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THE DAILY PERFORMANCE OF A NEW SOLAR STILL UNDER DIFFERENT DESIGN PARAMETERS

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ABSTRACT: Seven designs of solar still have been investigated and tested for its performance under different design modifications in order to maximize the solar still productivity. These modifications are cover thickness, cover slope, evaporation and condensation surface areas and shapes and the internal volume. The obtained results showed that, when the cover thickness increased from 2 to 3 then to 4 mm, the daily output decreased by 2% and 7%, respectively. The cover slope with tilt angles with 17^o, 25^o, 50^o and 75^o on vertical direction has been tested with tilt angles on horizontal direction the tested tilt angles were 5^o, 8^o and 11^o. The greatest amount of fresh water obtained under tilt angle of 50^o and 11^o. The effect of the internal volume experimentally studied and observed that, increasing the internal volume by 25%, 50% and 78% decreases the still output by 4.4%, 12.8% and 21%, respectively. Increasing the evaporation surface area by 46.2% increased the productivity by 16.7%, while increasing the condensation surface area by 24% it improved the productivity by 20%.

Keywords: *Solar Still, Desalination, Brine Depth, Evaporation, Internal Volume, cover slope.*

INTRODUCTION

Solar distillation of brackish water is a practical alternative which offers life to those regions where the lack of fresh water hinders development. It has been shown that solar distillation remains the most favorable process for the supplying of water to small communities in remote locations where there is solar radiation as arid zones.

Water and energy are two inseparable items that govern our lives and promote civilization. Looking to the history of mankind, one finds that water and civilization were also two inseparable entities. It is not a coincidence that all great civilizations were developed and flourished near large bodies of water, (Delyannis, 2003).

The most widely used solar desalination system is a simple solar still, where the heat collection and distillation processes take place in the same instrument, (Al-Kharabsheh and Yogi Goswami, 2003)

Four single effect basin type solar stills were designed, constructed and tested. Three stills had a glass cover of different thickness (3, 5 and 6 mm) while the fourth cover was plastic. Daily average product per m^2 of Still 1 (3 mm) is about 0.03 kg higher than that of Still 2 (5 mm) and 0.04 kg higher than that of Still 3 (6 mm). The still with the thinnest glass cover had shown the highest production rates, up by 15.5%, (Abdulrahman, *et al.* 1997).

Basin type solar still has been tested with various cover tilt angles of 15, 25, 35, 45 and 55^0. An optimum tilt angle for water production was 35^0 during the month of May, because of the location and the time of the year, (Bilal, *et al.*, 2000).

Tanaka *et al.*, (2000b) constructed a vertical single distillation cell with a 5 mm gap using a very small wooden lump sandwiched in the middle of the cell between a glass partition and a heating metal partition in contact with a saline soaked wick to keep the 5 mm gap. The results showed that, when the thickness of the gaps is reduced from 10 mm to 5 mm or from 10 mm to 2 mm, the proposed still increases its productivity by 31% or 78%, respectively, at the summer solstice.

Mosalam, (1998) reported that, Egypt is considered one of the richest countries of the world in solar energy potential, most of Egypt lands recive a considerable annual average of solar energy radiation, ranging between 5.6 kWh/m^2.d at Marsa Matrouh in the north coast and 6.5 kWh/m^2.d at Aswan in the south of Egypt. Aslo it is found that, the mean value of the energy dnsity ranges from 500 to 1400 W/m^2).

The main objective of this study is improving the solar still performance by modify the parameters affecting on the still performance such as (internal volume, condensation and evaporation shapes and surface areas, cover slope, brine depth and cover cooling).

MATERIALS AND METHODS

The experiments were carried out during years from 2001 to 2003 in Faculty of Agriculture, Zagazig University on Agricultural Engineering Department building, and Zankaloun Research Station, Water Management Research Institute.

2.1. Test-Rig Description:

The construction of the schematic test-rig of the proposed solar still as shown in Fig (2.1). The raw water tank was placed at the back side of the solar still, to prevent any solar shading problem. The still unit length is 1 m, and the width along the east-west directions is 0.6 m with effective width of 0.5 m which created a net square area of 0.5 m^2 and this was sufficient to study the variation in the temperature and different parameters. The still unit had one raw water inlet located on the back side, two distilled water out-lets on the corners of the back side and one out-let of saline water located on the middle of the back side. The solar still has a rectangular basin shape with curvature cover shape, consists mainly of a black tray as evaporation surface, made of galvanized iron (GI), which contains raw water with shallow depth. The space above the basin is completely enclosed with air-tighten cover. The cover is made from cast acrylic sheet (CAS), type (Colorless Crystaplex), manufactured locally. CAS has a very high Light transmission which has a luminous transmittance of 92 %. Addition to it is lighter than glass and easer to manufactured in different shapes with high durability compared with glass and will not yellow under normal exposure. It has a very high transparent, having excellent weathering characteristics and being easy to maintain, addition to it is non toxic.

The condensing surface in the still units was formulated in different curvature shapes in one piece in order to allow the distilled water to creep to the still edges with keeping the accumulated heat inside the raw water as shown in Fig (2.1).

The bottom of the unit was flat-plate (tray) and stepped shapes as shown in Fig (2.2), which painted with black dye to absorb the maximum amount of solar radiation incident on it. Two collecting troughs are used for still units to collect the distilled water and it painted with white paint to prevent the distilled water evaporation. These troughs are fixed to the rectangular right and left sides of the condensation shapes.

In the inner and the outer sides of the still unit, all the connection joints are filled by silicon and the acrylic sheet cover is fixed with rubber seal in order to insure complete tightness and prevent escaping of the vapor water. Floppy tubes were used to connect the still unit to the raw water supply and the graduated glass bottles. One-polyethylene plastic tank with capacity of 25 litters was installed to supply the units with raw water.

2.2. Measurements and Instrumentation:

The measurement technique, which was used in the solar still, was divided as follows:

2.2.1. Temperatures measurement

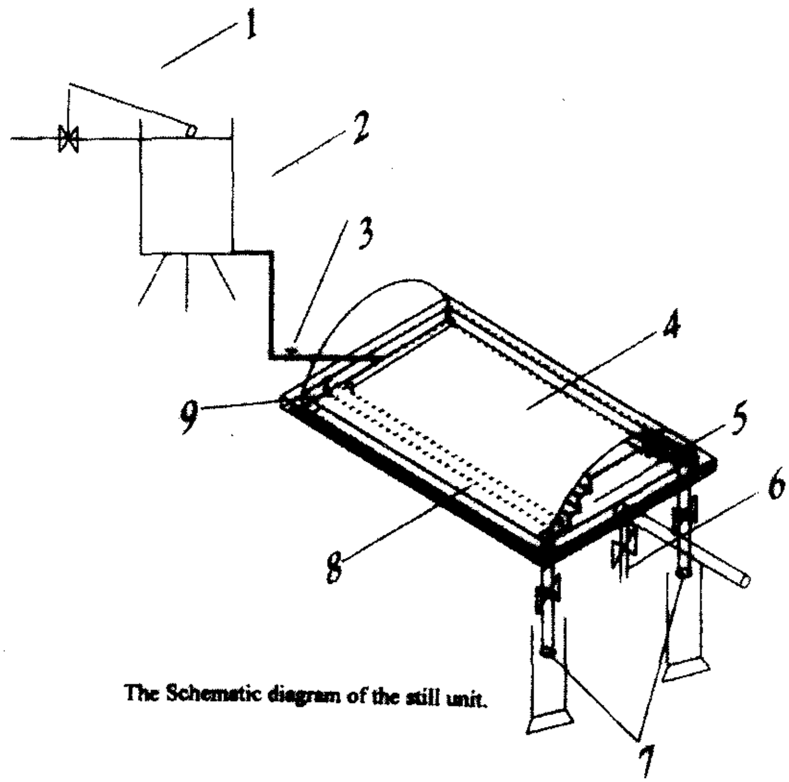
The temperature of distilled and raw water, inner and outer surfaces of the covers, the surface of basin, and ambient temperature were observed and recorded directly by using the digital thermometer. The following observations were recorded from 9:00hr to 17:00hr with an hour intervals. For all the temperature observations, the same type of the thermocouple (type T) was used.

Three thermocouples were connected to the inner surface of the plastic cover and three thermocouples connected to the outer surface to measure the cover temperature. For the collector surface temperature measuring, nine thermocouples were used. For raw water temperatures measuring nine of the thermocouples were fixed on the water, also for air gap temperature measuring nine thermocouples were used. Three thermocouples were used for measuring ambient temperature. The water tank temperature was measured using two thermocouples fixed into the middle of the tank.

2.2.2. Solar intensity measurement

The solar intensity was recorded every one hour from 9 O'clock to 17 O'clock.

A pyranometer with resolution of 0.001 W/m^2 used for total solar radiation incident measuring, the instrument put on the horizontal plane. The output of the pyranometer is W/m^2.



Part number	Specification
1	Swimmer and water level controller
2	Water tank
3	Control gauge
4	Condensation surface
5	Evaporation surface
6	Raw water exceeding and still washing outlet
7	Distilled water outlets with distilled water tanks
8	Distilled water troughs
9	Insulation box

Fig. (2.1): The Schematic diagram of the still unit.

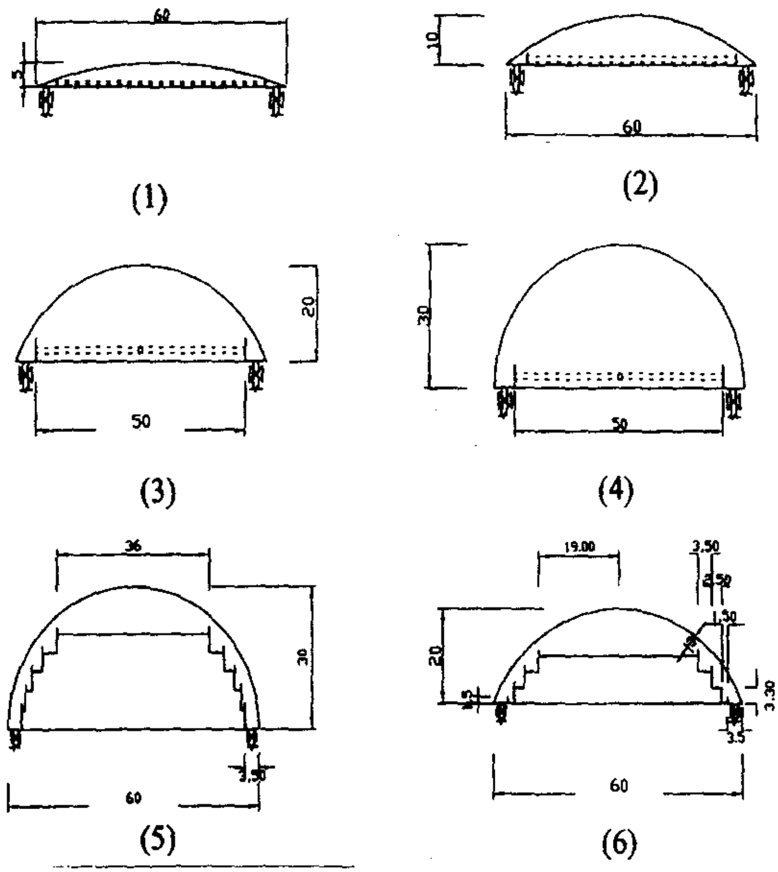


Fig. (2.2): The side view sections of different cover shapes.

RESULTS AND DISCUSSIONS

3.1. Effect of Solar Radiation on the Still Productivity:

The effect of the solar radiation on the solar still productivity on an average day of August (16/8/2002), in Eastern Delta region with a daily global insolation of 6.44 kW/m^2. The variation of the hourly solar still yield and the average solar radiation for a typical day for the still having a 1 cm of water depth and 4.0 cm thickness of insulation are graphically presented in Fig (3.1). The maximum insolation occurred at 13:00 pm, with delaying in the peak of the productivity by 50 minuets later, this result completely agreed with H.Tanaka *et al.* (2000a) and S.Al-Kharabsheh, *et. al,* (2003), where the maximum yield of 1.5 kg/m^2.h occurred at 13:50 pm as demonstrated in Fig (3.1), this shift is due to the time lag of the system response

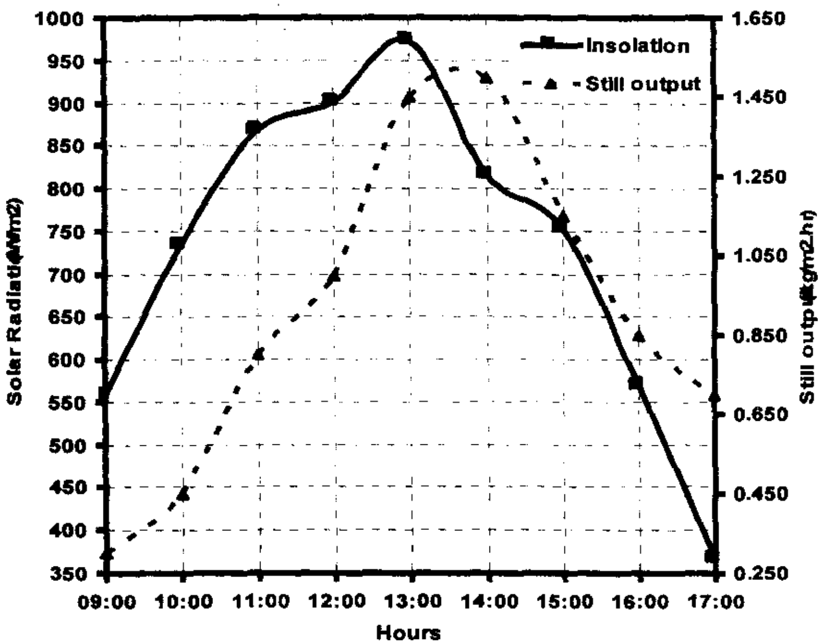


Fig (3.1): The hourly variations of solar intensity and still output.

3.2. Effect of Design Parameters on the still productivity:

3.2.1. Still Shape:

A large number of investigators have modified the horizontal single basin still, usually fixed on horizontal surface, to an inclined type to receive maximum solar radiation. Another way to maximize the benefit of solar radiation, the present work has been designed to be greenhouse solar still type with curvature cover shape and stepped evaporation surface shape.

3.2.1.1. Condensation surface shape:

New material, method and shapes of still covers were considered because the cover shape has large influence on the distillate output because it affects the solar radiation entering in the still unit. High strength cast acrylic sheets were used to fabricate four still covers which designed as curvature shape with peaks of 5, 10, 20 and 30 cm, the obtained results are graphically presented in Fig (3.2). From the experimental observations, however the cover of curvature peak of 5 cm achieved a very high storage heat capacity and high evaporation rate but it produced very little amount of distillate water because it did not sponsor suitable tilt angle for distillate water to be collected in the two side troughs.

Due to the cohesion phenomena the drops became very heavy then it dripped from the cover back to the water bed. Therefore the results related to this still are not realistic and will not be further discussed or generalized in this work. The other three treatments were examined for different cover shapes, from the results obtained it is clearly observed that, the greatest amount of distillate water 7 lit/d.m^2 obtained under cover with curvature peak of 20 cm followed by curvature peak of 30 cm and 10 cm whereas the still productivity was 6.5 and 6.1 lit/d.m^2 respectively. Although the heat storage capacity under cover of curvature peak of 10 cm was the highest, it gave the lowest output of distillate water 6.1 lit/d.m^2, this because the cover tilt angle with the vertical direction was not sufficient to collect all distillate water, hence the fresh water returned back to the raw water basin. Under the cover of curvature peak of 30 cm, the tilt angle of the cover was 75^o on right and lift sides, this angle is sufficient to collect all the distilled water but under this treatment it creates a high internal volume which leads to low storage heat capacity, hence the still unit using this curvature peak for its cover produce small amount of distillate water.

The still cover with curvature peak of 20 cm as graphically shown in Fig (3.2) compared with the other designs, it seems that, the evolution of the instantaneous still output from the still with cover of curvature peak of 20 cm is higher than the other two treatments during the day hours although the peak of the two curves for the other two treatments were higher than which for the curvature peak of 20 cm, but the accumulated output was the highest (7 lit/d.m^2). So this design insures high storage heat capacity therefore satisfactory evaporation rate and acceptable cover tilt angle to collect most of distillate water.

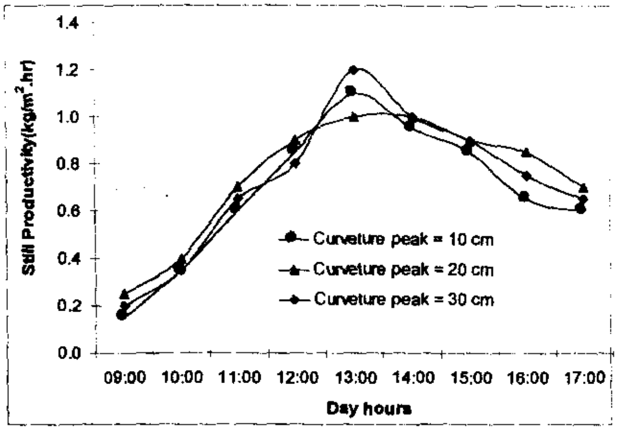


Fig (3.2) The evolution of still productivity under different cover shapes.

3.2.1.2.Evaporation surface Shape:

The evaporation shapes were flat-plate and stepped with three and five steps, the objective of examining different evaporation shapes is to keep the internal volume with high heat storage capacity as well to increase the collector surface area, with suitable slides tilt angles for distilled water collecting. Three still units with different evaporation surface shapes have been designed, fabricated and tested. The first shape was flat-plate, this shape maintained a very high storage heat capacity which leaded to high evaporation rate which would produce high amount of fresh water, but actually it didn't due to the aforementioned reasons in the previous topic.

The stepped collectors were fabricated because the flat evaporation surface shapes did not produce satisfactory output of fresh water (6.6 lit/d.m^2), the first effort to increase the evaporation and collector areas was fabrication the second still unit with stepped collector with five steps for each side (right and left), each step has vertical face as black collector surface and horizontal face as evaporation surface, the produced fresh water from this design was 7 lit/d.m^2 with increment of only 6%

more than produced from flat-plate shape, although the collector surface area increased by 54% (from 0.50 to 0.93) m^2, the reason of this small increment which is corresponded to the big increment in the collector area is the shadow problem from the back side on the front side during the first half of the day, while the opposite trend observed during the second half of the day.

Fig. (3.4) shows the hourly volumetric rates of distilled water produced from both sides. It is clearly noticed that the front side, which receives lower amounts of solar insolation, produces more distillates than the back side does. This is due to the fact that the front side loses more heat and is not exposed directly to sunlight, thereby being cooler, so it condenses more water. The picture becomes more clear when the total accumulation of fresh water is collected, for the front, left and the two sides combined. A greater amount of water is collected from the left side (3.8 lit/d.m^2) than from the front side (3.2 lit/d.m^2). This trend reversed after midday due to the shadowing problem. This results is completely agreed with Bilal, *et al.* (2000).

To overcome the shadow problem from one side to anther, the third unit with three steps collector shape has been designed and tested for its performance, from the obtained results, it is clearly observed in Fig. (3.3) that, the hourly output of the still unit higher than the other designs, hence it produced the highest amount of fresh water (7.8 lit/d.m^2) with increment of 15.4% and 10.2% more than which produced from flat-plate shape and five steps shape respectively.

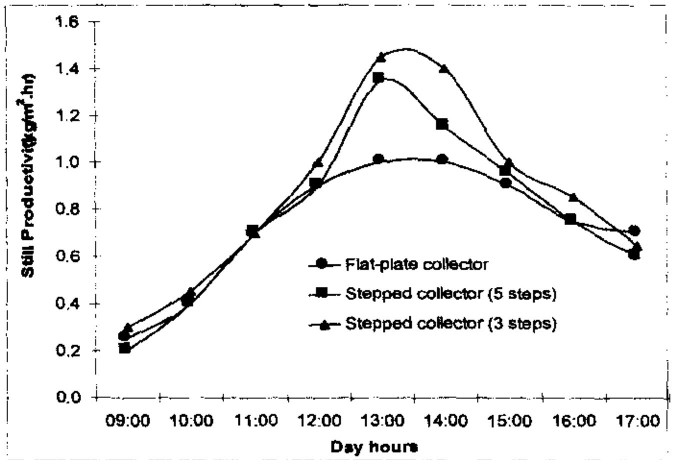


Fig (3.3): The interaction between collector shape and hourly productivity.

With stepped evaporation surface shape with three steps both sides receives solar radiation more or less equal, it means front and back sides produced fresh water more or less equal (3.85 and 3.95) lit/d.m^2 for front and back sides respectively, as shown in Fig. (3.5), the hourly productivity curves for both sides are matched together for the most hours during the day and it is completely matched in the midday hours.

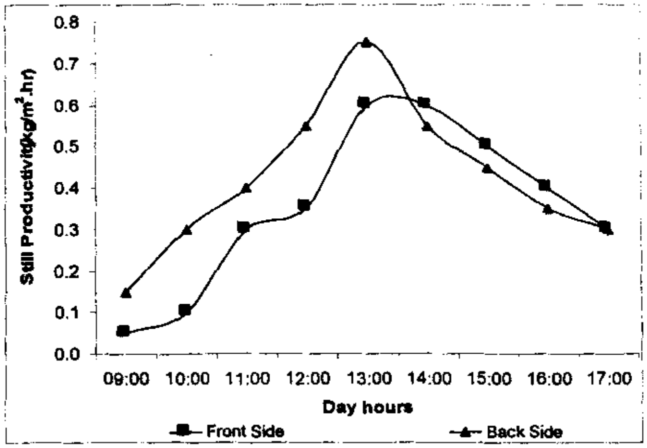


Fig (3.4): The effect of side direction on the hourly productivity under curvature peak of 30 cm.

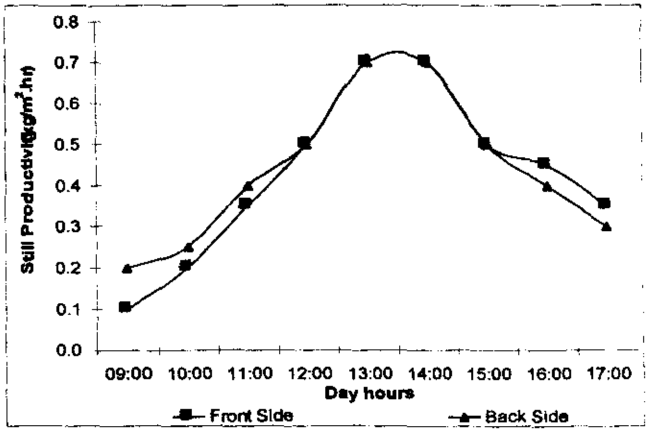


Fig (3.5): The effect of side direction on the hourly productivity under curvature peak of 20 cm.

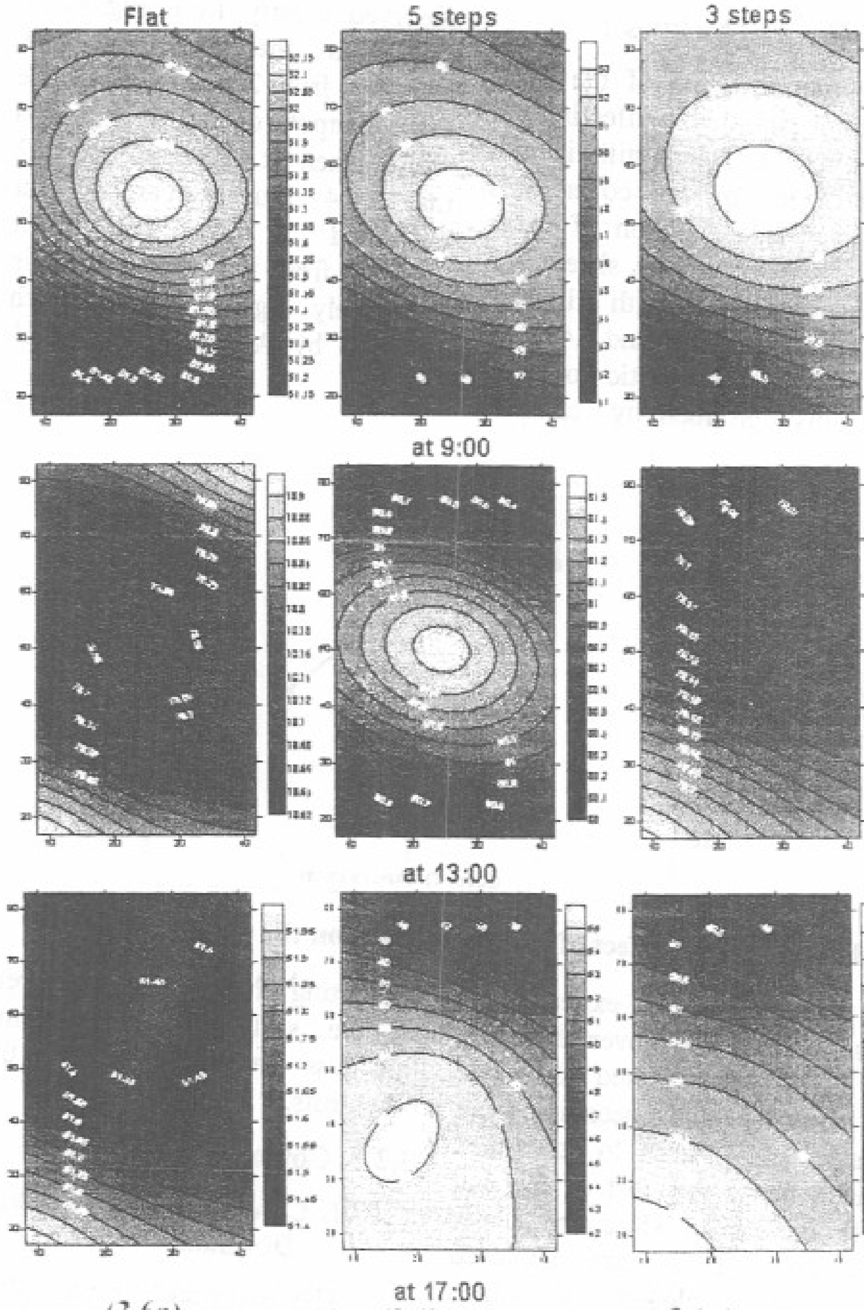
A very interesting evaluation parameter for still design efficiency is examination the temperature distributions on different zones on the still unit because it is indicator to the energy balance inside the still unit whereas the still unit at different zones should receives more or less the same energy, the still unit was divided into three sections each section divided into three zones, these nine zones monitored and evaluated for temperature distributions in order to illustrate which of the three previous still units is the most efficient.

The contour lines shown in Fig (3.6a) demonstrate the warming balance between different points on the flat-plate collector, the data obtained, it is clearly observed that 09:00hr, 01:00hr, and 17:00hr, these hours are the starting, the midday and the stop hours, the difference between warmest point and coolest point are only 0.55, 0.28 and 1.00 ^{0}C for the selected hours respectively it means that all zones receives more or less equal of the solar radiation because the collector surface is flat whereas the shadow problem disappears.

Fig (3.6b) shows the status of the stepped unit with five steps and it is noticed that, the difference between warmest point and coolest point are 13.0, 1.5 and 12.0 ^{0}C for the selected hours respectively, this data indicates that there is a very big difference between different zones and there is no energy balance inside the unit due to the shadow problem from the front side on the back side in the first half day and from the back side on the front one in the late half day. It is also noticed from Fig (3.6b) that at the starting hour (*first half of the day*)the front section (*the bottom contours*) was hotter than the back section (*the top contours*), this observation reversed at the stop hour (*second half of the day*) whereas the back section became hotter than the front section, while in the midday there was equity of temperature distributions whereas the hottest section was the middle one

Due to the problem of insufficient tilt angle to insure fresh water collecting in flat collector unit and the shadow problem in the steeped collector with 5 steps, the last one has been modified to be stepped collector with 3 steps. Fig (3.6c) shows the contour lines distributions of this stepped unit with three steps and it is observed that, the difference between hottest point and coolest point are 5.5, 0.18 and 5.0 ^{0}C for the selected hours respectively.

The difference between different zones is not far such as obtained for the stepped unit with five steps and this design insures sufficient tilt angle and overcome the shadow problem, hence it considered as the most efficient design among the others.



(3.6a) (3.6b) (3.6c)

Fig (3.6): Temperature contour lines under different still designs.

3.2.2. Cover Thickness:

Obviously one of the most important parameters affecting the output of a solar still is the transmittance of the cover, this parameter is a function of cover thickness. Cast acrylic sheet used as cover material with different thickness of (0.2, 0.3 and 0.4) mm. The effect of the plastic cover on the daily productivity can be observed clearly from Fig (3.7), that when the cover thickness increased from 2 mm to 3 mm, the daily output decreased by 2% while when it increased from 2 mm to 4 mm the daily output decreased by 7%. The result obtained from the present work is completely agreed with which obtained by Abdulrahman, *et al.* (1997).

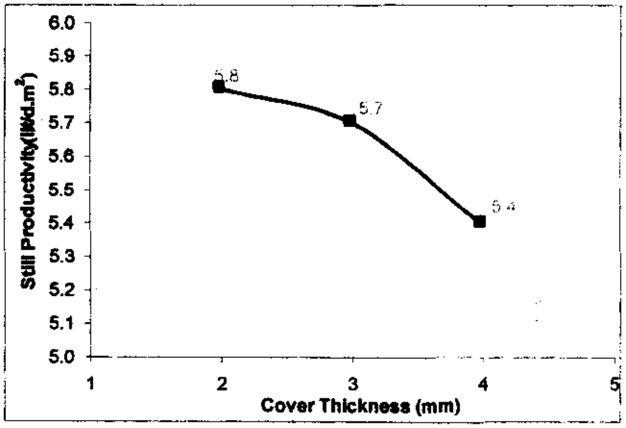


Fig. (3.7): The effect of cover thickness on the still productivity.

From the experimental observations, the cover thickness of 2 mm was affected somewhat by heating and became more elastic, so it needs to strengthen frame, hence the cost of the unit will increases, while the cover thickness of 3 mm achieved productivity closed to which achieved from 2 mm cover and supporting frame is not required, so the still cover of 3 mm thickness was considered for the other tests.

3.2.3. Cover Slope:

3.2.3.1. Cover Slope with Vertical Direction:

The cover surface was tilted on vertical direction with tilt angles of 17^o, 25^o, 50^o and 7°°. The results obtained shown in Fig (3.8) demonstrates that increasing the vertical tilt angle from 17^o to 25^o, the still productivity increased by 8.2% and when the tilt angle increased from 17^o to 50^o caused output increment by 16.4%. While increasing the tilt angle from 50^o to 7°°, the productivity decreased by 3%, this due to this design create big internal volume which caused less heat storage capacity and low evaporation rate, so the reduction of the productivity under this case is not due to the increasing tilt angle.

The greatest amount of fresh water 6.6 lit/d.m^2 produced under case of tilt angle of 50^o, this tilt angle coinciding with the curvature cover of 20 cm, which is considered the most suitable cover design among the other designs. This results completely agreed with Abdel-Kader (1998). During the experimental run, it is observed that, with tilt angle of 50^o which insures good creping for water drops in one direction (*vertically*), but it was observed in the middle section as shown in Fig. (3.8), there was fresh water losses by dripping back to the brine of some big droplets. To overcome this problem, the still unit with cover tilted at 50^o with vertical direction has been modified and it tilted again with horizontal direction as illustrated in next topic.

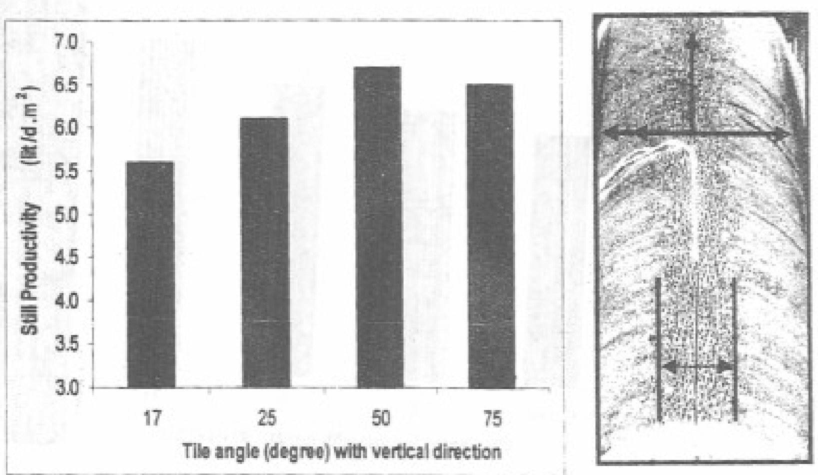


Fig. (3.8): The effect of tilt angle with vertical direction on the still productivity.

3.2.3.2. Cover Slope with Horizontal Direction:

In order to maximize the benefit form the condensate water, the still unit has been modified with tilt angle on horizontal direction combined with tilt angle on vertical direction which haven't been done by any other investigator, by this modification the drops creep in two directions and all condensate water has been collected to the side trough shown in Fig (3.9). To chose the best tilt angle with the axial direction of the still unit, three angle were tested, 5°, 8° and 11° as revealed in Fig (3.9). The observed trend from the obtained data was, with increasing the tilt angle, the productivity improve, whereas when the tilt angle increased from 5° to 8° the productivity increased from 7.8 to 8.0 lit/d.m^2 and when it increased from 5° to 11° the productivity increased from 7.8 to 8.2 lit/d.m^2 with increment about 0.4 lit/d.m^2 with tilt angle of 11°, all condensate water collected and there was no need to increase the tilt angle behind this level because according to the present work design, increasing tilt angle in this direction decreasing the condensation surface area, which has negative effect on the productivity behind this level.

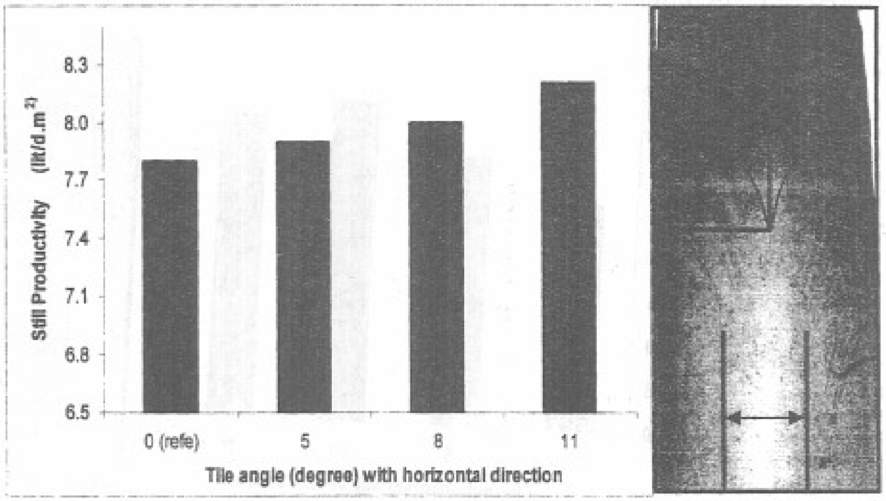


Fig. (3.9): The effect of tilt angle with horizontal direction on the still productivity.

3.2.4. Gap Distance (Internal Volume):

The distance between still unit partitions called *air gap*, it is relevant to the internal air volume. The effect of the internal volume between evaporation and condensation surfaces experimentally studied, and the trend was overall daily productivity exponentially increases with internal volume decreases as illustrated in Fig (3.10). Four internal volumes were tested (30, 40, 80 and 135) cm^3 and from the obtained results, it is clearly evidenced that increasing the internal volume by 25% (*from 30 to 40*) cm^3 the still output decreased by 4.4 % and when it increased by 50% (*from 40 to 80*) cm^3 the still output had reduction by 12.8%, while increasing the internal volume by 77.8% (*from 30 to 135*) cm^3 decreases the product fresh water by 21%.

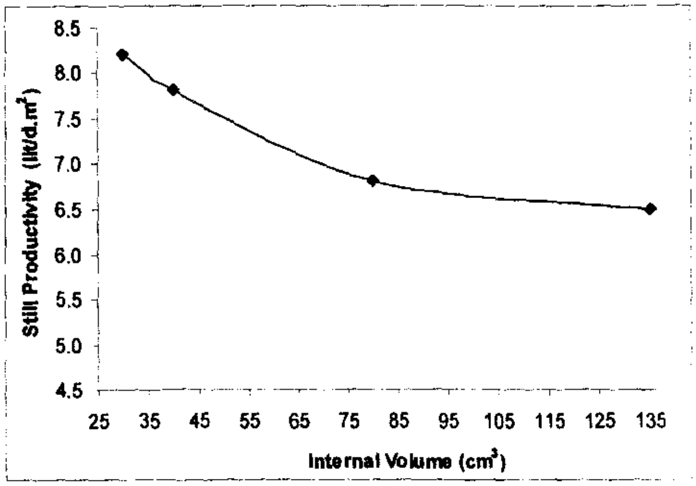


Fig. (3.10): The effect of the internal volume on the still productivity.

Generally, the obtained results as demonstrated graphically in Fig (3.10) revealed that, increasing the internal volume with small ranges decreases the productivity with small reduction while increasing with large range caused drastic reduction, this results agreed with Tanaka *et al* (2000a) and Sherif *et al.* (2001).

3.2.5. Evaporation Surface area:

The evaporation surface area plays an important role in improving the still daily productivity. In the present work the effect of increasing the evaporation surface area has been experimentally studied and evaluated, the obtained results showed in Fig (3.11), it is clearly seen that increasing the evaporation surface by 32.5% (*from 0.500 to 0.741*) m^2 improved the still productivity by 7.1% while increasing it by 46.2% (*from 0.500 to 0.930*) increased the productivity by 16.7%.

The obtained results showed disagreement with S.Kumar (1998), who found reversal trend and he referred it to the lower storage heat capacity under large evaporation surface area, while the obtained results showed good agreement with most investigators such Kalogirou, (1997), Le Goff, *et al.* (1991) and with H.S.Kwatra (1996).

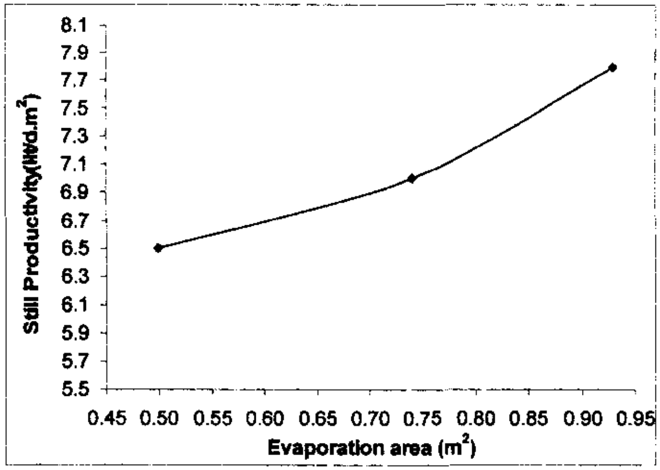


Fig. (3.11): The effect of evaporation surface area on the daily productivity.

3.2.6.Condensation Surface Area:

The condensation surface area is the most important component in the solar still, whereas the evaporated water can be condensate. The effect of the condensation surface area experimentally studied in the present work and the obtained results is graphically showed in Fig (3.12).

It is very evident from the experiment results that increasing the condensation surface area decreases the fresh water temperature and store all the evaporated water subsequently increases the still output. As the condensation surface increased from 0.573 to 0.638 m^2, the productivity increased from 5.6 to 6.1 lit/d.m^2 (9.2%) while increasing it form 0.573 to 0.753 m^2 it improved the productivity by 20% (*from 5.6 to 7*) lit/d.m^2. The obtained results showed good coinciding with Al-Kharabsheh (2003) and E1-Bahi (1999).

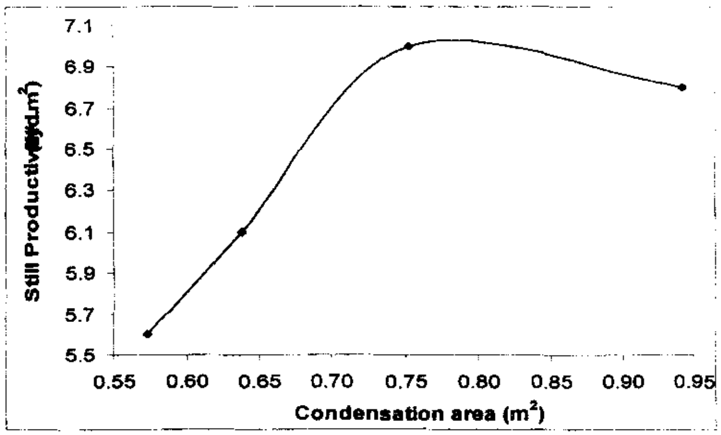


Fig. (3.12): The effect of condensation surface area on the daily productivity.

Under the present work design, by increasing the condensation surface area the productivity increases in linear relationship up to critical point then the productivity decreased as shown Fig (3.12), when the condensation surface area increased from 0.753 to 0.942 m^2 the productivity decreased by 3% because in the present design the condensation surface is correlated with the evaporation surface area, and increasing the condensation surface area without increasing the evaporation surface are will due to more internal volume subsequently undesirable fresh water production.

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معدل الأداء اليومى لمقطر شمسى جديد تحت تأثير عوامل التصميم المختلفة

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تم تصميم وتصنيع سبعة مقطرات شمسية بغرض دراسة عدة عوامل تتعلق بالتصميم حيث تم تطوير بعض أسس التصميم لتعطى معدل أداء أفضل. من عوامل التصميم التى تم دراستها هى: سمك الغطاء، زاوية ميل الغطاء مع المستويين الأفقى والرأسى، مساحة سطح التبخير ومساحة سطح التكثيف وحجم الفراغ الداخلى. ومن النتائج المتحصل عليها تبين أنه بزيادة سمك الغطاء من ٢ مم الى ٣ مم ثم الى ٤ مم قلت الأنتاجية بمقدار ٢% و ٧% على الترتيب.

من النتائج المتحصل عليها تبين أنه بزيادة زاوية الميل مع المستوى الرأسى من ١٧° إلى ٢٥° زادت الإنتاجية بمقدار ٨,٢% بينما بزيادة هذه الزاوية من ١٧° إلى ٥٠° كانت الزيادة فى الإنتاجية بمقدار ١٦,٤%. بينما بزيادة هذه الزاوية حتى ٧٥° قلت الإنتاجية بمقدار ٣% وذلك لأن تحت هذا التصميم يزداد حجم الفراغ الداخلى بين سطح التكثيف وسطح التبخير وبالتالى تقل السعة التخزينية الحرارية للمقطر وعليه تعتبر أنسب زاوية ميل للغطاء مع المستوى الرأسى هى ٥٠° حيث حقق المقطر بها أعلى إنتاجية (٦,٦ لتر/م^{2}.يوم). مع زاوية ميل الغطاء مع المستوى الرأسى لوحظ وجود قطاع طولى كبير من سطح التكثيف تعلق به القطرات ثم تسقط فى حوض المياه المالحة وبذلك يتسبب فى فقد كبير فى المياه العذبة. لذلك تم التفكير فى عمل زاوية ميل للغطاء مع المستوى الأفقى بالتوافق مع زاوية الميل مع المستوى الرأسى وتم دراسة ذلك على ثلاث زوايا هى ٥°، ٨° و ١١° وكانت أنسب زاوية هى ١١°.

أظهرت النتائج أنه بزيادة حجم الفراغ الداخلى بمقدار ٢٥% قلت الإنتاجية بمقدار ٤,٤% بينما بزيادة بمقدار ٥٠% قلت الإنتاجية بمقدار ١٣%، ولكن عند الزيادة الكبيرة بمقدار ٧٨% فى حجم الفراغ الداخلى أدى الى نقص فى الإنتاجية بمقدار ٢١%.

من النتائج المتحصل عليها تبين أن بزيادة مساحة سطح التبخير بمقدار ٣٢,٥% زادت الإنتاجية بمقدار ٧% بينما بزيادة مساحة السطح بمقدار ٤٦,٢% كانت الزيادة فى الإنتاجية بمقدار ١٦,٧% كما لوحظ أن العلاقة بين مساحة سطح التبخير والإنتاجية كانت علاقة خطية.

كما تبين من النتائج أنه بزيادة مساحة السطح بمقدار ٢٣% زادت الإنتاجية بمقدار ٢٠% ولكن هذا التأثير لوحظ حتى مستوى محدد من الزيادة فى المساحة بعدها ينقلب تأثير مساحة سطح التكثيف حيث تحت التصميم المختار بعد حد معين من زيادة مساحة سطح التكثيف تقل الإنتاجية إلا إذا زادت مساحة سطح التبخير بنفس المقدار.