigated. The results are shown in Fig 8. The average daily yield output per square meter from the conventional still was 2.97 kg and that from the elevated basin solar still was 4.26 kg and this were recorded on 23/04/2018. The maximum hourly productivity per unit area was reached on 3 pm on that date and found to be 0.458 kg/m^2 and 0.607 kg/m^2 for the conventional still and the elevated basin still with internal reflectors, respectively. The reflectors increase the productivity throughout the whole day. This can be attributed to centralizing the incident of reflected solar radiation on the basin. In addition, the reflectors still reduce the energy lost from the solar system. Thus, the water temperature in the presence of reflectors is much higher than that in the absence of the reflectors. The experimental works carded out by researchers [10-12] indicated that the reflector panels can additionally enhance the still productivity.

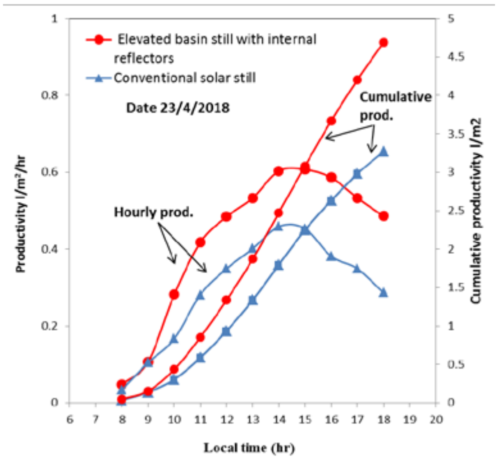

Fig. 8. The hourly and cumulative yields for the elevated basin still with the internal reflector and the conventional stills.

4.1.3. Elevated basin still with the combination internal reflective plates and inclined fins

Figure 9 shows the impact of integrated inclined fins in the elevated still with reflectors. The productivity from the traditional solar still was 3040 mL/m^2/day while the yield output obtained from the elevated basin solar still was 4851 mL/m^2/day on 24th April 2018.

However, the maximum hourly production per unit area was recorded on 3 pm and found to be 0.465 kg/m2 and 0.652 kg/m2 for the traditional solar still and solar still with elevated basin and internal reflective inclined fins, respectively.

As fins were used, absorber plate able to absorb more solar energy due to increase in surface area and this led to productivity increase. On the other hand, the angle of the inclined fins is helping to increase water heating by acquiring more solar radiation. The optimum angle of absorption of solar radiation during winter in Iraq is 45^o [50].

However, Arunkumar et al. [27] obtained daily distillate outputs per square meter of 2.4 kg and 2.6 kg for spherical design and concentrator coupled single slope solar still system, respectively. This shows that the distilled output from the last two solar stills less than the distilled output of the elevated basin still with the combination of internal reflective plates and inclined fins.

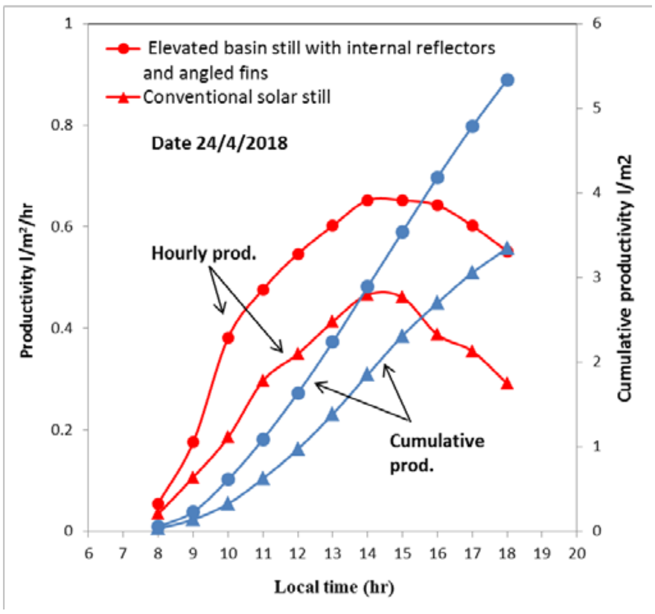

Fig. 9. Hourly and cumulative yields for the elevated basin solar still with the internal reflector, inclined finned absorber and the conventional stills.

4.2. Comparison of the productivity increase of conventional and modified stills

The percentage increase in daily distilled output can be written as:

$$Percentage\ of\ increase\ (\%) = \frac{P_m - P_c}{P_c} \quad (1)$$

where, P_m is the daily productivity of the modified stills and P_c is the daily productivity of the traditional still.

The percentage increase in the production of traditional and modified stills were compared and shown in Fig. 10. At the same basin condition, the distillate yield is enhanced by about 28%, 43%, and 59% for elevated basin still only, elevated basin still with internal reflectors and elevated basin still with internal reflectors and inclined finned absorber. The data of the yield for various designs were collected under the same weather conditions (clear weather) and for three consecutive days.

The results shown in Fig. 10 present the cumulative water production when different modifications in traditional solar still were made. It was noticed that the elevated basin considerably enhanced the water production and the maximum productivity was obtained when a combination of internal reflectors and inclined finned absorber were fixed in the elevated basin still. The maximum daily distillate yields per square meter were 5.30 kg and 3.20 kg for elevated basin system with internal reflectors and inclined finned absorber and conventional solar still respectively.

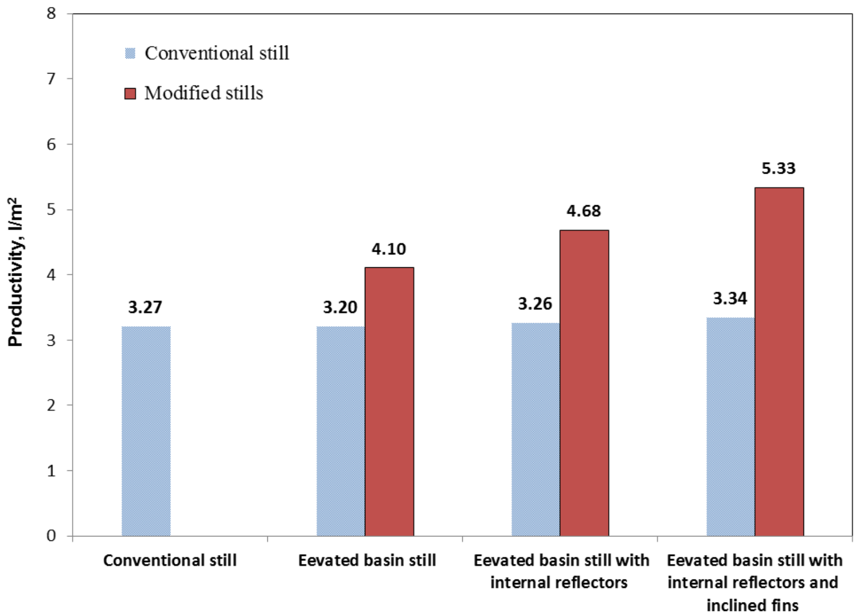

Fig. 10. Comparison of the accumulated productivity for various modifications.

4.3. Comparison of current work with previous studies

The comparison with the productivity of solar stills in other tests depicted in Table 2. In the current study, the increment in the yield of the still system with elevated basin, internal reflectors, and inclined fins ranged from 28-59%. This increase found within the increment in the productivities that reported by the researchers mentioned in Table 2. Other researchers such as Tanaka [9] and Omara et al. [11] and Naim and El Kawi [12] reported very high increase in the yield of their designed solar stills and this can be attribute to the difference in weather, material, and design.

Table 2. Comparison of previous research' results and current work.

No.	Author's name	Enhancing technique	Production growing
1	Dwivedi et al. [5]	Integrated with flat plate collector	60%
2	Tanaka and Nakatake [10]	adding a vertical external reflector	15%-27%
3	Tanaka [9]	adding an inside and outside reflector	70%-100%
4	Omara et al. [11]	inside and outside reflectors	125%
5	Naim and El Kawi. [12]	phase change material	26%-300%
6	Panchal [7]	coupling with curvy reflector	25%-35%
7	Chaichan et al. [13]	black rubber and black gravel	20%
8	Kabeel et al. [18]	CuO nanoparticles	22%
9	Malaeb et al. [26]	Still with fin	53%
10	Al-Mahdi [25]	Solar water heater to solar still and gravel material	18%-48%
11	Present work	Elevated basin, internal reflector, and inclined fins	28%-59%

5. Conclusions

The key findings from this study can be listed as

- Daytime yield is increased when the basin water temperature was increased. The maximum basin water temperatures and productivity were (57 ˚C, 3.2 kg/m^2), (63 ˚C, 4.1 kg/m^2) , (66 ˚C, 4.6 kg/m^2) and (67.6 ˚C, 5.3 kg/m^2) for conventional, elevated basin, elevated basin with internal reflectors, and elevated basin with internal reflector and inclined finned absorber, respectively.
- For the elevated basin still only, the productivity was enhanced by 28% compared with the traditional solar still.
- For elevated basin still with internal reflectors, the distillate output was improved by around 43% compared with the traditional solar still. However, it is increased by around 12% compared with elevated basin still without internal reflectors.
- For elevated basin solar still with the combination of internal reflectors and inclined finned absorber, the distillate output was increased by around 59% compared with the traditional still while it was improved by 15% compared with elevated basin still without inclined finned absorber.
- Inclined fins not only increase the surface area but also act as extra absorbent surfaces for solar radiation. The fin inclination angle, position and geometry were carefully selected to give the best thermal performance. For future work, it is recommended to investigate the impact of number of fins and its configuration on the still productivity.

Nomenclatures

A_C	Area of condensation surface the conventional still, m^2
A_M	Area of condensation surface the modified solar still, m^2
L	Still length, m
P_c	Output of the conventional still, kg/m^2.day
P_m	Output of the modified stills, kg/m^2.day
W_C	Width of the conventional still, m
W_M	Width of the modified still, m

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Appendix A

Following formula of a triangle used to calculate the increase in the condensation area:

$$A_C = \left(\frac{W_C}{cos30}\right) * L = 2 * \frac{0.30}{0.866} * 1.25 = 0.866\ m^2$$

$$A_m = \left(\frac{w_M}{cos30}\right) * L = 2 * \frac{0.55}{0.866} * 1.25 = 1.58\ m^2$$

$$Percentage\ of\ increase\% = \frac{A_m - A_c}{A_c}$$

$$Percentage\ of\ increase\ of\ condastion\ area\ \% = \frac{1.58-0.866}{0.866} * 100 = 82.4\%$$

where A_c and A_m are the condensation surface areas of the basins used in the conventional solar still and the elevated basin solar still respectively.