PARAMETERS AFFECTING SOLAR STILL PRODUCTIVITY

العوامل المؤثرة علــــى انتاجيــــة المقطــر الشمســي

*A. SAFWAT NAFEY ** M. ABDELKADER

**A. ABDELMOTALIP *A. A. MABROUK

* Engineering Science Department, Faculty of Petroleum & Mining Engineering, Suez. Suez Canal University, Egypt.

** Mechanical Power Engineering Department, Faculty of Engineering, Port Said, Suez Canal University, Egypt.

الخلاصة

في هذا العمل تم بحث العوامل المؤثرة على الإنتاج اليومي للمقطر الشمسي تحت ظروف التشغيل المصرية. حيث تم تصميم و تنفيذ أربعة نماذج معملية للمقطر الشمسي للعمل تحت نفس ظروف التشغيل وقد أجريت التجارب المعملية خلال الفترة من يناير ١٩٩٨ إلى ديسمبر ١٩٩٨ بناءا على نتائج هذه التجارب تم إيجاد معادلة بسيطة لحساب الإنتاج اليومي للمتر المربع للمقطر الشمسي. هذه المعادلة عبارة عن علاقة بين الإنتاج اليومي و المتغيرات الجوية (الإشعاع الشمسي ، درجة حرارة الجو ، سرعة الرياح)و بعض المتغيرات التصميمية (زاوية ميل الغطاء الزجاجي ، النسبة بين عمق الماء المالح في الحوض وارتفاع الجدار الأمامي للمقطر) ويمكن بواسطة هذه المعادلة حساب الإنتاج اليومي للمقطر الشمسي بخطأ لا يتجاوز ± ٥ %

ABSTRACT

In this work, investigation of the main parameters affecting solar still performance under the weather conditions of Suez Gulf area is considered. Four solar still units are designed and constructed to operate under the same weather conditions with different design parameters. A general equation is developed to predict the daily productivity of a single-sloped solar still. The developed equation relates the dependent and independent variables, which control the daily productivity. This equation could be used to predict the daily productivity with reasonable confidence level (max. error ± 5 %).

INTRODUCTION

Good predictions for the solar still performance under certain weather conditions and design parameters not only will save time but also save money. The water productivity can be predicted by a number of published correlations that was given by Ebiling *et al.* (1971) and Riera *et al* (1978). These correlations have been deduced from experimental data under certain operating conditions. However, the design parameters such as glass cover inclination angle and brine depth have not been considered. Also, the validity and the applicability of these correlations are not fully examined under the Suez Gulf weather conditions. Therefore, it would be important to develop an acceptable relationship for solar still productivity as a function of the weather conditions of Suez Gulf area and some of the design parameters. Experimental evaluation of some published mathematical models of the solar still has

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been conducted by Abd elkader *et al.* (1999). They concluded that the mathematical model of Malik *et al.* (1982) is in a good agreement with the experimental single sloped solar still operated under the weather conditions of Suez Gulf area. The main objective of this work is to deduce an equation to predict solar still productivity and investigate the main parameters affecting this productivity experimentally and theoretically based on the mathematical model of Malik *et al* (1982)

EXPERIMENTAL SET UP

Four identical units of single-sloped solar still were constructed as shown in Figure (1). These units allow investigating the effect of different parameters under the same operating conditions. Each unit consists of a metallic box having four sides. These sides are made of steel sheet, 2 mm thick. Sides of each box are painted with white color from the inside to reflect the solar radiation to the water surface. The base of each unit is painted with black color to increase the solar absorptivity. The outside walls and the base of each unit are insulated with foam of 4 cm thick The insulation is mounted on the wall by a certain adhesive. The condensing surface in each still unit is a glass cover of 3 mm thick. The glass cover of each still box is adjusted on the edge of the rectangular sides Silicon rubber sealant is used to prevent leakage from any gap between glass covers and still box. A collection trough is used for each still box to collect the condensed water This trough is fixed to the lower rectangular side of the still box. The amount of distilled water is measured at hourly intervals. The wind speed is measured by an anemometer. Solar intensity is measured by Silicon Pyrometer with Integrator (Solar 118 model 8347).

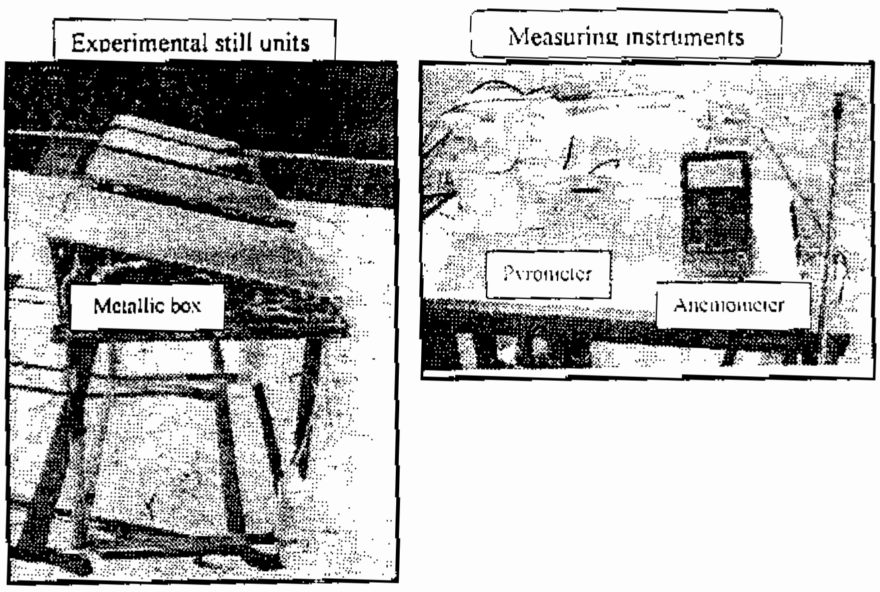

Fig. 1 Experimental test rig of the solar still units

RESULTS AND DISCUSSION

A. *Effect of solar radiation*

The effect of the solar radiation on productivity has been investigated in many publications [1,5,6]. It was found that the solar radiation is the most affecting parameter on the still productivity

The available pyrometer is used to record simultaneously two values of solar energy that incident on a horizontal surface at the site of Suez Gulf area. The first reading referred as ***Irradiance energy*** which is defined as the radiant energy per unit time, (W/m^2) and the other value is referred as ***Irradiation energy*** (integration of Irradiance over an hour, Wh/m^2). The two measured data of the solar radiation intensity are presented in Fig.2 This figure shows that, irradiation energy is lower than the irradiance energy during the morning, however the converse situation is noticed during afternoon periods

The measured values of both Irradiance and Irradiation energy are used as input data to the Malik's model (1982) for calculation the still productivity. The numerical results showed that, the still productivity based on the data of Irradiation energy is in a good agreement with that obtained experimentally as shown in Fig.3.

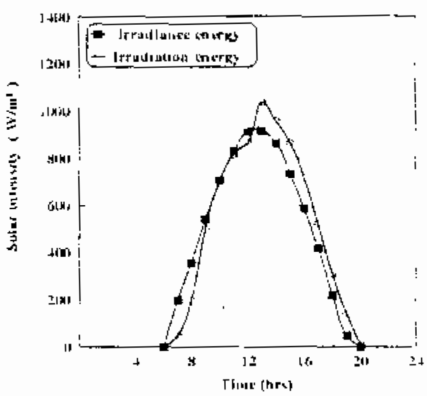

Fig.2: A typical data of solar energy recorded on May, 1998 at the site of Suez city

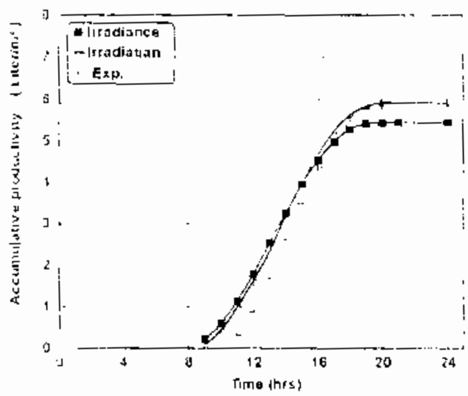

Fig.3: Accumulative productivity variation along the daytime

In general, the productivity of the solar still increases as the incident solar radiation increases. Fig.4 illustrates both the solar radiation intensity and still productivity variations along the year (1998). This figure indicates that the solar radiation intensity affected still productivity and this effect is pronounced on summer season. Also this figure shows that, the productivity of the single sloped-solar still through the year is averaging 4.2 (liter/m² day) approximately

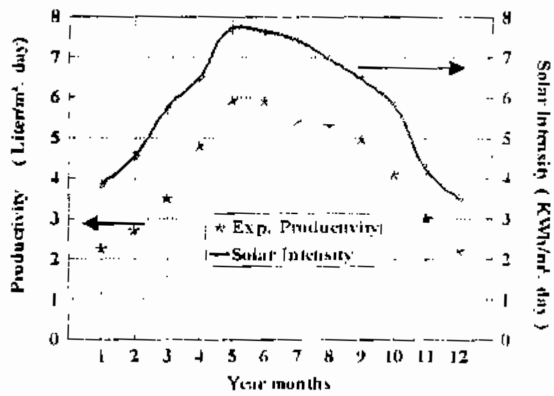

Fig.4: Variation of both solar radiation intensity and still productivity along the year months

B. *Effect of the brine depth*

Theoretical investigation is carried out with the computer aid based on the model of Malik *et al.* (1982), under the weather conditions of September 1998 The numerical results are represented in Fig.5 This figure illustrates that as the brine depth increases, the solar still productivity decreases.

Experimental investigation is carried out under the weather conditions on September 1998, by using the four still-units Each unit is employed to operate at specified brine depth. The experimental results are shown in Fig.6 This figure indicates that as the water depth increases from 2 cm to 7 cm, the output decreases with 14 % It is observed from the experiments that a still with 2 cm water depth will start producing earlier than with other of greater thickness and at a higher rate through the day periods, but the productivity diminishes rapidly after sunset. On the other hand, the still unit with 7 cm water depth lags at all day with the difference in accumulated productivity reaching 1 Liter/m^2 in the afternoon, but due to its large thermal capacity it keeps producing after sunset and during the night. It should be noticed from Figs.5 and 6 that, the numerical results are in a good agreement with the experimental results.

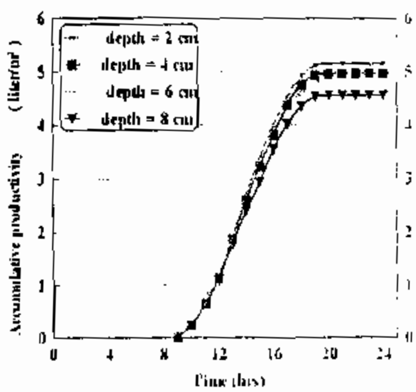

Fig.5: Theoretical variation of still productivity with brine depth

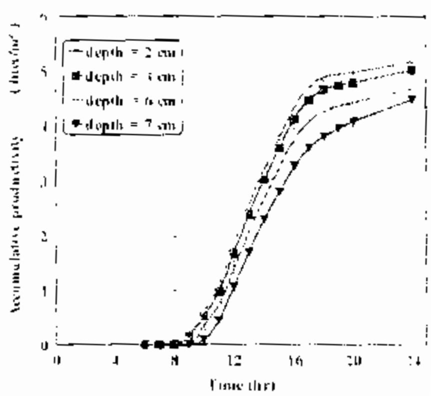

Fig.6: Experimental variation of the still productivity With brine depth

C. *Effect of glass angle*

The slope of the cover must be sufficient to ensure that the condensed water runs smoothly to the trough without reflecting too much solar energy and without forming large droplets. It is found that, the mathematical model of Ghoraba (1987) has the distinction of considering the glass angle parameter. So Ghoraba's model is employed to predict the angle of the solar still cover that will give optimum productivity under the Suez Gulf weather conditions.

Under the local weather conditions of Suez City in January 1998, the effect of the glass angle variations on the solar still productivity is shown in Fig.7. This figure illustrates that; the productivity increases as the glass angle increases. These results may be attributed to the lower declination angle of the incident solar energy in winter season. The declination angle is amounted by -23.0° in January, however this value is amounted by 23.45° in June [2].

Under the weather conditions of July 1998, the effect of glass angle variations on the productivity is illustrated also in Fig.7. This figure illustrates that, as the cover slope decreases the productivity increases. This may be because, the horizontal plane surfaces receives more solar radiation than the inclined surfaces during summer season. From the previous points, it may be concluded that, the glass angle must be as small as possible in the summer season, however, during the winter the converse situation should be maintained.

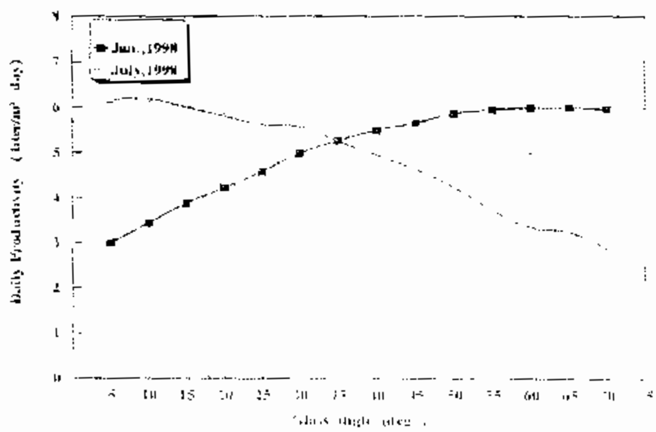

Fig.7: Theoretical variation of the still productivity with glass tilt angle

The effect of glass angle on the productivity is experimentally investigated under the winter (January 1998) and the summer (May 1998) weather conditions. Four glass angles of 15°, 20°, 25° and 40° are considered under the same operating conditions [illegible] both seasons. Fig.8 illustrates that the output increase as the cover inclination angle decreases during the summer season. However, for the winter [illegible] the productivity increases [illegible] with the increase of the glass angle.

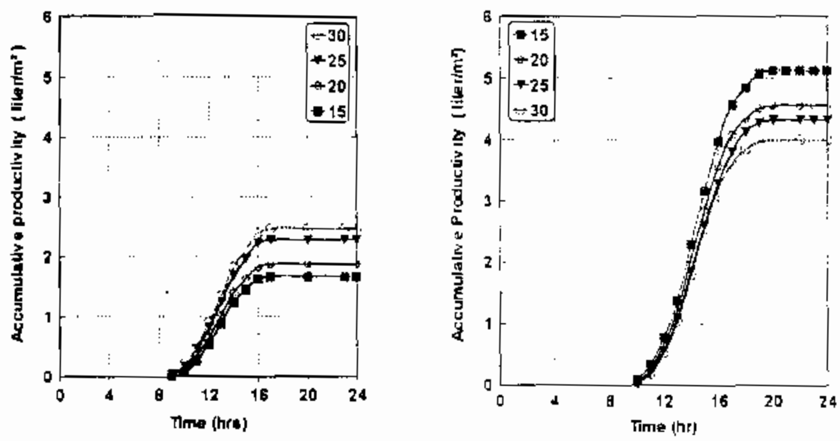

Fig.8: Experimental variation of the still productivity with glass tilt angle

SUGGESTED EQUATION FOR THE DAILY PRODUCTIVITY

The experimental work was carried out during the period that extended from January 1998 to December 1998 in order to cover the whole year. All the measured and recorded data during the experimental work are tabulated in Table (1). This table includes the weather conditions such as solar irradiation (H), the average ambient air temperature (ta), and the average wind speed (V). Also this table includes some of the design and operating conditions such as, inclination of the glass cover (θ), brine depth and the ratio of brine depth to the height of the frontal wall of the still (δ / l). From table (1) it can be seen that under the Suez Gulf region weather conditions, the average productivity of the single sloped solar still is about 4.2 (Liter/m² day)

Table (1) Results of the experimental work which carried out from Jan.1988 to Dec. 1998

Month	H_d kWh/m²	ta °C	V m/s	θ degrees	Depth cm	δ / l dimensionless	P Liter/m²day
Jan.	3.85	23.55	4.5	30	1	0.17	2.35
Feb.	4.56	23.7	3.9	30	1	0.17	2.81
Marsh	5.75	24	3.8	30	3	0.5	3.49
April	6.52	24.4	2.4	30	1	0.17	4.75
May	7.71	28.5	3.5	15	2	0.33	5.83
June	7.63	31	2.8	15	2	0.33	5.9
July	7.41	32.4	2.8	15	2	0.33	5.39
August	6.94	34	4.4	15	2	0.33	5.38
Sept	6.45	30.8	4.4	15	2	0.33	4.96
Oct	5.59	28.7	2.4	15	2	0.33	4.1
Nov.	4.2	25	2.7	15	3	0.5	2.4
Dec.	4.0	24	4	15	1	0.17	2.5

Based on the data of Table (1) and with the aid of SPSS computer software package [[illegible]], an equation for the prediction of the daily productivity of the solar still can be obtained by using multiple linear regression technique as follows,

$$P_d = -1.39 + 0.894\ H_t + 0.033\ t_a - 0.017\ V - 0.008\ \theta - 1.2(\delta / l) \quad (1)$$

To measure the strength of the relation between the dependent and the independent variables of Equation (1), the multiple correlation coefficient (R) is calculated. The multiple correlation coefficient (R) was calculated and found to be 0.99 for still productivity. This indicates that 98 % of the variability of the dependent variable (P_d) has been explained by the fitted multiple regression of (P_d) on the five variables [10].

VALIDITY OF THE SUGGESTED EQUATION

A comparison between the productivity calculated by the suggested equation and that calculated by published equations by Ebiling (1971) and that given by Riera (1978) is reported. The comparison is performed under the same weather and operating conditions as given in the experimental work of Mowla *et al.* (1995), Table (2)

Table (2) Climatic conditions and designs parameter as presented in Mowla *et al.* (1995)

Solar energy	[illegible]5 kWh/m²
Average ambient temperature	[illegible] °C
Wind speed	[illegible] m/s
Depth of water	2 cm
Glass angle	[illegible]6
Basin area	1.0 m²
Still daily productivity	[illegible] kg/day m²

Fig 9 illustrates that the productivity obtained by the suggested equation is the nearest one to the experimental productivity obtained by the work of Mowla *et al.* (1995)

To examine the validity of the developed equation [illegible] year months the fractional error (F) is used and defined as follows

$$\% F = \frac{Y - Y_{cal}}{(Y + Y_{cal})/2} \quad (2)$$

The fractional error (F) is calculated for each [illegible] equation using the Suez Gulf region weather conditions along [illegible] the [illegible] comparison [illegible] shown in Fig 10. This figure indicates [illegible] is more suitable to the Suez zone weather conditions [illegible] predict the [illegible] productivity with reasonable confidence [illegible] 5 [illegible]

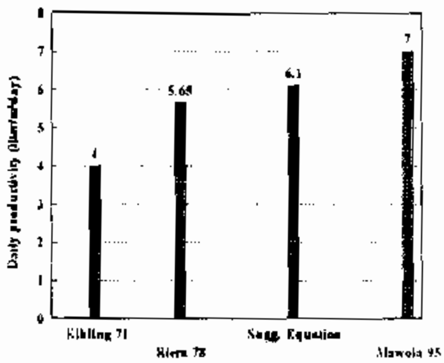

Fig.9: Validity of the suggested equations.

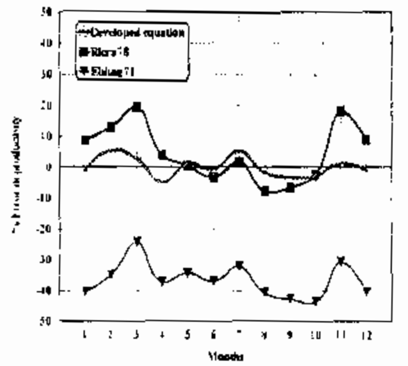

Fig. 10: Validity of the developed equation.

CONCLUSIONS

The most important conclusions of the present work are:

1. Under the Suez Gulf region weather conditions, the productivity of the single sloped- solar still through the year is averaging 4.2 (liter / m^2.day) approximately.

2. A general equation is developed to predict the productivity of a single-sloped solar still. The developed equation relates the dependent and independent variables, which control the daily productivity. This equation could be used to predict the daily productivity with reasonable confidence level (max. error ± 5%)

NOMENECLATURE

F	:	Fractional error in the productivity, (dimensionless)
H_d	:	Solar irradiation, (kWh/m^2)
h_e		Evaporative heat transfer coefficient (Water & glass), (W/m^2 ^{0}C)
h_c		Convective heat transfer coefficient (Water & glass), (W/m^2 ^{0}C)
h_r		Radiative heat transfer coefficient (Water & glass), (W/m^2 ^{0}C)
h_{ca}		Convective heat transfer coefficient (ambient & glass), (W/m^2 ^{0}C)
P_d	:	Daily productivity of the solar still, (liter/m^2 day)
$(P_d)_{EXP}$	:	Daily productivity obtained from the experimental work, (liter/m^2 day)
t_a		Average ambient air temperature, (^{0}C)
V		Wind velocity, (m/s)
θ	:	Glass inclination angle, (degrees)
δ / l	:	Brine depth to the frontal height of the still ratio, (dimensionless)

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