การประเมินสมรรถนะระยะยาวเครื่องกลั่นน้ำพลังงานแสงอาทิตย์โดยใช้ฟังก์ชั่นการใช้ประโยชน์

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บทคัดย่อ

งานวิจัยนี้ได้ทำการศึกษาสมรรถนะของเครื่องกลั่นน้ำพลังงานแสงอาทิตย์ สมรรถนะที่สนใจคือ อัตราการกลั่นน้ำ จากการทดลองพบว่าอัตราการกลั่นรายชั่วโมงไม่มีความสัมพันธ์แบบเส้นตรงกับค่ารังสีอาทิตย์รายชั่วโมง เป็นผลเนื่องมาจากความจุความร้อนของน้ำในเครื่องกลั่น แต่พบความสัมพันธ์แบบเส้นตรงระหว่างค่ารังสีอาทิตย์และอัตราการกลั่นน้ำรายวัน และความสัมพันธ์ระหว่างอัตราการกลั่นน้ำรายวันที่คำนวณโดยวิธีของ Dunkle กับค่ารังสีอาทิตย์รายวันก็เป็นแบบเส้นตรงเช่นเดียวกัน ผลของอุณหภูมิสิ่งแวดล้อมและความเร็วลมต่ออัตราการกลั่นขึ้นต่อค่ารังสีอาทิตย์ค่อนข้างมาก ดังนั้นจึงสามารถคำนวณสมรรถนะระยะยาวของเครื่องกลั่นน้ำได้ง่ายโดยอาศัยฟังก์ชั่นการใช้ประโยชน์ โดยสร้างฟังก์ชั่นนี้ได้จากค่ารังสีอาทิตย์รายวัน สมรรถนะที่ประเมินโดยวิธีนี้มีค่าใกล้เคียงกับผลการคำนวณด้วยวิธีของ Dunkle ที่ใช้ข้อมูลรังสีอาทิตย์รายชั่วโมงเฉลี่ยรายเดือน

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Long -Term Performance Estimation of Solar Water Still Based on Utilizability Function

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Abstract

Performance of a basin solar water still such as production rate is studied in this research. It is observed that the measured production rates of the still do not vary linearly with hourly solar radiation incident on the basin. This is due to water heat capacity effect. The measured daily still productivity depends linearly on daily total solar radiation. The relation between the calculated daily still productivity based on Dunkle's method and daily total solar radiation is also linear. Effects of ambient temperature and wind speed on still output strongly depend on solar radiation. So long-term performance of the still can be easily calculated based on utilizability function. The function is developed from daily solar radiation. This performance is comparable to that of Dunkle's of which monthly mean hourly solar radiation is input data.

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1. INTRODUCTION

Potable water is often scarce in semi-arid area. Even though abundant fresh water is found in many areas, it is expected that in the near future people around the world will be short of drinking water due to water pollution. The powerful tool to solve this critical problem is a solar water still. It can be operated with salty as well as contaminated water and insolation as input energy. Calculation of long-term performance of the still based on hourly calculation is more expensive. The objective of this study is to investigate the climatic parameters affecting still output. This knowledge can be used to develop an effective and economical technique to predict long-term performance of solar water still based on utilizability [1]. Utilizability is a function based on one available data, daily solar radiation.

2. EQUIPMENT AND EXPERIMENT

The experimental unit (Fig. 1) has 17 cm height on average and 1.62 x 0.54 m absorbing basin area. It is well insulated with 3 cm foam. The outside and inside surfaces are made of stainless steel sheet of 1 mm thickness. The glass cover is 3 mm thick and inclined 14 degrees to horizon. The unit is placed on a stand and oriented south-facing. Black aluminium sheet as a solar energy absorber is placed inside the still. Water depth in the still is 2 cm and kept constant by the supply tank during experiment. At the end of each hour, ambient temperature, wind velocity, solar radiation and productivity are measured. Hybrid recorder (Yokogawa, Japan), hot-wire anemometer (Kanomax, Japan), solarimeter (Kipp & Zonen, Holland) and one-liter cylinder are used as equipment and materials in this out-door test.

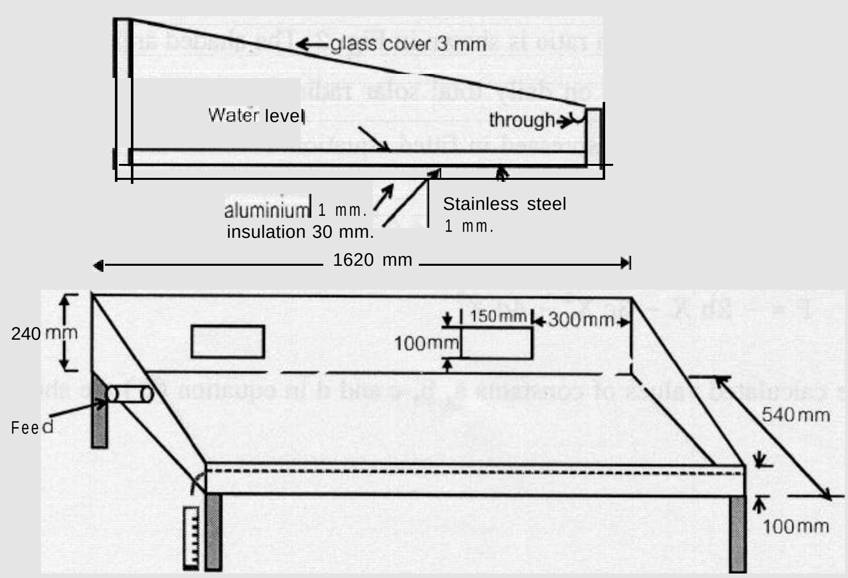

Fig.1 A horizontal basin solar still

Experimentation is done from 8.00 a.m. up to 5.00 p.m. Parameters used in calculation for this basin solar still are the same as in [2]:

a (absorber) = 0.9, a (glass) = 0.1, ε (water) = 0.96, ε (glass) = 0.85, ε (aluminium) = 0.33, τ (water) = 0.9, τ (glass) = 0.74, (mC_p)-glass = 4314 JK^{-1}, m is weight of glass, C_p (water) = 4186 J $kg^{-1}K^{-1}$, bottom loss coefficient = 1 $Wm^{-2}K^{-1}$, C_p (glass) = 670 J $kg^{-1}K^{-1}$

convective heat transfer coefficient (out side of the still) = 6.6 $Wm^{-2}K^{-1}$

radiative heat transfer coefficient, (out side of the still) = 2.3 $Wm^{-2}K^{-1}$.

3. UTILIZABILITY

Utilizability is a ratio of total useful solar energy to total solar energy collectable in particular period. It can be used for calculation of performance of solar collectors as in [1,3]. It can be calculated from:

$$\phi = \int_{F_C}^{1} (X - X_C)\, dF \qquad (1)$$

or

$$\phi = \int_{X_C}^{X_{MAX}} (1 - F)\, dX = 1 - \int_{0}^{X_C} (1 - F)\, dX \qquad (2)$$

where X is a ratio of daily solar radiation to its mean in a month. X_c is a critical value that the corresponding production rate is zero. X_{max} is maximum radiation ratio. F is fractional time that has radiation ratio less than X. F_c is fractional time that has radiation ratio less than Xc. The fractional time relating to radiation ratio is shown in Fig. 2. The shaded area represents utilizability (φ). Utilizability functions based on daily total solar radiation on a horizontal plane (KMUTT, Bangkok, 1979-1988) can be expressed in fitted equation as follows:

$$\phi = 1 - (a X_c + b X_c^2 + c X_c^3 + d X_c^4) \qquad (3)$$

and

$$F = -2b X - 3d X^2 - 4d X^3 \qquad (4)$$

where calculated values of constants a, b, c and d in equation (3) are shown in Table 1.

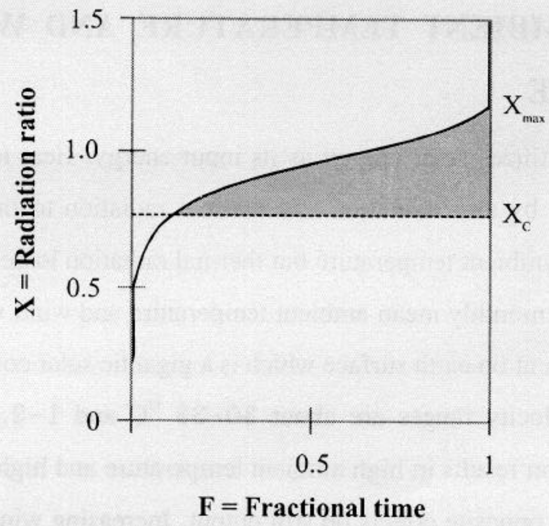

Fig. 2 Cumulative radiation frequency curve in January 1979-1988 (KMUTT, Bangkok).

Table 1. Values of constants a, b, c and d in eqnation (3)

Month	a	b	c	d	R^2	SEE
Jan	1.030	-0.028	0.298	-0.338	1	0.006
Feb	1.076	-0.359	0.814	-0.567	1	0.005
Mar	1.086	-0.467	0.968	-0.629	1	0.003
Apr	1.052	-0.275	0.611	-0.444	1	0.001
May	1.010	-0.127	0.318	-0.280	1	0.002
Jun	0.924	0.363	-0.431	0.046	1	0.004
Jul	0.952	0.215	-0.208	-0.050	1	0.003
Aug	0.943	0.174	-0.221	-0.014	1	0.002
Sep	0.906	0.267	-0.365	0.055	1	0.004
Oct	0.900	0.490	-0.623	0.129	1	0.005
Nov	0.957	0.245	-0.248	-0.038	1	0.005
Dec	1.106	-0.497	1.047	-0.691	1	0.002

4. EFFECT OF AMBIENT TEMPERATURE AND WIND ON PERFORMANCE

Basin solar still utilizes solar energy as its input energy. Heat losses from its outside are due mainly to convection by air circulation and thermal radiation to the sky. Convection losses depend on both wind and ambient temperature but thermal radiation losses on ambient temperature. As shown in Fig. 3 and 4 monthly mean ambient temperature and wind velocity vary linearly with solar radiation [4 - 5] incident on earth surface which is a gigantic solar collector. The corresponding temperature and wind velocity ranges are about 30- 33 °C and 1 - 2.5 m s^{-1}, respectively. In summer high solar radiation results in high ambient temperature and high wind. Wind velocity and ambient temperature have opposite effects on still output. Increasing wind speed slightly decreases production rate [6]. But increasing ambient temperature increases basin water temperature and thus production rate of the still. The difference between two calculated total production rate [7] based on daily mean and hourly ambient temperature and wind is about 3.3% (Fig. 5).

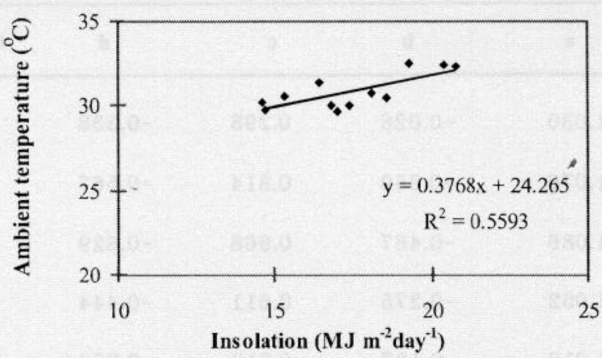

Fig. 3 Mean ambient temperature as a function of mean daily total solar radiation in a month in Bangkok.

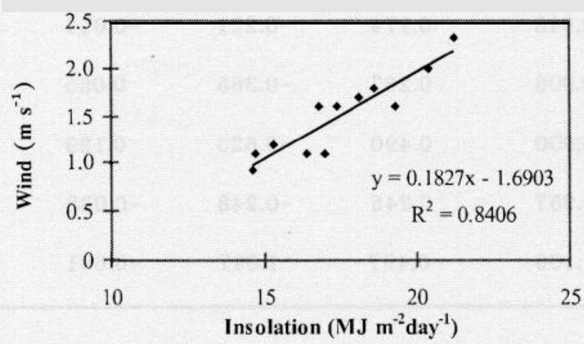

Fig. 4 Mean wind velocity as a function of mean daily total solar radiation in a month in Bangkok.

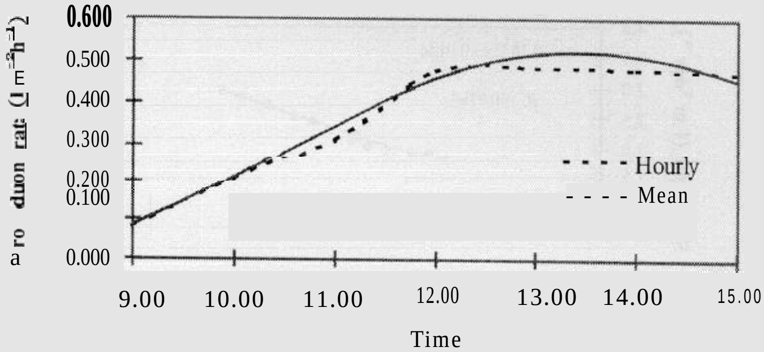

Fig. 5 Comparison of hourly production rate between those calculated based on daily mean and hourly ambient temperature and wind velocity.

5. EFFECT OF TOTAL SOLAR RADIATION ON PRODUCTION RATE

Hourly total solar radiation on a horizontal plane and the corresponding production rate are plotted comparatively as a function of time. Hourly production rates do not vary linearly with hourly solar radiation. More production rates for the same energy input are obtained in the afternoon due to water heat capacity in the basin as shown in Fig 6. Temperature cycle in basin water is complete within **one** day ensuring that absorbed solar energy is used up. Wibulswas [8] and Farid and Hamad [9] found a linear relation between daily solar radiation and production rate of the basin solar still.

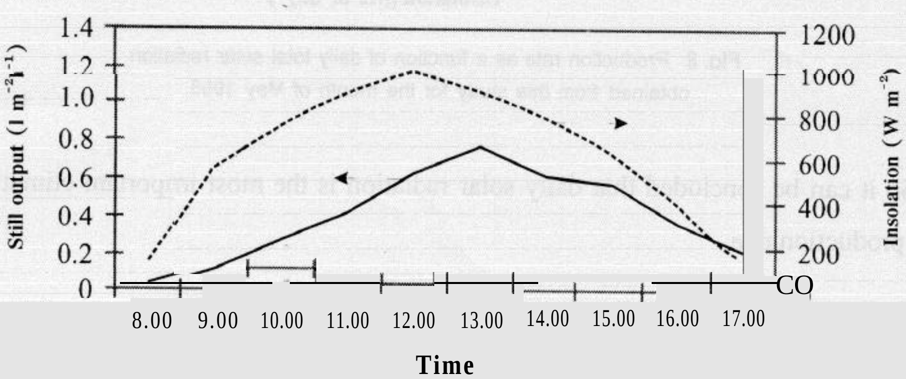

Fig. 6 Hourly production rate and total solar radiation as a function of time.

Dunkle [7] proposed a technique to predict the performance of a basin solar still based on hourly insolation. A linear correlation between monthly mean daily still output and total solar radiation calculated based on Dunkle's method [7] with addition of transient terms is shown in Fig. 7.

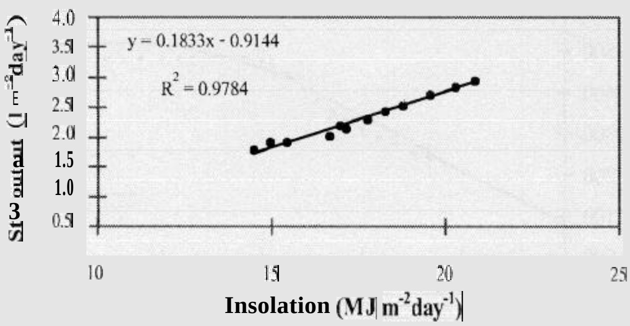

Fig. 7 Still output calculated based on Dunkle's [7] as a function of monthly mean daily total solar radiation.

In this study measured daily production rate strongly depends on daily total solar radiation as shown in Fig. 8.

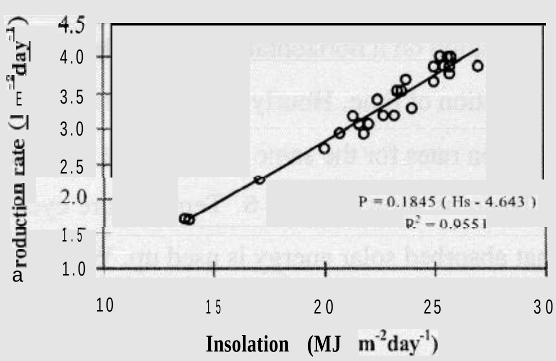

Fig. 8 Production rate as a function of daily total solar radiation obtained from this study for the month of May 1998.

So it can be concluded that daily solar radiation is the most important climatic parameter affecting production rate.

6, PERFORMANCE ESTIMATION BASED ON UTILIZABILITY

The daily production rate in Fig. 8 can be approximately calculated from the fitted equation:

$$P_i = a(H_{Si} - H_C), \text{ for } H_{Si} > H_C \quad (5)$$
$$a = 0.1845, \; H_C = 4.643,$$

where P_i is daily production rate, a is a constant, H_{Si} is daily solar radiation and H_C is a threshold insolation. Daily mean production rate then can be calculated from:

$$\frac{\sum_N P_i}{N} = \frac{a\sum_N (H_{Si} - H_C)}{N} = P \quad (6)$$

and $$P = a\,H_S \int_{F_C}^{1} (X - X_C)\,dF \qquad (7)$$

or $$P = a\,H_S\,\phi \qquad (8)$$

where N is a number of days in a month. Variables with over-bar represent their corresponding means.

Examples

In January monthly mean daily total solar radiation is about 15.9 MJ $m^{-2}day^{-1}$. Critical solar radiation (Hc) is 4.64 3 MJ $m^{-2}day^{-1}$. So critical radiation ratio (Xc) is 4.643/15.9 = 0.29 Utilizability (ϕ) calculated from eqnation (3) is 0.6954. Then from eqnation (8) we obtain monthly mean daily production rate:

$$\bar{P} = 0.1845 \times 15.9 \times 0.6954 = 2.04 \text{ l } m^{-2}day^{-1}$$

The monthly mean daily production rates all the year are compared between hourly calculation based on Dunkle's [7] and that of utilizability concept from eqnation (8) as shown in Table 2. The two annual production rates are slightly different showing that the second one is higher than the first one within 8 %.

Table 2. The monthly mean daily production rates (l $m^{-2}day^{-1}$) and total solar radiation (MJ $m^{-2}day^{-1}$) obtained from hourly [7] and utilizability base calculation.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H_S	15.9	19.5	21.7	21.3	20.2	18.2	19	18	16.3	15.6	15.8	17.4
X_c	0.29	0.24	0.21	0.22	0.23	0.26	0.24	0.26	0.28	0.3	0.29	0.27
P(Utilizability)	2.04	2.72	3.13	3.06	2.88	2.51	2.66	2.49	2.19	2.03	2.05	2.32
P(Dunkle)	2.15	2.52	2.95	2.84	2.71	2.31	2.43	2.19	1.93	1.79	1.91	2.03

7. CONCLUSIONS

The performances based on Dunkle's [7] and utilizability are in good agreement. Effects of ambient temperature and wind on still output strongly depend on solar radiation. Measured daily productivity depends linearly on daily solar radiation. The performance estimation's technique based on utilizability then can be well developed. This new developing technique can not only save time but also reduce cost.

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NOMENCLATURE

a,b,c,d	constants in eqnation (3) and (5)
C_p	specific heat, J $kg^{-1}K^{-1}$
F	fractional time
F_c	fractional time at X_c
H_c	critical daily total solar radiation on a horizontal surface, MJ $m^{-2}day^{-1}$
$\overline{H}_s$	monthly mean daily total solar radiation on a horizontal surface, MJ $m^{-2}day^{-1}$
H_{Si}	daily total solar radiation on a horizontal surface, MJ $m^{-2}day^{-1}$
N	number of days in a month, days
$\overline{P}$	monthly mean daily production rate, l $m^{-2}day^{-1}$
P_I	daily production rate, 1 $m^{-2}day^{-1}$
X	ratio of daily total solar radiation to monthly mean daily total solar radiation
X_c	critical radiation ratio
X	maximum radiation ratio
ϕ	utilizability function based on daily total solar radiation
a	absorptivity
ε	emissivity
τ	transmissivity

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