# Experimental Study to Enhance the Productivity of the Active Solar Still Using U-Copper Tube in Evacuated Tubes with Reflectors

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## Abstract

In the present work, experimental study is done to explain the effect of coupling U-copper tube in evacuated tubes solar collector with reflectors, medium in evacuated tubes and weather conditions on the system productivity. Single slope-linear basin solar still have been used to do this purpose. Brackish water is pumped through evacuated tubes to absorb energy and return to the still, also three medium type in evacuated tubes have been used. The tests are done from May to August/2017 in Mosul City-Iraq (Latitude: $35.866°N$, Longitude: $43.296°E$, Elevation: 200 m, and 23° South-East face). Results showed that the maximum and minimum productivity of the simple and active solar still were ( 2.505, 8.437) and (2.105, 6.225) $kg/m^2$.day respectively. Increase the pump flow rate from (1 to 3) liter/min. enhance the yield output by about 30%, the using of air, water and oil mediums in glass evacuated tube produce 6.690, 7.762 and 7.832 $kg/m^2$.day respectively. The maximum efficiency of the simple and active still are 30.2% and 60.3%. The maximum rate of increase in the water production were 144.5%, 166.3% and 178.33% in case of using air, water and oil in evacuated tubes at 2cm water level and pump flow rate 3 liter/min. The increase of water level in the solar still from 3 to 4cm decrease the productivity by 39%. also it has been conclude that the increase of pump flow rate increase the collector efficiency.

**Keywords: solar still, solar collector, evacuated tubes and productivity.**

## 1. Introduction

Solar desalination is the process of utilizes solar radiation to produce fresh water **[4]**. Its consider simple and inexpensive method to transform brackish water into fresh water. There are two method used in the desalination process using solar radiation: passive desalination it's a direct method using solar radiation directly to heat up the water, and this method used to produce small amount of fresh water, on the other hand active desalination it’s a indirect method, using pumps and modification equipment's with respect to solar radiation, and this method used to produce large quantities **[8].** Many researchers studied the behavior of solar still at various conditions**[1].** present experimental study to show the influence of adding some absorbing materials to the solar still to enhance system yield **[12].** study the effect of integrated solar still with solar pond **[6].** compare the solar still performance with and without coupling flat plate collector (flat pate collector) **[11].** Rise the solar still productivity by coupled solar heater to still unit, evacuated tube collector are used to do this purpose at different intervals **[3].** studied the effect of coupling photovoltaic/ thermal solar water heater on still yield **[2].** improve still efficiency using heat pump system integrated with solar still **[5].** investigate experimentally the enhancement of the desalination in solar still by coupling evacuated tubes directly to the still and by adding float porous absorber inside basin also water high in the solar still was studied **[9]**. enhanced the solar still productivity utilized the solar heater as well as evacuated tubes **[7].** studied the possibility of increase the productivity of the system by blowing air over glass cover using Fan.

## 2.Theoretical Design of Solar Still

If the daily consumption for one person of drinking water are (2-3) Liter/day/one, so it has been required to design solar still produce this quantity of fresh water. The procedure of design as follow **[10].**

$$Q_{req} = Q_{inc}\, A_b \qquad (1)$$

$$Q_{req} = m_d\, h_{fg} \qquad (2)$$

$$Q_{req} = 3 * 2257 = 5642 \ \ kJ/day$$

$$Q_{inc} = 3600\, hr\, G_{inc} \qquad (3)$$

$$Q_{inc} = 3600 * 8 * \frac{600}{1000} = 17280 \ \ kJ/m^2.day$$

$$A_b = \frac{Q_{req}}{Q_{inc}} \qquad (4)$$

$$A_b = \frac{5642}{17280} = 0.326 \cong 0.4\, m^2$$

## 3. Experimental Work Of Solar Still Design

The solar still system was designed and constructed to verify the acceptable operational requirements. All the component were designed and selected according to either researches or studies and as on-hand in the markets, to get the optimum design to each component, to ensure that the system operation in best conditions with maximum productivity.

### 3.1 Still Basin

This part of the system used as storage to store the saline water. It must be sealed and coating with black color as possible, in order to absorb the solar incident radiation, also it must be strong, smooth, cleanable and upload. as possible. The present part constructed with the material of Galvanized Iron of (1.1mm) thickness in order to be strength, no toxic, and non-corrosive and light weight. The dimension of the basin was (80cm x 50cm) and this dimensions have been selected according to specific design. The coating were dark black in base and brilliant weight color on the another sides of the still to absorb and reflect sunshine light. These procedures according to recent studies in order to increase the saline water temperature and maximize the useful solar incident radiation absorbed in the system.

### 3.2 Glass Cover

In order to allow to the incident solar irradiation to passes through, Glass cover have been used in the present work due to its advantages such as high transparency, rigid, easy fabricated, and inexpensive. Glass cover of thickness (4mm) are used due to its advantages over another high dimension, and its tilted at 35.866° (Zone latitude). Glass cover consider one of the most important parts because of its relation to energy source and condensation process.

### 3.3 Condensate Accumulator

Its small passage used to collect and transfer the condensed water, its designed to be integrated with still body of the same material GI sheet of 1.1 mm thickness, with ignore area. In present work the trough design as triangular section of (3x3x50)cm. It must be small to prevent shading, on the other hand must be enough to collect and transfer the desalinated water.

### 3.4 Insulation

In order to prevent heat loss from the still body to the environment, thermal insulation have been used, because of the heat loss decrease the still performance and minimizes the productivity. In the present work Cork Board insulation of 60 mm thickness, and 0.043 (w/m.k) thermal conductivity have been used and fabricated around the stills, the choice of insulation type are necessary to improve thermal performance and must be have low thermal conductivity, light weight, available, inexpensive and easy fabricated.

### 3.5 Seal

It's a metal that used to prevent any leakage to or from the still, also it used to connect any two part or more as one structure. in our study this metal are used to prevent water vapor leakage from the stills inside space to the atmosphere, and water or dusty particles leakage also. It has been used Silicon rubber to fill the gaps between glass cover and still body, this type have been used because of low coast, inexpensive, easy to use, easy to remove without side effects when we need and controllable, two type have been used. Also window putty have been used to prevent leakage and this metal become hard after used. Also Foam have been used to close the evacuated tube upper end.

### 3.6 Piping, Fitting and Flexible Joint

Cupper pipe with (8mm in diameter, 0.7mm thickness and 18m length) have been used with all fitting and accessories, also rubber flexible joint are used in the system.

### 3.7 Evacuated Tubes

Used to collect solar energy and convert this solar energy to heat. Five all-glass evacuated tubes have been used with (180 cm length, inner and outer diameter 47 mm and 58 mm respectively)

### 3.8 Circulation Pump

Electric pump have been used to circulate the hot water between the still and Evacuated tubes through the U-shaped cupper tube, with three flow rate quantities (1, 2, 3) Liter/min.

### 3.9 Reflectors

In order to increase the rate of heat radiation incident on the collector parts (evacuated tubes), reflectors are used to increase efficiency reflect quantity of solar irradiation pass below the evacuated tubes. parabolic reflectors (0.4mm thickness, Anodized aluminum) used.

## 4. Desalinated Water

The productivity of the systems are measured hourly using digital balance.

## 5. Instruments Used

### 5.1 Solar Meter

( TES - 1333R Lutron Company-Taiwan), **Fig.1**.

### 5.2 Ambient Conditions

Portable Meter (LM-8000A, Lutron Company-Taiwan), **Fig.1**.

### 5.3 Data Logger

Data Logger, with 8 point of thermocouples type-K, (BTM-4208SD,Lutron Company - Taiwan), **Fig.1**.

### 5.4 Digital Balance Meter

Traditional type Digital balance meter **Fig.1**.

**Table. 1 Design data**

| Name | Description |
|---|---|
| Solar still | SingleSlop(50x80)cm |
| Basin type | Single |
| Basin Area | 0.4 $m^2$ |
| Length of still | 0.8 cm |
| Width of still | 0.4 cm |
| Still material | Galvanized, 1mm |
| Still Orientation | South face |
| Glass Area | 0.485 $m^2$ |
| Glazing material | Glass |
| Glass Thickness | 4 mm |
| glass Inclination | 36$^o$ |
| Trough | Triangular(50x3x3)cm |
| Insulation | Cork board (6 cm, 0.043 *w/m.$^o$C*) |
| Evacuated Tubes | Length 180cm, I.D & O.D: (4.7, 5.8) cm |
| Reflector | 0.9 mm Aluminum |
| Copper Tube | 18m Length, 0.8mm Diameter and 0.9mm thickness, 380 W/m.K Thermal Conductivity |
| Pump | Electric pump,3-Channel ,3-Flowrate quantity |

**Fig.1 Measurements used.**

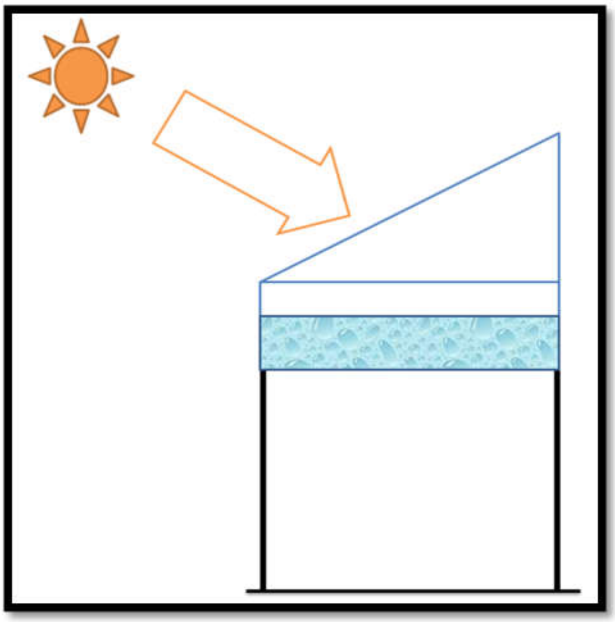


**Fig.2 Schematic of simple solar still.**

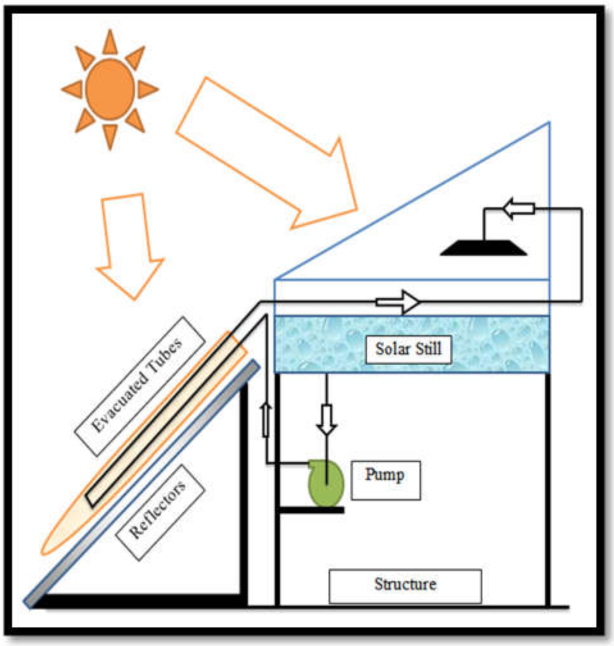



**Fig.3 Schematic of active solar still.**

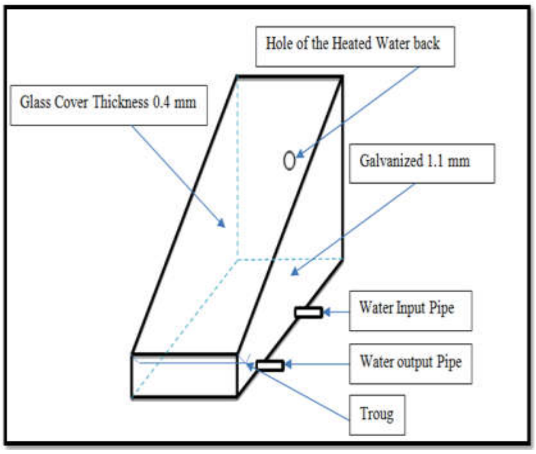



**Fig.4 Solar still details.**

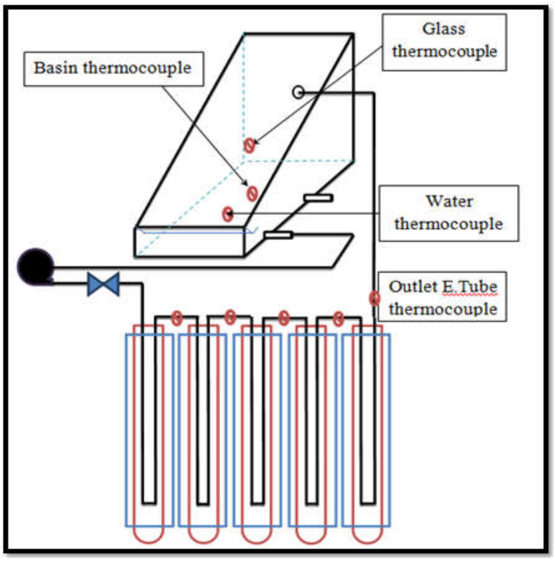



**Fig.5 Thermocouples distribution.**

**Fig.6 Experimental apparatus.**

## 6. Results and Discussion

The tests are take place during the interval from May to August month 2017 in Mosul City-Iraq, for the (Linear basin, single slope) solar still of 0.4 $m^2$ area, The results have been recorded during tests, through the time 24 hour, the tests was done for different water levels (4cm and 5cm) with and without insulation. Weather conditions represents the main factors effecting on the solar desalination process, and these parameters change with local time of the day and year seasons. **Figs. 7,8,9** represent the change of weather conditions for one day.

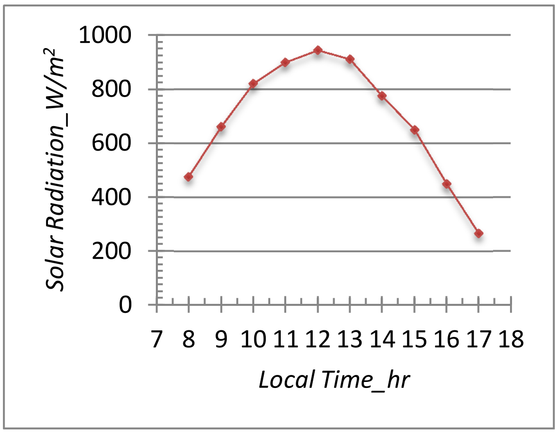



**Fig.7 Incident solar radiation with local time (8 a.m-5 p.m) at 29/7/2017.**

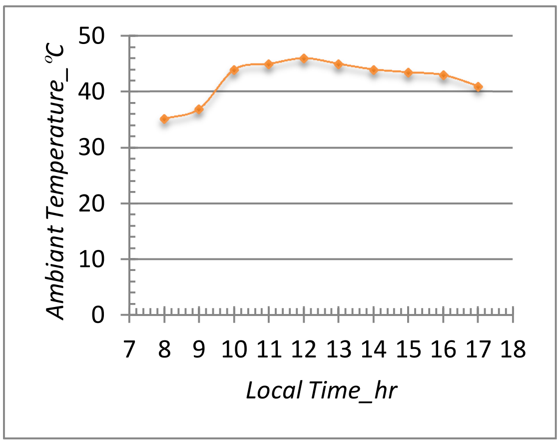



**Fig.8 Ambient temperature with local time (8 a.m-5 p.m) at 29/7/2017.**

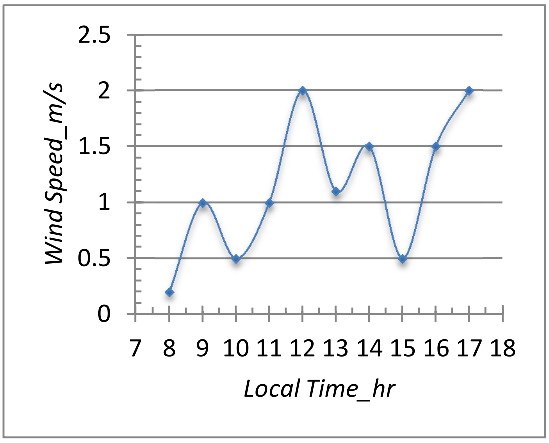



**Fig.9 Wind speed with local time (8 a.m-5 p.m) at 29/7/2017.**

## 7.1 Temperatures Variation

**Fig.10** show that the maximum temperature in the system is the basin's temperature of the active solar still $T_{w1}$, this is due to coupling the solar collector to the solar still, on the other hand the temperature of glass cover $T_{g1}$ also increase but stay below water temperature & ($T_{w1}$-$T_{g1}$) more than 5 degree in order to condensate the vapor on the glass.

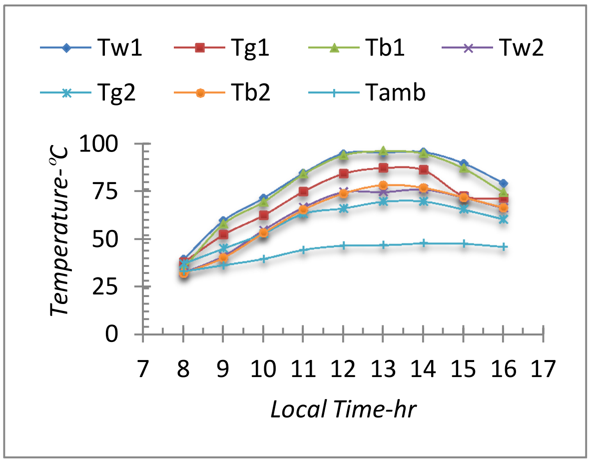



**Fig.10 Temperatures variation of (basin, water, wall, and glass), of active[1] and simple[2] solar still with local time.13/7/2017.**

## 7.2 Solar Collector Effect

From **Fig.11** it's obvious that the solar collector absorb the solar energy and convert it to heat energy which increase water temperature output of the solar collector, also the figure refer to that the difference between input and output be maximum at sunrise and minimum at sun set because of high intensity of radiation and low intensity respectively, that lead to maximize the yield output continuously.

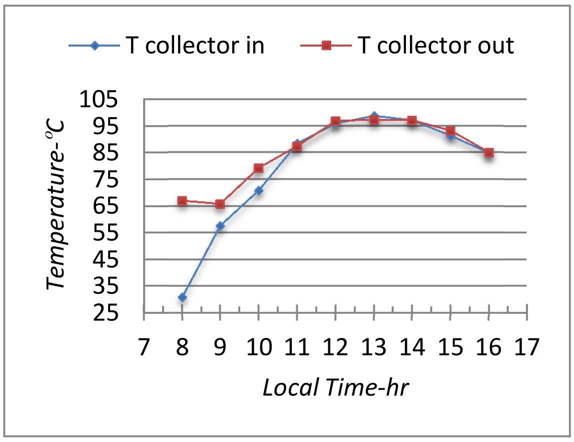



**Fig.11 Input and output temperatures of solar collector with local time.29/6/2017**

## 7.3 Temperature Difference ($T_w$-$T_g$) Effect on the Productivity

In **Fig.12** it's obvious that the productivity of the system directly increase with that of temperature difference between water and glass ($T_w$-$T_g$) refer to formula of the system yield output. The yield output be maximum when the difference be maximum and minimum when the difference minimum.

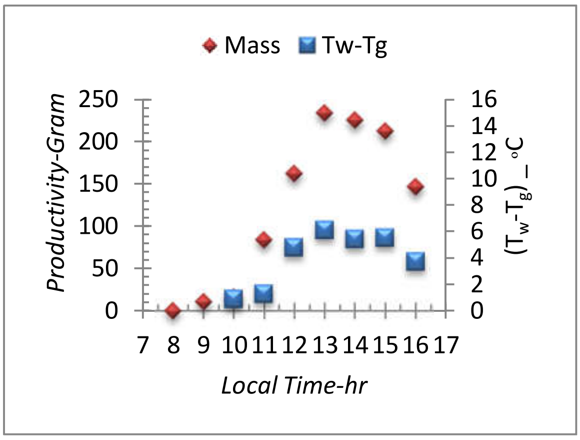
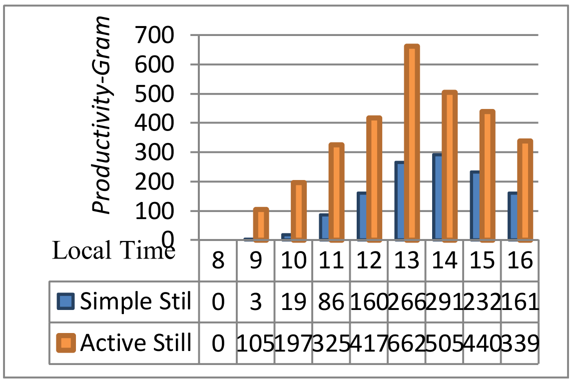



**Fig.12 Variation of productivity with temperature difference ($T_w$-$T_g$).13/8/2017**

## 7.4 Productivity Variation With Local Time

**Fig.13** show the productivity of the active solar still be more than simple solar still during the interval (8 a.m to 4 p.m). Its increase continuously until be maximum then decrease, this is due to the effect of incident solar radiation which be maximum between (12-1p.m) then decrease.

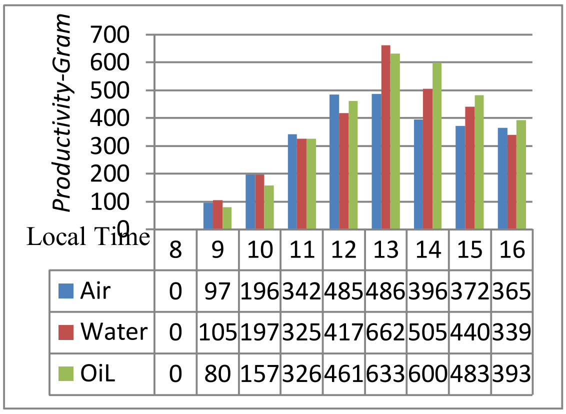



| Local Time | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| Simple Stil | 0 | 3 | 19 | 86 | 160 | 266 | 291 | 232 | 161 |
| Active Still | 0 | 105 | 197 | 325 | 417 | 662 | 505 | 440 | 339 |

**Fig.13 Productivity of the simple and active solar still with local time 26/7/2017.**

## 7.5 Effect of Medium in Evacuated Tubes on the Productivity

**Fig.14** refer to the effect of medium in evacuated tubes on the yield output under the same conditions, it has been notes that the system with oil in evacuated tubes produce desalinated water more than that of air or water due to the characteristics of heat transfer and conductivity of oil, the Prandtl number of oil is a very large as compared to that of air and water this result high Rayleigh number then high natural convection and heat transfer, that mean the water passes through the copper tube absorb more heat energy and increase the saline water then desalinated water.




| Local Time | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| Air | 0 | 97 | 196 | 342 | 485 | 486 | 396 | 372 | 365 |
| Water | 0 | 105 | 197 | 325 | 417 | 662 | 505 | 440 | 339 |
| OiL | 0 | 80 | 157 | 326 | 461 | 633 | 600 | 483 | 393 |

**Fig.14 Productivity of solar still using (air, water, and oil) in the evacuated tubes.**
**13,16/7/2017, 15/8/2017.**

## 7.6 Effect of Average Solar Radiation on the Productivity

**Fig.15** show the productivity of the simple and active solar still at the average solar radiation, the average value of the solar radiation in this case is the value during one hour and the productivity for one hour also. It has been noted that the system yield change directly with solar radiation value, especially at sunrise because this parameter dominated, but after noon another variables play important rule in this case such heat storage of the mediums in evacuated tubes and weather conditions.

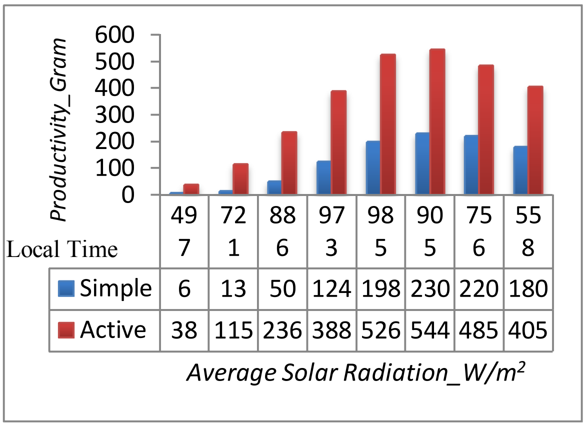



**Figure.15 Productivity of simple and active solar still with Solar radiation 26/8/2017.**

## 7.6 Accumulated Yield Output of the System With Local Time

**Fig.16** show the accumulated desalinated water for simple and active solar still respectively, it has been noted that the active one produce desalinated water more than that of simple one due to integrated solar collector to the system that absorb more heat to the system and this heat energy evaporate more water them more potable water produce.

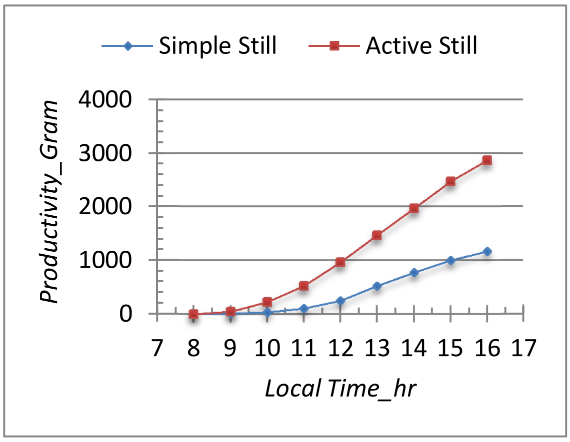



**Figure.16 Accumulated yield output of simple and active solar still with local time13/8/2017.**

## 7.6 Effect of Pump Flow Rate on the Collector Efficiency

**Fig.16** show that the collector efficiency change directly with that of pump flow rate , so its values increase with increase of pump flow rate with respect to all types of medium in evacuated tubes. because the collector efficiency directly proportional to flow rate when another parameters are constant.

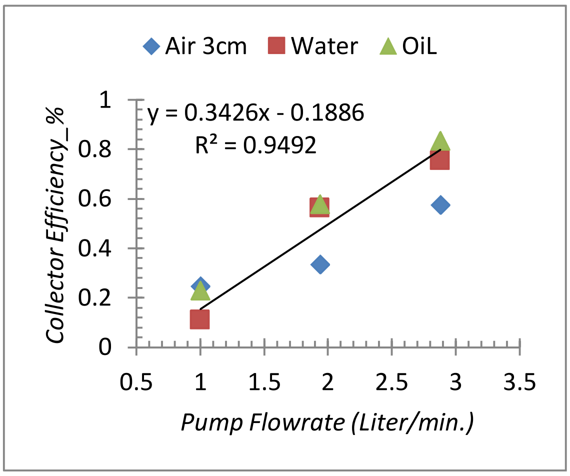



**Figure.16 Variation of collector Efficiency with Pump flow rate 1,3,5,8,13,19/8/2017.**

## 8. Conclusions

From the experimental study, It has been conclude that:

1. Maximum and minimum productivity of the simple and active solar still were: (2.505, 8.437)and(2.105,6.225) $kg/m^2$.day respectively.
2. Increase the pump flow rate from 1 to 3 liter/min., enhance the productivity by 30%.
3. Using of (air, water and oil) as mediums in glass evacuated tube produce (6.690, 7.762 and 7.832) $kg/m^2$.day of fresh water.
4. Maximum efficiency of the simple and active still were 30.2 % and 60.3 % respectively.
5. Maximum rate of increase in the water production were 144.5%, 166.3% and 178.33% in case of using air, water and oil in evacuated tubes at 2cm water level and pump flow rate 3 liter/min.
6. Increase water level in the solar still from 3cm to 4cm decrease the productivity by 39%.
7. It has been conclude that the increase of pump flow rate increase the collector efficiency.

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## 9. Nomenclature

$A_b$= Basin area, *$m^2$*.
$G_{av}$=Daily average solar radiation, *$W/m^2$*.
$G_{inc}$ = Incident solar radiation, *$W/m^2$*.
$h_{fg}$= Latent heat of vaporization, *kJ/kg*.
$m_d$= Solar still productivity, *$kg/m^2.day$*.
$Q_{req}$= Solar energy required, *kJ/day*.
$Q_{inc}$=Incident solar energy, *$kJ/m^2.day$*.

# دراسة تجريبية لتحسين الإنتاجية لمقطر شمسي فعّال مقرن بأنابيب مفرغة ذات الأنبوب النحاسي الراجع والعاكسات

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## الخلاصة

أجريت في البحث دراسة تجريبية لدراسة تأثير إضافة مجمع شمسي ذي الأنابيب المفرغة على إنتاجية المقطر الشمسي. مقطر شمسي أحادي الميل-أحادي الحوض استخدم في هذه الحالة. الماء المالح يتم ضخه خلال الأنابيب المفرغة لامتصاص الطاقة الحرارية والعودة إلى المقطر, كذلك استخدمت أنواع مختلفة من الأوساط داخل الأنابيب المفرغة. الدراسة تمت من شهر يونيو إلى نهاية شهر أغسطس 2017 في مدينة الموصل (خطوط الطول 43.296 والعرض 35.866 درجة وبارتفاع 200 متر عن سطح الأرض). النتائج بينت أن أعلى واقل إنتاجية للمقطر البسيط والفَعّال كانت (2.505 و8.437) و(2.105 و6.225) كغم/م2.يوم على التوالي. زيادة تصريف المضخة من (1-3) لتر/دقيقة يحسن الإنتاجية بنسبة 30%. استخدام الهواء والماء والزيت كأوساط داخل الأنابيب المفرغة ينتج 6.690و 7.762 و7.832 كغم/م2.يوم على التوالي. أعلى كفاءة للمقطرين البسيط والفَعّال كانت 30.2% و 60.3%. أعلى نسبة زيادة في الإنتاجية كانت 144.5% و166.3% و178.33% على التوالي في حالة حالات استخدام الهواء والماء والزيت داخل الأنابيب المفرغة وعند مستوى ماء داخل المقطر 2سم وتصريف 3 لتر/دقيقة. كذلك بينت الدراسة أن زيادة منسوب الماء داخل المقطر من (3-4) سم يقلل الإنتاجية بنسبة 39%, كذلك تم الاستنتاج بأن زيادة تصريف المضخة يزيد من كفاءة المجمع الشمسي.

**الكلمات المفتاحية: المقطر الشمسي, المجمع الشمسي, الأنابيب المفرغة, الإنتاجية.**