

NEW CONCEPT FOR IMPROVING SOLAR STILL PERFORMANCE BY USING VIBRATORY HARMONIC EFFECT EXPERIMENTAL PREDICTION, PART-1

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طريقة جديدة لتحسين اداء المقطرات ذات الحوض التي تعمل بالطاقة الشمسية
باستخدام التأثير الاهتزازي

ملخص

هذه المقالة تقدم فكرة جديدة لتحلية المياه معمليا بواسطة المقطرات ذات الحوض التي تعمل بالطاقة الشمسية باستخدام التأثير الاهتزازي الايجابي. تعتمد هذه الفكرة على استخدام طبقة مرنة من الاسلاك الحلزونية المشدودة طوليا فوق قاع الحوض والمصنعة من النحاس والتي تكون اكثر انقواء للاهتزازات الناتجة من مولد اهتزازات تم استخدامه لهذا الغرض. وتعتبر طبقة الاسلاك المرنة المطلية بالون الاسود بيئة جيدة لامصاص ونقل الحرارة وكمخزن للطاقة. وتم تثبيت مولد الاهتزازات في موضع مناسب في الهيكل الانشائي للمبخر. ويعمل مولد الاهتزازات على توليد حركة اهتزازية تعمل على اثاره طبقة الاسلاك الحلزونية فتعمل بدورها على زيادة معامل انتقال الحرارة القصرى و تقليل مقاومة الطبقة الجدارية مما يرفع كفاءة المقطر. كذلك تم استخدام رقائق البولي كربونات الشفاف بدلا من الزجاج وذلك لكي يتجاوب مع الاهتزازات بطريقة افضل مما يؤدي الى مساعدة قطرات الماء المتكثف على الانزلاق بسهولة بفعل ريادة قوى القصور الذاتي على قوى التوتر السطحي، مما يزيد من كمية الماء المتكثف الناتج. تم استنباط معامل تأثير الاهتزازات والذي يمثل النسبة بين الزيادة الناتجة بفعل الاهتزازات الى الطاقة المستنفذة في الاهتزازات. كذلك تم المقارنة مع المقطرات ذات الحوض التقليدية. وقد كان مقدار الكمية المنتجة باستخدام طبقة الاسلاك الحلزونية هو ٤,٣ لتر/يوم بكفاءة مقدارها ٣٥% اما باستخدام الاهتزازات فقد زادت هذه الكمية المنتجة الى ٥,٨ لتر/يوم والكفاءة الى ٦٠% كذلك فان نسبة الانتاج الليلي فقد تراوحت ما بين ٣٥ الى ٥٧% من الانتاج الكلى.

ABSTRACT

A new concept of active vibratory solar still is experimentally presented. Firstly, a flexible packed stretched media is installed in the bottom of the basin to increase the efficiency of the still. Secondly, a vibratory harmonic effect is applied. The flexible packed media is formed from stretched helical coiled black coated copper wires, which is considered as a good media for heat absorbing and transferring and as simple thermal storage system. Also, a vibrator (resonator) is installed in the middle of the system structure. The target of using the vibrator is to generate forced vibration to excite the flexible packed media to break the boundary layer and surface tension of the saline water and improve convective heat transfer, and also to excite the condensed polycarbonate glass cover to assist the condensed droplets to slide down before it becomes bigger and possibly falls down in the basin, thus increasing the water vaporization and condensation. The performance is compared with the conventional solar stills (CSS). The vibratory excitation effect is accounted by the new parameter 'vibratory performance gain'. The productivity due to added backed helical wires is found to be 3.4 l/m² day, with efficiency of about 35 %, and the productivity with vibration is

increased to be 5.8 l/m²day and the average daily efficiency is about 60%. The nocturnal production ranges are found from 38 to 57 %.

Keywords: Distillation; solar still; vibratory harmonic motion; nocturnal production.

NOMECLATURE

C_{pw} and C_{pb} : Specific heat of helical wires and brine water, respectively.

m_w and m_b : Masses of the helical wires and brine water, respectively.

A_w and A_b : Surface areas of helical wires and brine water, respectively.

$(\alpha\tau)_w$ and $(\alpha\tau)_b$: Absorptivity and transmissivity of the helical wires and brine water respectively.

q_t : Total solar insulation per day, MJ/m²day.

q_g, q_b, q_w : Total solar irradiation absorbed by polycarbonate glass cover, brine water, and helical wires backed layer, W/m²

I_s : Solar insulation power, W/m²

ρ_d : Distillate density, kg/m³

L_d : Distillate latent heat = 2.34 MJ/kg

P_v : The vibrator motor power, W.

W_{d2}, W_{d1} : Productivities with and without vibration l/m²d.

η_w : Solar still efficiency with helical wire packing layer

η_{wv} : Solar still efficiency with helical wire packing layer and vibration applied

Subscripts:

w : Helical wires packing

b : Brine water

CSS: Conventional solar still

PRP: Production Rate Performance

VPG: Vibratory Performance Gain

1, 2: during sunlight, after sunset

1- INTRODUCTION

It is well known that the water problems, which are either the lack of it or pollution, have become very large in many areas of our

planet, especially in deserts, at traditionally dry regions and in modern industrial areas. Moreover, remote areas or islands with low population, where fresh water supply by means of transport is expensive, face the problem of water shortage every day. However, it is for those areas the installation and operation of solar stills seems to be a promising and the most appropriate way to deal with their water problem. In addition, the process includes the use of clean, abundant, free and friendly to the environment solar energy, easiness of construction, operation and maintenance of solar stills by local people and concurrence of periods of high sunshine with high water demand.

Numerous studies on solar stills of various designs to increase its productivities and efficiencies have been carried out theoretically and experimentally. These studies include the determination of the dependence of the productivity on weather, the design and operation parameters [1]. Solar stills are classified into two groups in terms of energy supply; passive and active. The passive solar stills are conventional solar stills (CSS) which use the solar energy falling on the basin effective area as the only source of thermal energy. However, in the active solar still, extra thermal energy is given to the passive solar still for faster evaporation, and hence increasing productivity.

Increasing the productivity of the solar stills attract many investigators, several techniques are tried and tested in order to satisfy this main target. A technique of floating sponge, Hegazy [2]; as an absorbing media is used to increase the conduction heat transfer of the brine water and hence accelerate the evaporation rate. A modified type of wick type solar still based on the

good capillarity of a jute wick is studied by AL-Karafhouli et al. [3], this type is simply a conventional solar still provided with a blackened jute wick floated with a polystyrene sheet. Results showed that the floating-wick type solar still gives higher productivity but it can't resist contamination. This type is developed by Minasian et al. [4] by increasing the cooling effect of the condensing cover. The technique of adding one or more outside condensing chambers to magnify the condensing effect is studied also by Tiwari [7] and El-Bahi [8] the daily production is increased by 70% and in case of adding a double glass with minimum inclination, [9] and [10], the productivity was in good agreement with what obtained by other authors and the efficiency was increased from 37% to more than 69% when the condenser cover was cooled down.

A multiple effect solar stills is studied by Tanaka et al [5,6], they constructed and tested vertical two and three-effect-type stills with recycling the condensing heat to increase the total amount of distillate and its efficiency. They developed it by adding a heat-pipe solar collector and the still is predicted to produce distilled water with efficiency increased factor of 1.2 – 1.6. This technique is developed by adding air blown by Mink et al. [10]; they estimated the effect on the still productivity and found it very promising for enhancing the thermal efficiency, and thus a further increase in the productivity per unit area.

Active solar distillation on the other hand is considered a second type of the used techniques to increase the productivity and efficiency of CSS. Prasad et al. [11] and Phadatare et al. [12] found that when feeding the thermal energy into the basin from external source, it can increase the evaporating surface temperature and can lead to increase the nocturnal production. The

first study on nocturnal production was reported by Malik and Tran [13]. Voropoulos et al. [14] used hot water tank underneath the absorbing surface working as energy storage tank, they found that the nocturnal production is increased relatively with the total production by 60 % [15-17].

Zeinab et al. [18] presented a new active technique by using rotating shaft installed close to the basin water surface to break the boundary layer of the basin water surface together with adding packed thermal layer. The packed layer is installed in the bottom of the basin to increase the efficiency of the still; it is formed from glass balls which are considered a simple thermal storage system. They found that the efficiency of the modified solar desalination system using packed layer was increased by 5 - 7.5 %, and by 2.5-5.5 % for the modified one using rotating shaft.

For improving the solar still performance new approaches are highly welcome. An attempt to improve the performance of solar still should include an investigation on the performance of new design configurations. To the best of our knowledge, a vibratory excited flexible packed stretched media installed in the basin has not been investigated.

The objective of this study is to investigate the performance enhancement of a solar still coupled with vibratory excited flexible packed stretched media in two modes of operation. The first mode includes the operation of the still with a flexible packed stretched media installed in the bottom of the basin. For the aim of comparison; in the second mode a vibratory harmonic excitation is applied together with the first mode. In this respect, the article is concerned mainly with the system productivity to evaluate the effect of proposed concept on improving the

performance of the solar stills. Also the effect of increasing the thermal storage capacity of the basin brine water on the nocturnal production has been studied.

We can summarize the concept technique in the following notes:

- 1- Installing flexible packed media (stretched helical coiled copper wires) on the bottom of the basin submerged in the brine water.
- 2- Applying forced vibration of very low power to excite the modified absorbing media.
- 3- Increasing the stored energy capacity by increasing the water depth and using good isolation.
- 4- Improving collection process of the condensate.

2. EXPERIMENTAL WORK

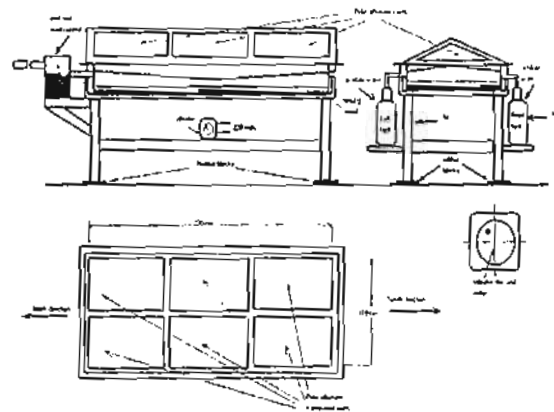
2.1. Solar still station configurations

This active solar still is designed and built in the southern desert area of Saudi Arabia (Wadi El-dwaser, 21.5° latitude and 44° longitude), in the year 2006 to supply distillate water to a battery service center in a large farm. It uses the under ground water as a brine, which is lifted from deep wells.

The system has a double sloped cover of 30° inclination with the horizontal and total effective area of 2.064 m². It is made from coated steel sheets and angles, Fig (1) shows a schematic drawing of the solar still, it is equipped with basin level control valve, which is included inside closed tank. The transparent cover is made from polycarbonate composite sheets of 4 mm thickness partitioned to six segments, three on each side. A tight sealing of the inside enclosure is attained by using silicon rubber past with galvanized bolts for all connections of top cover and basin parts. The basin total height is 70 mm and it has two troughs, one on each side for collecting the distillate, then

transferring it to the outside collecting vessels, which are tight closed and located at a shaded spots in the way of natural air ventilation stream.

Fig (1) Active solar still configurations



Helical copper wires are stretched over the basin bottom, as shown in Fig (2). The coil mean diameter is 25 mm and the wire diameter is 1.5 mm, they are blackened as the basin bottom. The average depth of the brine water in the basin is 60 mm, and the total average water mass is about 80 kg.

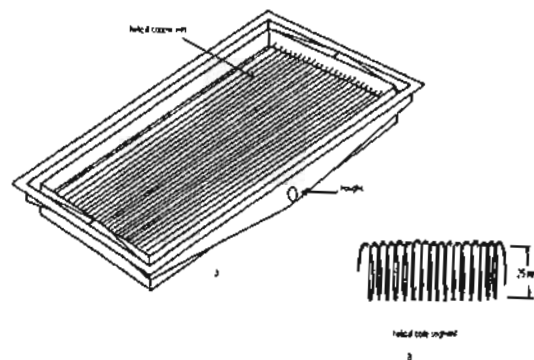


Fig (2) Basin and stretched helical coiled wires

The vibrator is located at the center of the base bottom as shown in Fig (1). It is composed of a rotating disk driven by ac motor, as shown in Fig (3), the disk has an unbalance mass of 20 grams, located at radius of 40 mm. The motor speed is 1800 rpm, so the frequency of the vibration is 30

Hz. and the maximum exciting force is about 20 Newton. The vibration is directed mainly to the vertical direction by using unidirectional elastic supports (rubber constrained layer) underneath the four columns which are carrying the system. The power consumed by the vibrator is about 60 watts, so that the daily electric consumption is about 1.44 kWh.

The basin outside surface is covered by two layers of foiled glass-wool of total thickness of

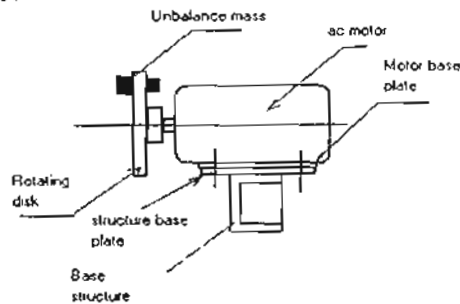


Fig (3) Vibrator configuration

40 mm and rested on wooden plates of thickness 25 mm. The solar still is directed to the north-south direction.

The design parameters of the system are:

- Effective black area of basin is 2.064 m²;
- Net helical coil wires surface area is 4.750 m²;
- Coil with a diameter of 25 mm.
- Copper wire with a diameter of 1.5mm
- Density of wire material (copper) is 8890 kg/m³;
- The double-sloped angle is 30 deg. horizontally.
- The basin height is 70 mm.
- Brine water depth is 60 mm.
- The isolation thickness is 40 mm of wool glass of thermal conductivity of Kw.g = 0.038(W/mK). And wood of thickness 25 mm of thermal conductivity 0.04 W/mK.
- Vibrator frequency is 30 Hz.
- Exciting force is 20 N.
- Mass of the station is 150 kg.
- Mass of brine water is 80 kg.

- Mass of helical coiled wires is 6.55 kg.
- Density of polycarbonate glass sheet is 900 kg/m³.

2.2. Experimental measurement procedure

The measurements of the productivities, with and without vibration, of the proposed solar still station are done during the first three weeks by running the vibrator day by day in order to have two consecutive day records at the same climatic conditions, for evaluating the vibratory harmonic effect. These two days (19th and 20th of September 2006) were found to have the same climatic conditions in these two days. The starting measuring time begins at 6 am and along 24 hours following this time until the ending measuring time at 6 am of the second day, so the quantity of distillate water is measured each six hours, at 12 pm, 18 pm, 12 0.0 am and 6 am. The solar irradiation distribution is calculated in the day of 20th September 2006 [19] and [20], for autumn sunny day and the total solar insolation is found to be 22.43 MJ/m²day.

3. GOVERNING EQUATIONS

3.1. Thermal analysis of the helical wires without vibration

The helical wires are used to assist the desalination process during the sunrise and after the sunset. The target of using it is to increase the distillate water productivity per day. The thermal equations of the helical wires are derived with no vibration and neglecting losses as [18]:

a- During sunlight:

$$q_{w_1} = m_w C_{pw} \frac{\partial T_{w_1}}{\partial t} \quad (1)$$

$$q_{w_1} = A_w I_x (\alpha\tau)_w + A_b I_x (\alpha\tau)_b \quad (2)$$

b- After sunset:

$$q_{w_1} = m_w C_{pw} \frac{\partial T_{w2}}{\partial t} \quad (3)$$

$$q_{w_2} = m_w C_{pw} \frac{\partial T_{w1}}{\partial t} + m_b C_{pb} \frac{\partial T_b}{\partial t} \quad (4)$$

The total absorbed solar radiation will be:

$$q_t = q_x + q_b + q_w = \int I_s dt \quad (5)$$

The performance of the modified solar still using helical wires is evaluated by the ratio of the energy that utilized in water vaporization in the still for daily distillate water productivity (W_{d1}), to the total input solar energy ($3600 \times \int I_s dt$) as follows:

$$\eta_w = \frac{W_{d1} \rho_d L_d}{3600 \times \int I_s dt} \quad (6)$$

3.2. The effect of the vibratory harmonic on the performance

The efficiency of the still when vibration is applied (η_{wv}) is expressed by the ratio of the energy that utilized for water productivity (W_{d2}) vaporization to the net input energy, that as:

$$\eta_{wv} = \frac{W_{d2} \rho_d L_d}{3600 \times \int I_s dt} \quad (7)$$

The vibratory harmonic effect can be expressed by the ratio between the increased distillate mass and the vibrator consumed power. This ratio is suggested to be called "vibratory performance gain (VPG)", as follows:

$$VPG = \frac{(W_{d2} - W_{d1}) \rho_d L_d}{P_v \times 24 \times 3600} \quad (8)$$

The value of the VPG may have a value greater than 1.0, because the power consumed by the vibrator is not converted to thermal power in the energy balance process, but it works as a catalytic agent to assist the heat transfer process, and hence increasing the rate of vaporization, also assisting the condensed droplets on the polycarbonate covers to slide down easy by breaking the surface tension before it grow up and possibly get lost.

The VPG may be calculated either for each period of the day or as average value per day.

4. EXPERIMENTAL RESULTS

4.1. Effect of flexible packed helical wires

The productivity of the solar still with modified helical packed wires is shown in Fig (4); it reached value of 3.4 l/m²day, with efficiency of 35%, see Fig (6).

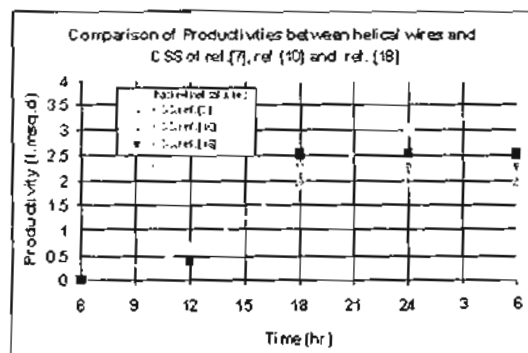


Fig (4) Effect of packed helical wires on the accumulated daily productivity and comparison with Ref. [7], [10], and [18]

There is a significant increase when compared with productivity of CSS of reference [18] by a ratio of 36%. The figure gives different comparisons with other

references [7] and [10] with increasing ratios more than the obtained ratio by reference [18]. The peak of performance rate production (PRP) is occurred at time hour 18 (6 pm), see Fig (5).

4.2. Effect of harmonically exiting on the system.

The effect of modified absorbing surface coupled with harmonically exited vibration on the production rate performance (PRP) is shown in Fig (5). There is a significant increase from 1.3 (l/m²h) to 2.2 (l/m²h) with increasing ratio of 69 %, while the accumulated daily productivity is increased, as shown in Fig (6) from 3.4 l/m²d to 5.8 (l/m²d) by increasing ratio of 72 %. The peak value of (PRP) is shifted from time hour 18 (6 pm) to be occurred at time hour 24 (12 0.0 pm), this due to the effect of excitation for utilizing the thermal stored energy. Fig (7) shows the average daily productivity and efficiency through out three weeks and comparisons with helical wires and CSS results of reference [7] which is measured in the same day of the year.

The "Vibratory Performance Gain (VPG)", which is defined by equation (8) is shown in Figure (8), there is a peak value of 4.4 at time hour 24 (12 pm mid night) and the daily average value is found to be 2.6. The figure indicates that the value of VPG is started from zero at the beginning of the solar time hour (6 am) and increased gradually by a constant rate until it reaches its peak at time hour 24 (12 pm) at mid night. This happened due to the excitation of thermal storage which is utilized for increasing the nocturnal production.

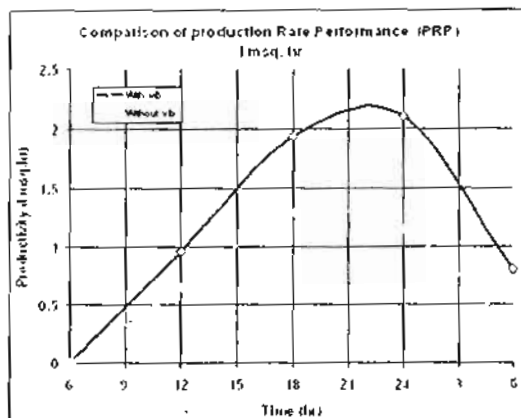


Fig (5) Production rate performance (PRP) of helical packed wires

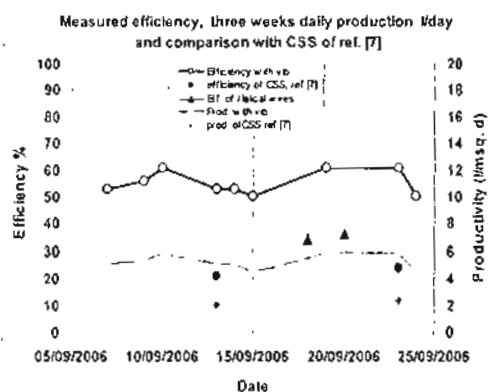
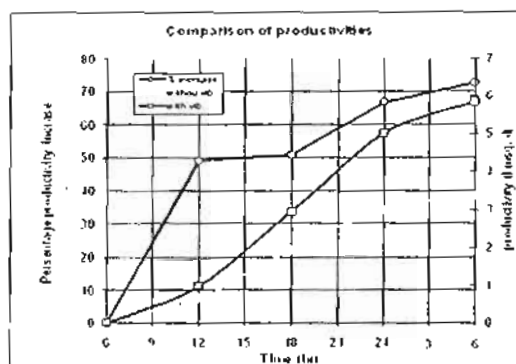


Fig (6) Comparison of accumulated daily productivities

Fig (7) Productivity and efficiency for 3 weeks and comparison with reference [7]

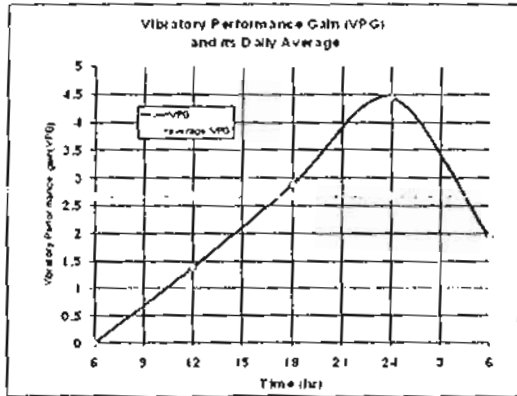
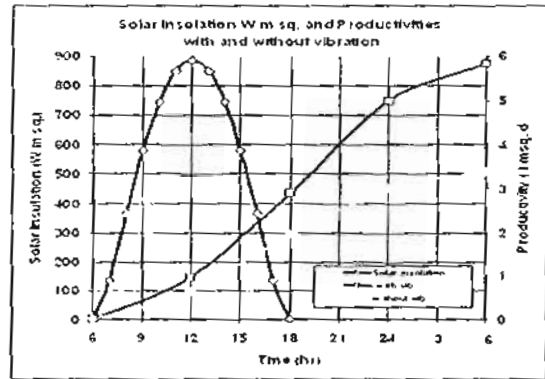


Fig (8) Vibratory performance gain (VPG) and its average

4.3. Effect of thermal storage

The effect of thermal storage in the basin brine water and helical packed wires on the nocturnal production is shown in Figure (9) with hourly solar insolation during the day of the 20th of September 2006 in the area of Wadi Eldwaser. It is shown that the nocturnal production is increased by 1.4 (l/m²d) with percentage of 41 % when operating without vibration and increased by a value of 2.9 (liters/m²d) with percentage of 50% when operating with vibration.

The maximum production rate performance (PRP) is found at time hour 18 (6 pm) for the helical packed wires and at time 24 (12 pm) when working with vibration, so that the vibratory excitation extending the nocturnal production period by about 6 hours, see Fig (10).



Fig(9) Solar insolation and accumulated productivities

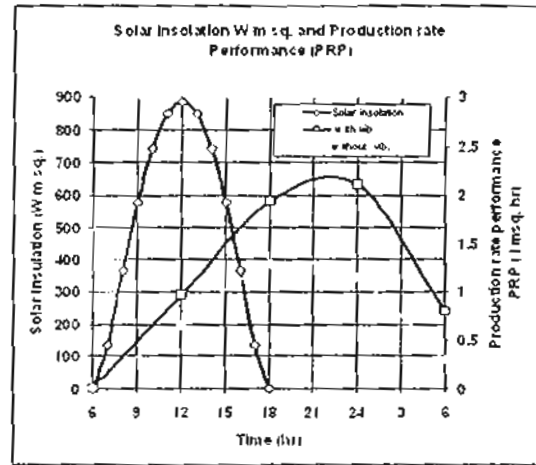


Fig (10) Solar insolation and Production Rate Performance (PRP)

The percentage of nocturnal production for three weeks with vibration is shown in Fig (11); its value is ranging from 37 to 50%.

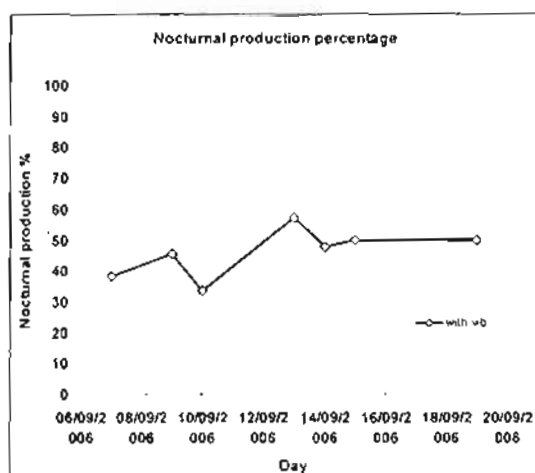


Fig. (11) Nocturnal production percentage

5. CONCLUSION

A new concept is used in the present work, it is based on modifying the absorbing surface media by installing stretched helical coiled wires in the basin of the solar still, and this packed layer has a good performance effect when it is excited harmonically.

The vibratory excitation is found to have a good effect on the performance of the modified solar still. Due to increasing the evaporation rate by the flexible packing layer and by improving the condensation mechanism on the polycarbonate covers

The productivity of the of the still with added helical wires is found to be 3.8 l/m² day with efficiency of 35% and increased with vibration to 5.8 l/m²day with efficiency of 60 %. The increasing percentage in the productivity due to the vibratory excitation effect is 72 %.

The productivity of the still with helical wires is 35 % more than the productivity of CSS and when vibration is applied this ratio increases to 132 %.

The effect of vibration is defined by the new parameter 'vibratory performance gain', it was found to be of average value of 2.6 and peak value of 4.4

The increasing percentage of nocturnal production with vibration is applied is found to be from 37 to 50% and its time is extended by about 6 hours more.

The results showed that using this concept is very promising for developing basin-type solar stills with very low investment costs.

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