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SOLAR DISTILLATION OF GROUND-WATER UNDER FAYOUM CLIMATIC CONDITIONS

Ragab I. A. Mourad*   Abd El-Wahed M. Aboukarima**

ABSTRACT

Solar distillation of Fayoum ground-water was applied to decrease the ground-water level, using a single sloped solar water-still. Some variables were investigated to evaluate the water-still performance, (solar radiation (R), ambient air temperature (T_a), and temperature difference between maximum and minimum ambient temperature (T_d)). The performance was characterized by the distillation water yield (Y). A statistical model, based on step-wise regression analysis was has shown to be significant for the included variables at the level of 0.001 significance. Four different equations for the distillation water yield were fitted as affected by experimental days, solar radiation, ambient air temperature and temperature difference. Results showed that, increasing distillation water yield as increasing temperature difference, and as solar radiation and ambient air temperature decrease. Also, the solar earth-water still gave a much higher water yield during the winter months than during the summer months.

INTRODUCTION

Hans and Jeans (1992) reported that, the major problem of Fayoum's agriculture is soil degradation, caused poor drainage, under-irrigation and inadequate soil leaching, due to a lack of adequate water supply to "tail end" sites of the Fayoum basin, and a lack of an adequate field drainage system in low lying areas of the basin.

The solar earth-water still may assists in meeting drinking water and solving the poor drainage problem. A single basin solar-still has been studied by many researchers {Ahmedzadeh, (1978), Moustafa & Brusewitz, (1979), Ahmed et al., (1986), and Clark, (1990)}. In addition, Mink et al., (1998), reported that, solar stills in many respects might be an ideal source of fresh water for both drinking and agriculture in arid zones. Minasian et al., (1992), designed a solar earth water-still for productivity drinking water in remote areas. They also, reported that, there is no need to line the bottom of the basin, and to insulate it, this reduces the initial cost of these stills. Ahmedzadeh (1978), Peralta et al., (1984), and Minasian et al., (1992), concluded that, the solar earth water-still gave a much higher output during the winter months than the summer months. They also, reported that, the high rate of output was happened during the nighttimes. Mink et al., (1998), reported that, about $1 m^3/m^2$/year was produced from the single solar water-still. Gonzalez et al., (1992), developed a mathematical model to predict the performance of shallow solar pond water heaters with black colored water bags. Fernandez and Chargoy, (1990), reported that, the rate of production of distillate is proportional to the evaporative surface in their horizontal multiple-effect still.

*Lect. Agric. Eng., Fym. Fac. of Agric., Cairo Univ.
**Res., Agric. Eng. Res. Inst., Agric. Res. Center

Ahmed et al., (1986), developed a multiple linear regression equation to predict water from hot-box solar earth water-still. The pertinent variables included, soil moisture, solar radiation and (maximum and minimum) daily temperatures.

Many prediction statistical models were developed. Minasian et al., (1992), developed the following regression equation;

$$P = 2800 - 69.7\ T_a + 6.62\ W - 3.23 \times 10^{-3}\ R\ ,$$

where; P is the output in ml/m^2/day, T_a is the ambient air temperature in, ^{o}c, R is the global solar radiation in W/m^2/day and W is the wind speed in, m/s. Peralta et al., (1984), reported that, a regression equation for a still with mean height of 20 cm and reflective interior siding has been developed and has the form of;

$$Y = -32.3\ MC + 0.022\ SR + 28.9\ TX - 24.4\ TN + 1136$$

where; Y is water production in gr/m^2/day, MC is soil moisture in, %, SR is solar radiation in kJ/m^2/day, and TX & TN are the maximum and minimum daily temperatures in, ^{o}c. Ragab, (2000), developed a regression model for a single sloped solar still, which has a form of;

$$Q = 0.002\ R + 0.011\ T - 0.042\ W + 0.08\ H + 137.93\ C - 0.03\ S - 17.9\ D$$

where; Q is the output in L/m^2/day, H is the percentage of daylight, C is the glass cover thickness in, m, S is the water salinity in, moms/cm, D is the initial water depth in, m, T is the ambient temperature in, ^{o}c, R is the solar radiation in, W/m^2/day, and W is the wind speed in, m/s. Clark, (1990) and Harprect, (1996), gave the total distillation yield Y from the following mathematical equation,

$$Y = 0.5\ A_e\ k\ h'c\ (p_c - p_g)$$

where; Y is the distillation yield in, kg/s, A_e is the total water evaporation area in, m^2, k is mass and heat transfer proportionality constant (7×10^{-9} kgk/PaJ), h'c is the modified convection coefficient in, W/m^{2}k, p_c is the water saturation pressure at collector in, Pa and p_g is the water saturation pressure at glass in, Pa.

This study aims to introduce and test the applicability of using a solar water-still model under Fayoum climatic conditions. Focusing on many parameters, such as, (solar radiation, ambient air temperature, temperature difference, and distillation water yield) during winter and summer seasons. Also, a regression equation was developed, using a step wise statistical analysis.

MATERIALS & METHODS

The experimental work was carried out during the period of December, January and February, as winter experiments, and during June, July and August, as summer experiments, at El-Gharak, Ettsa, El-Fayoum Governorate. This location has a sandy clay loam soil texture, as shown in Table (1). This location is ideal for these experiments due to the soil texture and the existence of ground water at shallow depths (about 0.78 m and 0.85 m below ground surface, during winter and summer season respectively). Moreover, this soil texture is considered to be good for this study due to its high capillarity and high stability against expected collapse of the hole sides (Minasin et. al. 1992). Thc salinity of the ground water in this area is normal. It's electrical conductivity (EC) ranges from 1.34 to 3.62 moms/cm.

Table (1): The mechanical analysis of the soil sample .

Sand (%)	Silt (%)	Clay (%)	Texture classes
78.37	6.50	15.17	Sandy clay loam

Experiments were carried out using one single sloped solar water-still of the type shown in Fig.(1). It consisted of a wooden frame of 1x1 m^2, with a 4 mm glass cover thickness inclined at an angle of 16^o to the horizontal. The still was oriented to face an east-west direction. A plastic channel was fitted under the lower side of the glass cover to collect the condensed water. The channel was terminated with a small plastic pipe, which drained the distillated water into an external vessel installed below the ground level. All openings in the sides of the still and all joints in the glass cover and channel were well sealed with silicon rubber sealant to minimize water vapor leakage. The still was placed directly over a hole, which has an area of 1x1 m^2 and 1 m deep. After placing the still, soil was used to seal around the wooden frame to prevent water vapor leakage.

leakage.

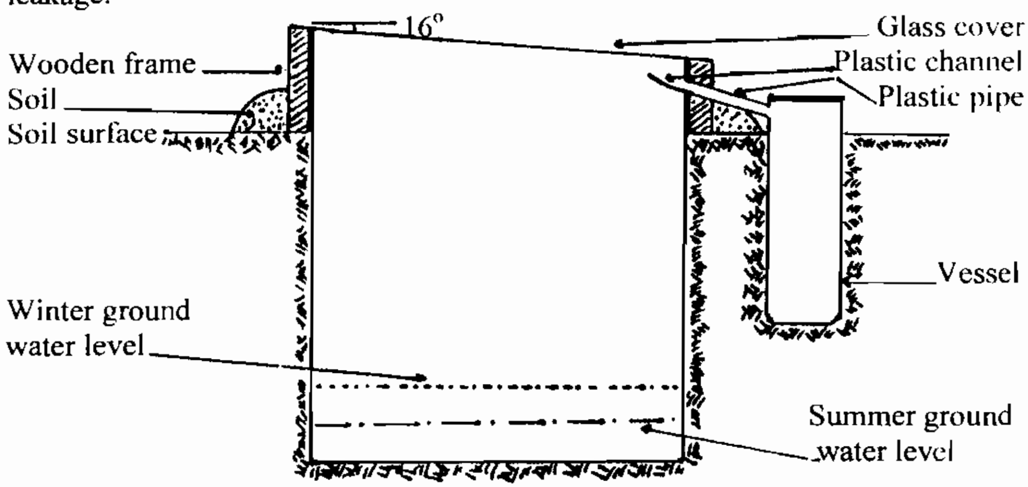


Fig.(1): The schematic diagram of the ground water solar still model.

Global solar radiation,(R), ambient air temperature, (T_a), and difference between maximum and minimum ambient temperature during daytime, (T_d), were measured. The value of distillation water yield, (Y), was measured daily between 8:00 am to 8:30 am.

RESULTS & DISCUSSIONS

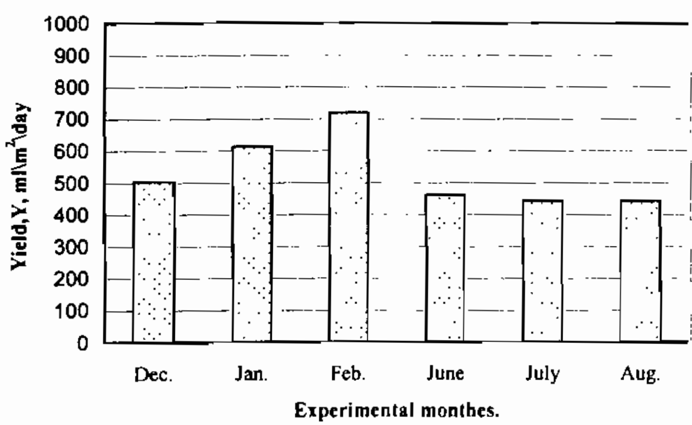
The following items introduce the results and discussions of this study.

Distillation Date Effect, (D):

As shown in Table (2) and Fig. (2), the better distillation water yield was obtained during winter months especially, at February, than during summer months, especially, at August. The obtained results agreed well with these reported by {Ahmedzadeh, (1978), Peralta et al.,(1984), and Minasian et al.,(1992)}. They stated that, the solar earth water-stills gave a much higher output during the winter months than during the summer months. This obtained results, because condensation is increased more strongly by a reduced ambient air temperature, (T_a) in winter season than it is increased by a warmer ground water temperature during hot months.

Table (2): The average data and the standard deviation of solar radiation, ambient temperature, temperature differences, and water yield during the winter and the summer seasons.

Variables as Avg. values	Winter months			Summer months		
	Dec. ±SD	Jan. ±SD	Feb. ±SD	June ±SD	July ±SD	Aug. ±SD
R, $W/m^2/d$.	451.6 ±42	446.6 ±27	440.5 ±64	539.7 ±31	564.8 ±63	613.9 ±49
T_a, °C.	24.70 ±1.6	22.20 ±1.7	19.20 ±1.8	26.80 ±2.6	29.90 ±2.8	32.60 ±2.9
T_d, °C.	16.60 ±1.0	17.30 ±1.3	19.10 ±1.6	12.70 ±1.7	11.20 ±1.9	10.90 ±1.7
Y, $ml/m^2/d$.	503.8 ±66	612.6 ±57	718.8 ±41	461.7 ±46	444.3 ±60	442.5 ±58



Fig(2): Monthly distillated water yield.

Two equations were developed by Grapher Statistical Software, as shown in Fig.(3). One equation for winter period, which has a form of;

$$Y = 362.18\ D^{0.1424} \qquad R^2 = 0.96$$

And the second equation for summer months, which has a form of;

$$Y = 464.98\ D^{-0.01176} \qquad R^2 = 0.96$$

Where; Y is the distillation water yield in $ml/m^2/day$, and D is the day number during the experiments.

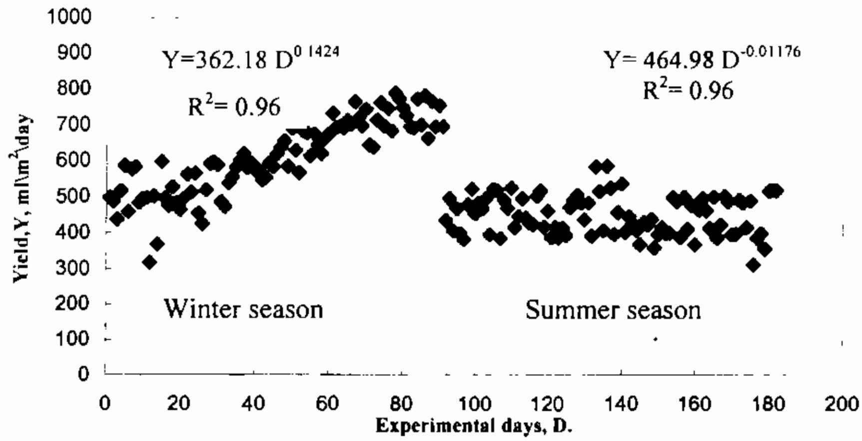


Fig.(3):Effect of experimental days on distillated water yield.

Temperature Difference Effect, (T_d):

Figs.(4 and 5) show the effect of temperature difference on distillation water yield. It's clear that, as temperature difference increases, the distillation water yield increases. In general, the high values of temperature difference were appeared during winter months, so, the high distillation yield was resulted during winter months, than during summer months. Data of temperature difference was fitted using Grapher Statistical Software, and the following equation was resulted;

$$Y = 90.861\ T_d^{0.6555} \qquad R^2 = 0.93$$

Where; Y is the distillation water yield in ml/m²/day, and T_d is the temperature difference in °c.

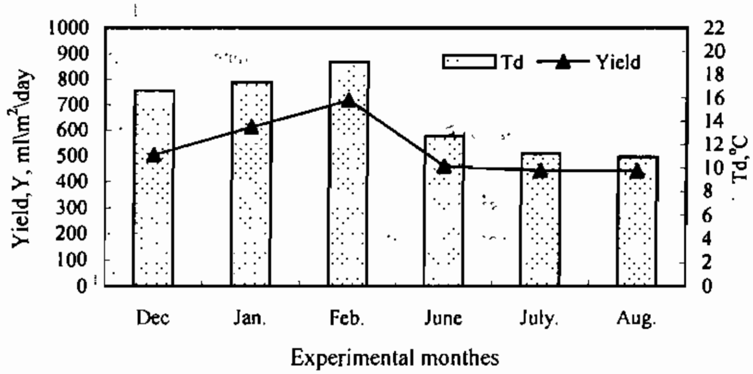


Fig.(4): Effect of monthly temperatures differences on distillated water yield.

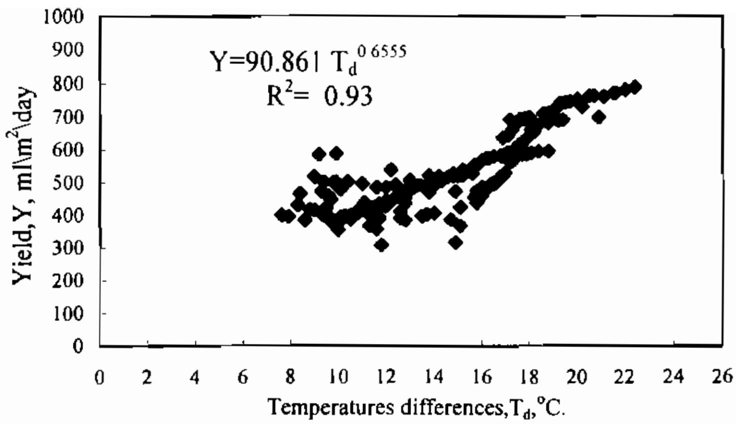


Fig.(5): Effect of temperatures differences on distillated water yield.

Ambient Air Temperature Effect, (T_a):

Fig. (6) shows the effect of ambient temperature on distillation yield. It's indicated that, as ambient air temperature decreases, the distillation yield increases. However, the decreasing of ambient temperature is caused to decrease the glass cover temperature, so condensation take place and distillation yield increases. The Grapher Statistical Software was used to develop the best fit of data. The obtained equation is in form of;

$$Y = 23143.8\ T_a^{-1.182} \qquad R^2 = 0.92$$

Where; Y is the distillation water yield in ml/m²/day, and T_a is the ambient air temperature in °c.

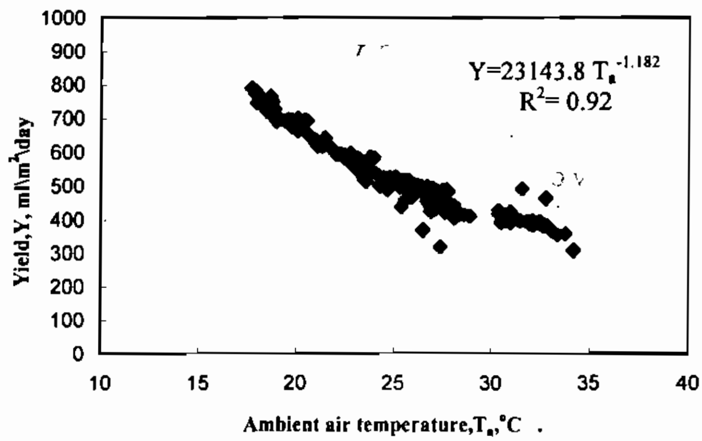


Fig.(6): Effect of ambient temperature on distillated water yield.

Solar Radiation Effect, (R):

In illustration Fig.(7), in general, that, there was a decreasing in distillation water yield, with increasing solar radiation. The obtained results a greed well with those reported by Minisian et al, (1992). They stated that, days of increased output correspond to days of decreased ambient air temperature and decreased solar radiation. An equation was developed by Grapher Statistical Software, which has a form of;

$$Y = 222281\ R^{-0.974} \qquad R^2 = 0.0.85$$

Where; Y is the distillation water yield in $ml/m^2/day$, and R is the solar radiation in $W/m^2/day$.

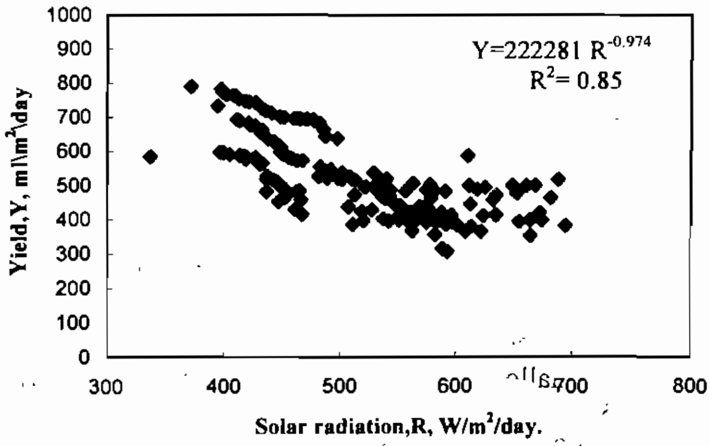


Fig.(7): Effect of solar radiation on distillated water yield.

The Solar Still Efficiency (η):

To calculate the ground water solar still efficiency, the following formula (by Moustafa and Brusewitz, 1979) was used;

$$\eta = q_e / R$$

where; η is the operation efficiency of solar still, %.

q_e is the rate of heat flux transferred by evaporation between water surface and still cover, W/m^2.

$$q_e = 0.0061\{(T_w - T_g) + (P_w - P_{wg}/0.265 - P_w).T_w\}^{1/3}.(P_w - P_{wg})L_w$$

P_w is the saturation pressure of water at T_w, MPa,

$$P_w = e^{25.317-(5144/Tw)}$$

P_{wg} is the saturation pressure of water at T_g, MPa,

$$P_{wg} = e^{25.317-(5144/Tg)}$$

L_w is the latent heat of water at saturation temperature (T_w), J/kg,

$$L_w = (2501.67 - 2.389\ T_w)\ .\ 10^3$$

T_w is the water temperature within the still, $^o k$,

T_g is the glass cover temperature within the still, $^o k$.

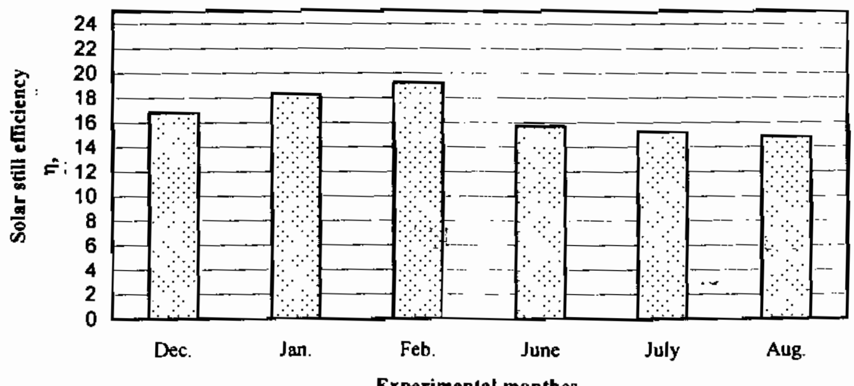
R is the solar radiation, W/m^2.

The calculations:

Table (3) and Fig.(8) show the calculated results of the solar still efficiency during the winter and the summer seasons. The results indicated that, the better still efficiencies were obtained during winter months especially at February, than during summer months especially at August.

Table (3): The calculated results of solar still efficiencies.

Parameters	Winter months			Summer months		
	Dec.	Jan.	Feb.	June	July	Aug.
T_a, °k.	297.7	295.2	292.2	299.8	302.9	305.6
T_w, °k.	295.8	294.8	293.1	299.3	303.2	306.2
T_g, °k.	308.2	307.9	307.2	311.1	313.7	316.2
R, W/m^2	451.6	446.6	440.5	539.7	564.8	613.9
P_w, MPa.	$2.77*10^{-3}$	$2.61*10^{-3}$	$2.36*10^{-3}$	$3.39*10^{-3}$	$4.24*10^{-3}$	$5.00*10^{-3}$
P_{wg}, MPa.	$5.58*10^{-3}$	$5.49*10^{-3}$	$5.28*10^{-3}$	$6.52*10^{-3}$	$7.50*10^{-3}$	$8.50*10^{-3}$
L_w, J/kg.	$1795*10^3$	$1797*10^3$	$1801*10^3$	$1787*10^3$	$1777*10^3$	$1770*10^3$
q_e, W/m^2.	76.8	80.0	83.0	85.0	86.0	91.3
η, %.	17.0	18.0	19.0	15.7	15.2	14.8



Fig(8): Solar still efficiencies during the experimental period.

Model Statistical Analysis:

Based on the effects of the introduced variables, each of them has its noticeable effect on the distillation water yield. They have many varying individual importance, and their interactions would be expected to affect the distillation water yield substantially. The effects of the individual variables (solar radiation, ambient temperature and temperature difference), and their interactions on the distillation yield were statistically analyzed. A simple statistical program was developed, utilizing the SAS statistical package. The forward step-wise regression analysis was applied to arrive at a reasonably good best set of independent variables. The result of the regression model could be shown as follows ;

$$Y = 380.87 + 1.075\ T_d^2 + 0.0157\ RT_d - 0.585\ T_aT_d$$

Where; Y is the distillation water yield in ml/m^2/day, and T_d is the temperature difference in °c, T_a is the ambient temperature in °c, and R is the solar radiation in W/m^2/day.

The model has shown the significance of all individual variables at significant level of 0.001. However, the temperature difference has shown a significance with its quadratic form T_d^2 at the 0.0001 significant level. The interactions between solar radiation and temperature difference and between ambient temperature and temperature difference have shown to be significant at 0.001 level. No other interactions or high order of any variables appeared to be significance. The coefficient of determination R^2 for the final model was 0.89 .

To evaluate the solar ground water-still model, a linear regression model was developed with observed distillated water and the predicted distillated. A graphical comparison of the observed versus predicted distillated water is presented in Fig. (9) and $R^2 = 0.85$.

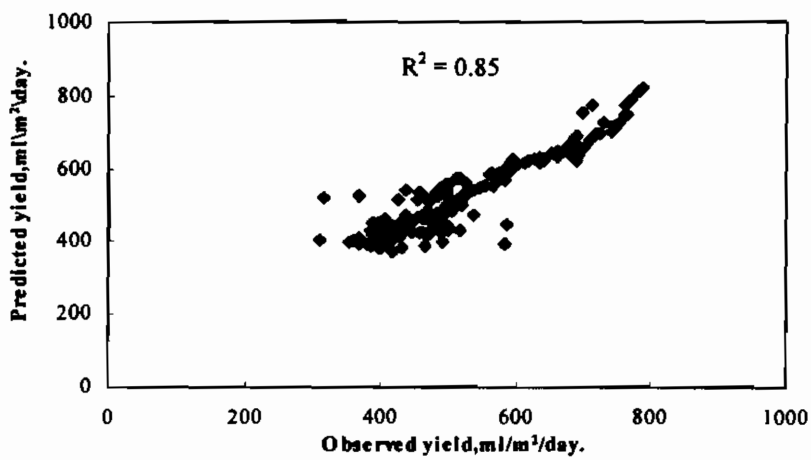


Fig.(9): Obseved water yield vs predicted water yield.

CONCLUSIONS

Based on the experimental results of 6 months, as sets of predictive equations are presented for estimating distillation water yield from the Fayoum ground water solar still. This set relates yield to solar radiation, ambient temperature and temperature difference.

As there is little water in the still, in the vapor state, relative to the production of the still, at any time, the rates of evaporation and condensation will be very nearly equal. These processes start directly after sunset and continue during the nighttime, as long as the temperature of the cover is below the dew point of the air vapor mixture in the still. At sunrise, the cover temperature rises and the evaporation-condensation processes decrease. This differs from that of a conventional basin-type solar still, where the basin is heated in the daytime to the point where the vapor pressure is high enough to cause condensation even through the cover is at a higher temperature.

RECOMMENDATION

This research is a trail to eliminate the Fayoum ground water, and to supply drinking water from the ground water. This idea can be applied on open drainers to supply drinking water.

REFERENCES

Ahmedzadeh, J.(1978) Solar earth-water stills. Solar Energy J.20(3):38- 391

Ahmed, Y.R.; R.C. Peralta; T.M. Skergan and D.B. Marx (1986). Potential solar earth-water distillate yield in Africa. Solar Energy J. 36(5): 451-458.

Clark, J.A. (1990) The steady state performance of solar still. Solar Energy J. 44 (3): 43-49.

Fernandez, J.L. and N. Chargoy (1990). Multi-stage indirectly heated solar still. Solar Energy J. 44(4): 215-223.

Gonzalez, J.; L.R. Perez and J. Benitez (1992). Modeling the thermal process a shallow solar pond water heater. Solar Energy J. 48(4): 261-265.

Harprect, S. K. (1996). Performance of a solar still : predicted effect of Enhanced evaporation area on yield and evaporation temperature. Solar Energy J. 56(3): 261-266.

Hans, C.J. and K.W. Jeans (992). Environmental profile, Fayoum Gover-Norate. Euro Consult, Darwish Consulting Engineers, Ershem, the Netherlands.

Minasian, A. N.; A.A. Al-Karaghouli; M. Hasan and A. shakir (1992). Utilization of solar earth-water stills for desalination of ground water Solar Energy J. 49(2) 107:110.

Mink, G.; M.M. Aboabboud and E. Karmazsin (1998). Air-Blown solar still with heat recycling. Solar Energy J. 62(4):309-317.

Moustafa, S.M.A. and G.H. Brusewitz (1979). Direct use of solar energy For water desalination. Solar Energy J. 22(3):141.

Peralta, R. C.; T. M. Skergan and D. B. Marxm (1984). Solar earth-water distillation for wet sand. Trans. Of ASAE 27: 1690-1695.

Ragab, I. A. M. (2000). The use of solar energy for desalination of salty Water from the lakes of Fayoum. Ph. Thesis Fayoum Fac. of Agric. Cairo University.

الملخص العربي

التقطير الشمسي للماء الأرضي
تحت الظروف المناخية لمنخفض الفيوم

*رجب إسماعيل أحمد مراد **عبد الواحد محمد أبو كريمه

أجريت هذه الدراسة بمنطقة الغرق- مركز اطسا بمحافظة الفيوم. تم عمل نموذج صندوقي للتقطير مصنع من الخشب وذو غطاء من الزجاج الشفاف الذي يميل على الأفقي بزاوية 16° ، بينما الجهة السفلية للمقطر مفتوحة لتواجه حفرة بقطاع التربة ذات أبعاد 1x1م^2 وبعمق 1م. حيث تم تقييم هذا النموذج من خلال دراسة بعض العوامل المؤثرة على كفاءة أداء هذا النموذج ، كالطاقة الشمسية ، درجة حرارة الجو والفرق بين درجتي الحرارة العظمي والصغرى ، حيث قدر الأداء بكمية المياه المقطرة خلال 24 ساعة . ولقد أوضحت النتائج ما يلي :-

1- عموما، زيادة كميات المياه المقطرة خلال أشهر الشتاء عن أشهر الصيف.

2- أعلى كمية مياه جمعت خلال شهر فبراير (حوالي 800 مل/م^2/يوم)

3- لوحظ أثناء التجارب ، ارتفاع معدل التقطير أثناء ساعات الليل عن ساعات النهار

4- استنبطت أربعة معادلات كأحسن توقع لقيم كلا من (أيام التجارب (D)، الطاقة الشمسية (R) ، درجة حرارة الجو (T_a) و الفرق بين درجتي الحرارة العظمى والصغرى (T_d)) وذلك من خلال استخدام برنامج Grapher الإحصائي .

5- تم حساب كفاءة المقطر خلال أشهر التجارب واظهرت النتائج تفوق اشهر الشتاء على اشهر الصيف.

6- أظهر التحليل الإحصائي معنوية عالية للمتغيرات عند مستوى 0.001 معنوية وكان النموذج الإحصائي الناتج على الصورة التالية:

$$Y = 380.87 + 1.075\, T_d^2 + 0.0157\, RT_d - 0.585\, T_aT_d \qquad R^2 = 0.89$$

حيث Y كمية المياه المقطرة خلال اليوم (مل/م^2/يوم) ، R قوة الشعاع الشمسي الساقط على الأرض (وات/م^2 /يوم)،T_a درجة حرارة الجو(°م) و T_d الفرق بين درجتي الحرارة العظمى والصغرى خلال اليوم (°م).

التوصية:-

تعتبر هذه الدراسة محاولة جديدة للعمل على تقليل منسوب المياه الأرضى بقطاع محافظة الفيوم ، كما انه من الممكن تطبيق هذه الفكرة على المصارف المكشوفة للاستفادة من المياه المتبخره الى الجو لانتاج مياه الشرب.

*مدرس الهندسة الزراعية – كلية الزراعة بالفيوم – جامعة القاهرة
**باحث – معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية