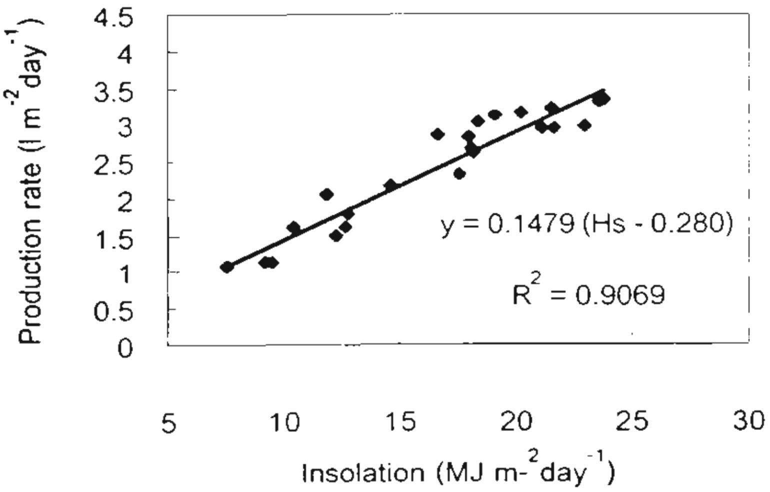
2.2 วิธีทดลอง

ทดลองกลั่นแอลกอฮอล์ที่มีความเข้มข้น 10, 30 (เม.ย-พ.ค.2542), 20, 40 %(เม.ย-พ.ค.2543)โดยปริมาตรโดยใช้แสงอาทิตย์ แต่แสดงกราฟเฉพาะความเข้มข้น 10% (รูป 2.2) ที่ใช้ในการประเมินสมรรถนะระยะยาวของเครื่องกลั่นเอทานอล สำหรับสารละลายที่ชาวบ้านผลิตได้เท่านั้น เพราะจุดประสงค์หลักของงานวิจัยนี้ต้องค้นพบวิธีประเมินสมรรถนะระยะยาวเท่านั้น และใช้ค่ารังสีอาทิตย์ 2522-2531 ของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี(คณะพลังงานและวัสดุ) มาพัฒนาฟังก์ชั่นการใช้ประโยชน์ [12]

2.3 ผลการทดลองและวิจารณ์

จากผลการทดลองหาอัตราการกลั่นเมื่อเครื่องกลั่นได้รับแสงอาทิตย์พบว่ามีความสัมพันธ์แบบเส้นตรงกับค่ารังสีอาทิตย์ที่ตกกระทบรายวันดังแสดงในรูปที่ 2.2 เมื่อเพิ่มความเข้มข้นของสารละลายที่ใช้กลั่น(10,20,30,40%) พบว่าอัตราการกลั่นเพิ่มขึ้นแต่ไม่ได้แสดงในที่นี่



รูปที่ 2.2 อัตราการกลั่นแปรตามค่ารังสีอาทิตย์รายวันแบบเส้นตรงสำหรับการทดลองเดือนพฤษภาคม 2542 เมื่อใช้สารละลายเริ่มต้นความเข้มข้น 10%[13]

การคำนวณสมรรถนะระยะยาวของเครื่องกลั่นโดยใช้ฟังก์ชั่นการใช้ประโยชน์

อัตราการกลั่นรายวันจากรูปที่ 2.2 สามารถประมาณได้ด้วยสมการเส้นตรง

$$P_i = a(H_{Si} - H_C), \quad \text{เมื่อ } H_{Si} > H_C \qquad (2.5)$$

$$a = 0.1479, \quad H_C = 0.2800,$$

เมื่อ P_i คืออัตรากลั่นแอลกอฮอล์รายวัน, a คือค่าคงที่, H_{si} คือค่ารังสีอาทิตย์รายวันในแนวราบ และ H_c คือค่ารังสีอาทิตย์วิกฤติที่เครื่องกลั่นเริ่มสามารถผลิตสารละลายเข้มข้นได้ อัตราการกลั่นแอลกอฮอล์เฉลี่ยรายวันสามารถคำนวณได้จาก

$$\frac{\sum_N P_i}{N} = \frac{a\sum_N (H_{Si} - H_C)}{N} = \bar{P} \qquad (2.6)$$

และ

$$P = a\,H_S \int_{F_C}^{1} (X - X_C)\, dF \qquad (2.7)$$

หรือ

$$\bar{P} = a\,\bar{H}_S\,\phi \qquad (2.8)$$

เมื่อ N คือจำนวนวันในเวลา 1 เดือน ตัวแปรที่มีขีดคือค่าเฉลี่ยของตัวแปรนั้น

ตัวอย่าง

ตัวอย่างของเดือนมกราคมมีค่ารังสีอาทิตย์ 15.9 MJ $m^{-2}day^{-1}$. ค่ารังสีอาทิตย์วิกฤติ (H_C) คือ 0.2800 MJ $m^{-2}day^{-1}$. ดังนั้นอัตราส่วนของค่ารังสีอาทิตย์วิกฤติคือ (X_C) คือ 0.2800/15.9 = 0.0176. ฟังก์ชั่นการใช้ประโยชน์(ϕ)คำนวณจากสมการ 2.3 คือ 0.9819. ดังนั้นจากสมการ 2.8 เราจะได้อัตราการกลั่นรายวันเฉลี่ยสำหรับเดือนมกราคมคือ

$$\bar{P} = 0.1479 \times 15.9 \times 0.9819 = 2.31 \text{ l } m^{-2}day^{-1}.$$

ตารางที่ 2.2 แสดงอัตราการกลั่นรายวันเฉลี่ยสำหรับทุกเดือน เปรียบเทียบระหว่างผลการคำนวณตามทฤษฎีการถ่ายเทความร้อน [1] และโดยใช้ฟังก์ชั่นการใช้ประโยชน์รายวัน พบว่ามีความแตกต่างกันอยู่ 11% แต่ผลจากการใช้ฟังก์ชั่นการใช้ประโยชน์มีความถูกต้องกว่าเพราะคำนึงเฉพาะปริมาณรังสีอาทิตย์ที่นำมาใช้กลั่นแอลกอฮอล์ได้เท่านั้น

ตารางที่ 2.2 อัตราการกลั่นรายวันเฉลี่ยรายเดือน (l $m^{-2}day^{-1}$) และค่ารังสีอาทิตย์รายวันเฉลี่ยรายเดือน (MJ $m^{-2}day^{-1}$) ได้จากการคำนวณตามทฤษฎีการถ่ายเทความร้อนและโดยอาศัยฟังก์ชั่นการใช้ประโยชน์[13]

เดือน	ม.ค.	ก.พ.	มี.ค.	เมย.	พ.ค.	มิ.ย.	ก.ค.	ส.ค.	ก.ย.	ต.ค.	พ.ย.	ธ.ค.
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	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02
P utilizability	2.31	2.84	3.16	3.11	2.95	2.65	2.77	2.62	2.37	2.27	2.30	2.53
P model	2.48	3.27	3.75	3.66	3.42	2.98	3.16	2.94	2.57	2.41	2.46	2.81

แนวทางการออกแบบเครื่องกลั่นเอทานอลพลังงานแสงอาทิตย์ขนาดอุตสาหกรรม

ควรใช้ค่า P utilizability (อัตรากลั่น) ในการออกแบบ เพื่อคำนวณหาพื้นที่ใช้งานของระบบกลั่น เมื่อทราบปริมาณแอลกอฮอล์ที่ต้องการผลิตเพื่อเพิ่มความเข้มข้น ถ้าใช้สารละลาย 10 % จะได้ผลผลิตความเข้มข้นประมาณ 18-20 % ปริมาตร และเพื่อให้ได้ปริมาณผลผลิตอย่างเพียงพอทุกๆเดือน ควรใช้ค่า P เพียงทศนิยม 1 ตำแหน่งและใช้ค่าอัตรากลั่นของเดือนตุลาคม (ค่าน้อยที่สุด, ตารางที่ 2.2) ในการออกแบบ.

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Research Output ที่ได้จากงานวิจัยในโครงการ

1. P. Namprakai, T. Kiatsiriroat, J. Hirunlabh, Parametric study on ethanol basin solar Still, submitted to Renewable Energy.
2. P. Namprakai, J. Hirunlabh, Ethanol still performance Estimation Based on Utilizability, submitted to Ambient Energy.

ภาคผนวก

Parametric study on ethanol basin solar still

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Abstract

Effect of various parameters on the performance of ethanol basin solar still was studied. Measured hourly productivity increases non-linearly with hourly solar radiation. The highest productivity is found after the time of maximum solar radiation due to heat capacity of basin solution. Monthly mean calculated productivity and measured solar radiation are linearly correlated. Effects of wind speed and ambient temperature on the still performance strongly depend on daily solar radiation. Still height has a little effect on the performance. Increase of initial solution concentration in the basin can improve the still yield. Lowering solution depth can also raise still product.

Keywords: Ethanol; Basin solar still; Parameters

1.Introduction

As environmental problem such as toxic emission gases from many oil-base vehicle increases, ethanol becomes the more promising fuel. In Brazil and U.S.A ethanol has been used as a substitute of oil in transportation and military base extensively. Although it has a higher cost comparing with fuel oils. Such application of ethanol in Thailand needs an effective and economical tool such as solar still to raise alcohol primary concentration. However, calculating of performance of such still [1] are few and do not give a very satisfactory result. Study of effect of major parameters on still performance is essential. In this study, relation between the still output and solar radiation was investigated theoretically and experimentally, focusing on the effect of wind speed, ambient temperature. The other parameters affecting still performance were also studied. Established mathematical model for our ethanol distillation bases mainly on Dunkle's and Spalding's [2] with the modification of Morse and Read; Howe and Tleimat [3]. Knowledge of heat and mass transfer within the still would be applied. More details and verification can be found in doctoral thesis of the author [4].

2. Equipment and experiment

The experimental unit (Fig. 1) has 17 cm. height and 1.62 x 0.54 m absorbing area. It is well insulated with 3-cm foam. The outside and inside surfaces are made of 1 mm thick stainless steel sheet. The glass cover was 3 mm. thick and inclined 14 degrees to horizontal. Two rectangular holes at the still back are for cleaning purpose. The unit was placed on a stand and oriented south-facing. Black aluminium sheet as a solar energy absorber was placed inside the still. Solution depth in the still basin was 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 were measured. Hybrid recorder (Yokogawa, Japan), hot-wire anemometer (Kanomax, Japan), solarimeter (Kipp & Zonen, Holland), one-liter cylinder and alcoholometer for measuring solution concentration were employed as

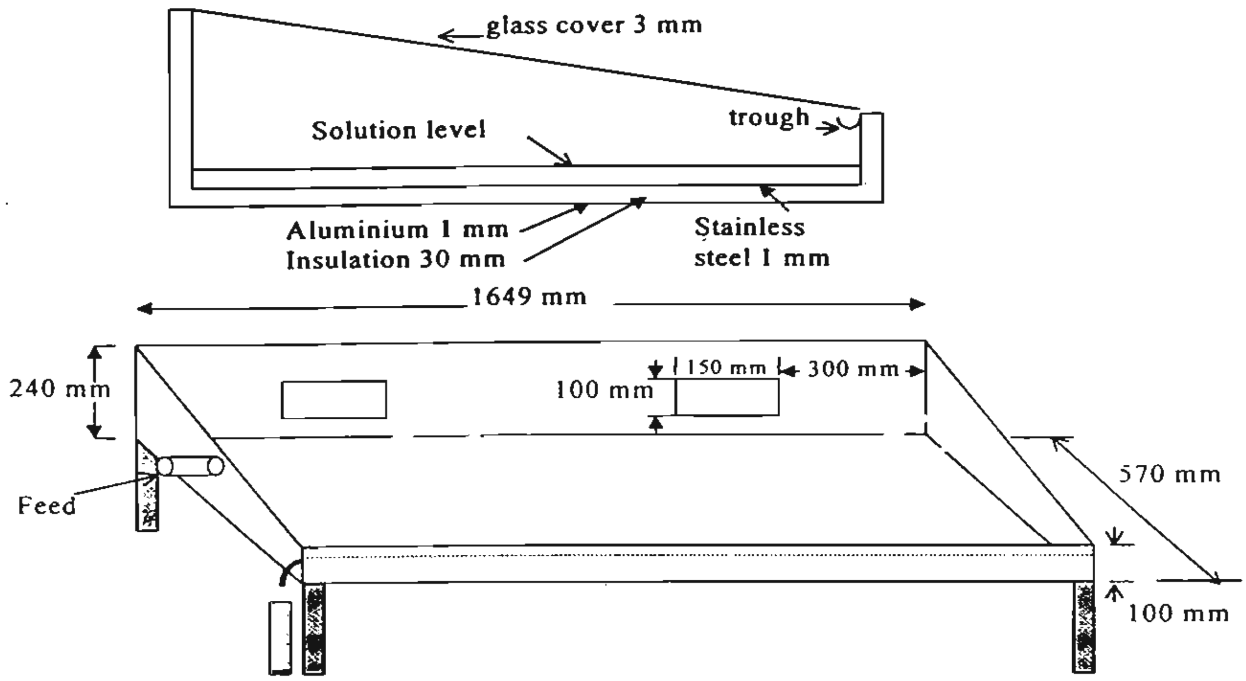

Fig.1 A horizontal basin solar still [4]

equipments and materials in this out-door test. Experimentation was done from 8.00 a.m. up to 5.00 p.m. Parameters used in calculation for this solar still are listed below [4]:

α(absorber) = 0.9, α (glass) = 0.1, ε (solution) = 0.96, ε (glass) = 0.85,

ε (aluminium) = 0.33, τ (solution) = 0.9, τ (glass) = 0.74,

C_P(ethanol) = 2508 J kg^{-1}K^{-1}, (mC_P)-glass = 4314 J K^{-1}, m is weight of glass,

C_P(water) = 4186 J kg^{-1}K^{-1}, C_P(glass) = 670 J kg^{-1}K^{-1}

ρ(water) = 0.9953 kg/lit., ρ(ethanol) = 0.7779 kg/lit.

From experiment: bottom loss coefficient, U = 1 Wm^{-2}K^{-1},

convective heat transfer coefficient, h_{ca}(outer side of the still) = 6.6 Wm^{-2}K^{-1}

radiative heat transfer coefficient, h_{rs} (outer side of the still) = 2.3 Wm^{-2}K^{-1}

3. Theoretical analysis

Alcohol in the basin

The absorbed solar energy by alcohol solution in the basin is equal to losses by convection, evaporation and radiation to the cover plus energy stored by basin alcohol and all heat losses through still wall and then surrounding. The mathematical expression based on Dunkle; Morse and Read [3] is shown as:

$$\alpha_{An}\tau_g AH_s = (q_e + q_c + q_r) + q_s + (\Sigma\, mc_P)_M \frac{dT_M}{dt} \tag{1}$$

The glass cover

Energy transfer by convection, evaporation and radiation from solution in the basin to the cover plus the absorbed solar energy by the cover are equal to energy stored by cover mass and energy convection by wind and thermal radiation to surrounding. Based on Dunkle; Howe and Tleimat [3], this energy balance can be mathematically expressed as:

$$\alpha_g AH_s + q_e + q_c + q_r = (mc_P)_g \frac{dT_g}{dt} + q_{ca} + q_{ra} \tag{2}$$

Heat convection by evaporation of alcohol may be calculated by using Spalding theory [2]. It is expressed as:

$$q_e = \Sigma m''_i .\, h_{fgi}\, A \tag{3}$$

The alcohol and water mass transfer rates in the still can be calculated from:

$$m''_i = m''.m_{iT} \tag{4}$$

Where m_{iT} is transfer mass fraction of component i, and m" is total mass transfer rate, which may be evaluated from [2,5]:

$$m'' = g \ln(1 + B) \tag{5}$$

g is mass transfer conductance and B is a driving force obtained from air mass fraction, which is [6]:

$$B = \left(\frac{m_G - m_S}{m_S - m_T}\right)_{air} \tag{6}$$

Where transfer mass fraction of air is normally zero. m represents mass fraction, G, S represent condensing and evaporating surfaces. The transfer mass fraction of component i , m_{iT} can be obtained from Namprakai et al.[6]:

$$m_{iT} = m_{iS} - \frac{(m_{iG} - m_{iS})}{B} \tag{7}$$

Mass transfer conductance (g) in the solar still is experimentally obtained [6]

$$\frac{g.x}{\rho D} = 0.064(Gr.Sc)^{1/3}(\%v/v)^{0.1776} \tag{8}$$

$$\text{turbulent}, \ 10^5 \leq Gr < 10^7$$

Where ρ is vapor density. Heat convection in the still is calculated from

$$q_c = h_c A\,(T_M - T_g) \tag{9}$$

Where h_c is convective heat transfer coefficient. It is obtained from a correlation for air in an enclosed space. By the assumption that the effect of vapors in the still is neglected. It is expressed as [7]:

$$\frac{h_c x}{k} = 0.075(Gr.Pr)^{1/3} \tag{10}$$

Energy losses by radiation in the still are assumed similar to those between parallel planes of equal area. It is calculated from [8]:

$$q_r = \varepsilon_M \sigma A[(T_M + 273)^4 - (T_g + 273)^4] \tag{11}$$

Energy lost from the cover is convection by wind and thermal radiation to surrounding. The heat convection is estimated from [8]:

$$q_{ca} = h_{ca}A(T_g - T_a) \tag{12}$$

Where h_{ca} = 2.8 + 3 V. V is wind velocity in m/s.
The second loss by thermal radiation is expressed as :

$$q_{ra} = \varepsilon_g \sigma A \left[(T_g + 273)^4 - (T_{sky} + 273)^4\right] \tag{13}$$

Where sky temperature is got from [8]:

$$T_{sky} = 0.0552\ (Ta + 273)^{1.5} - 273 \tag{14}$$

The last term for loss from outside of the still is:

$$q_S = UA\ (T_M - Ta) \tag{15}$$

Where $U = [L_s/k_s + 1/(h_{rs}+h_{ca})]^{-1}$, overall loss coefficient obtained from experiment.

4. Effect of solar radiation on still productivity

Computed productivity of 10 % ethanol solar still is shown linearly as a function of daily solar radiation, Fig.2. Temperature cycle of basin solution is complete within one day ensuring that absorbed solar energy is used up. Wibulswas and Amarage [9] experimentally found a linear equation of daily still yield and solar radiation with a little non-linear trend at high solar radiation. Measured hourly still output responds non-linearly to solar radiation, Fig.3. This is due to heat capacity of the basin solution.

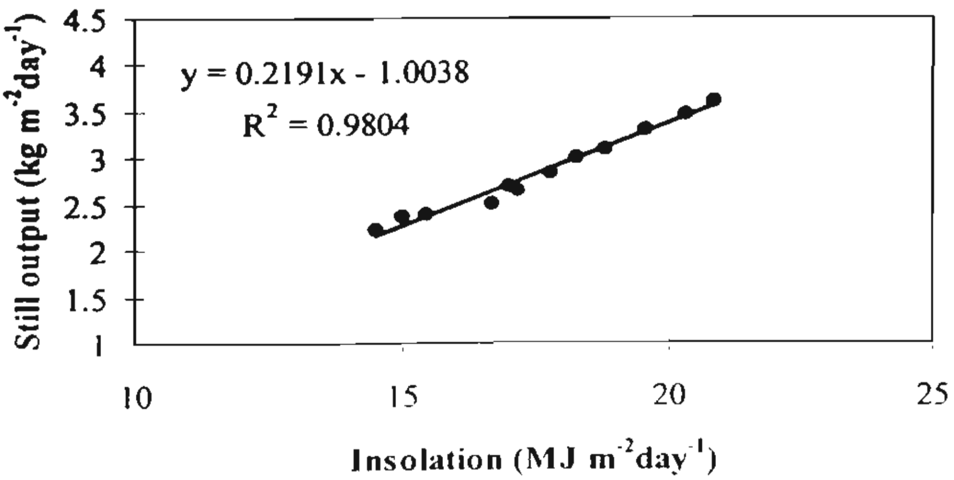

Fig.2 Calculated still output as a function of monthly mean daily total solar radiation

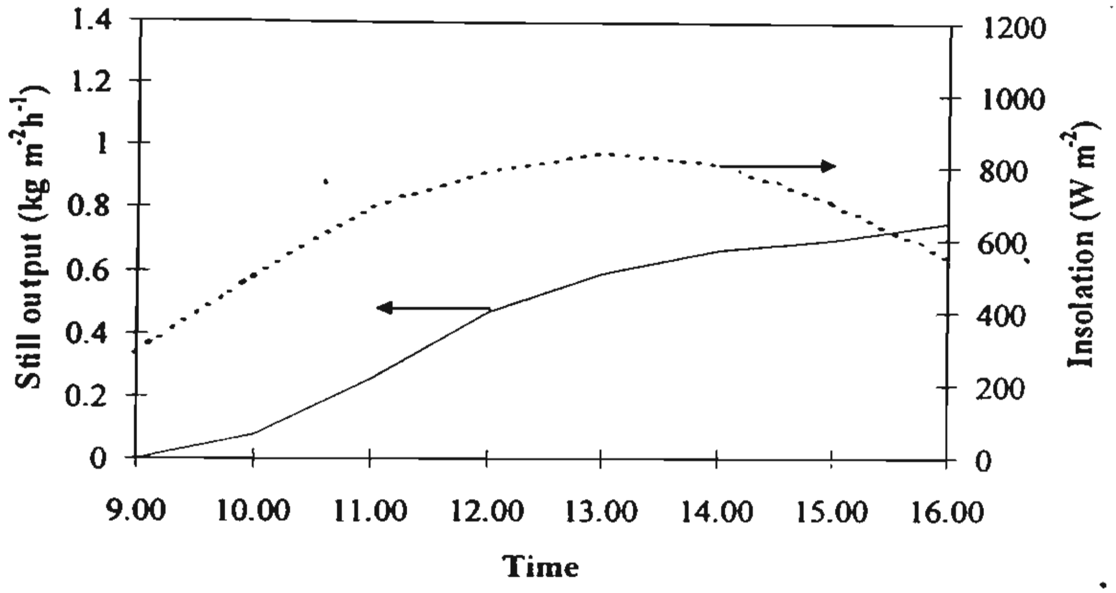

Fig.3 Measured hourly still output and total solar radiation as a function of time.

5. Effect of various parameters on still performance

From Namprakai's work [10] monthly mean wind speed and ambient temperature in Bangkok relate linearly to monthly mean daily solar radiation. That is high solar radiation resulting in high ambient temperature and wind speed. Estimations using hourly and daily mean wind speed and ambient temperature as a program input are nearly similar with only 3% total errors showing a natural dependence of still performance on daily averages of these parameters, Fig.4. Wind speed variation has a little effect on the still production [11]. Increasing wind speed slightly decreases the production rate [11]. However, increasing ambient temperature increases water temperature and thus production rate in a basin. Effect of these two parameters on still performance depends strongly on daily solar radiation.

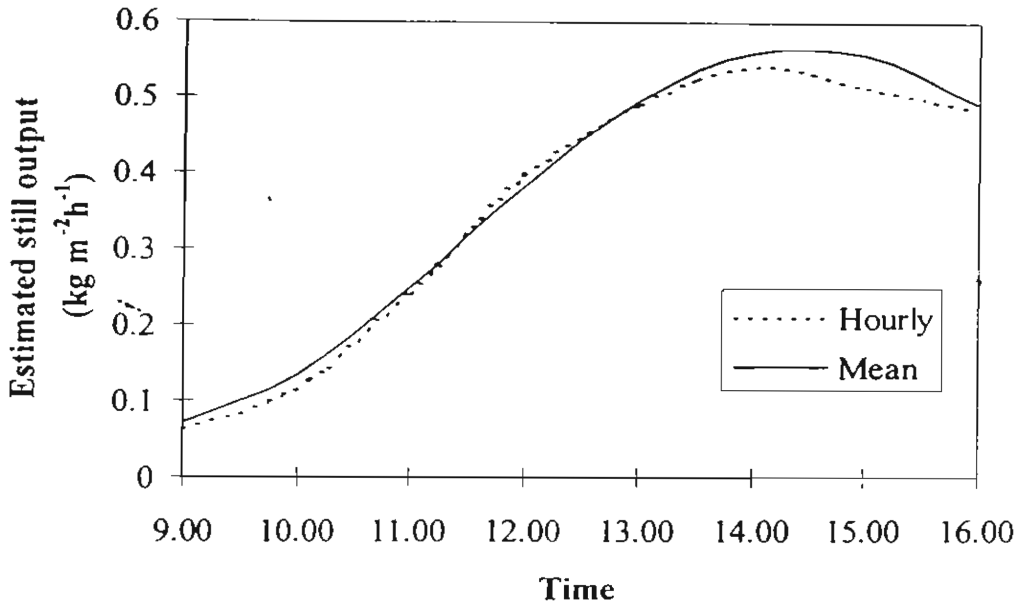

Fig.4 Comparison of hourly still output between those estimated using mean and hourly ambient temperature and wind speed.

Solution temperature in the testing 0.7 x 0.7 m still was controlled between 45-70 °C while initial solution concentration can be varied. Influence of initial solution concentration on mean still output from this indoor-test is presented in Fig.5 The optimal initial solution concentration for maximum productivity was found at 50 % v/v.

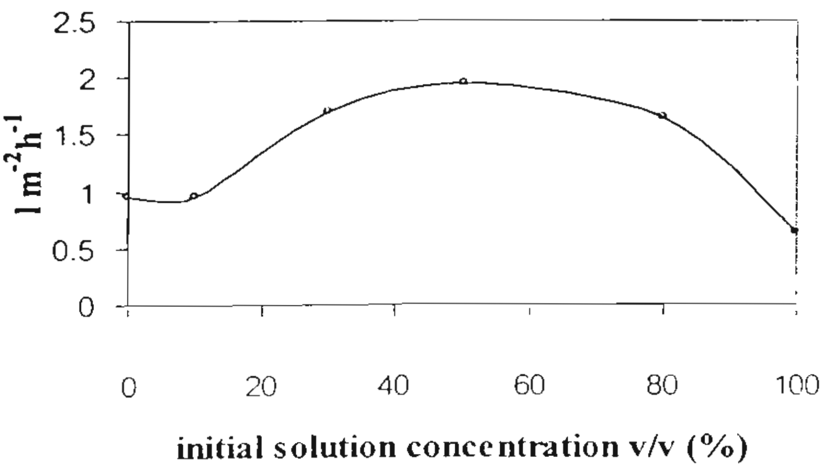

Fig.5 Mean still yield as a function of initial alcohol concentration.

Beyond this point, still performance gradually drops due to a massive molecule of alcohol, which can reduce the aid of convection current for more evaporation rate. Lowering solution

NOMENCLATURE

a,b,c,d	constants in eqns (3) and (5)
F	fractional time
F_C	fractional time at X_C
H_C	critical daily total solar radiation on a horizontal surface, MJ $m^{-2}day^{-1}$
$\bar{H}_S$	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
$\bar{P}$	monthly mean daily production rate, l $m^{-2}day^{-1}$
P_i	daily production rate, l $m^{-2}day^{-1}$
X	ratio of daily total solar radiation to monthly mean daily total solar radiation
X_C	critical radiation ration
X_{MAX}	maximum radiation ration
ϕ	utilizability function based on daily total solar radiation

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U overall loss coefficient from the bottom and side of the still, $W/m^2 K$
V wind velocity, m/s
x gap size, m

Greek Symbols
α absorptivity
ε emissivity
ρ density, kg/m^3
τ transmissivity
σ Stefan-Boltzmann constant, 5.67×10^{-8} $W/m^2 K^4$
% v/v percent by volume of alcohol solution

Subscripts

Aл black absorber
G condensing surface
g glass cover
i component i
M alcohol solution
S evaporating surface
T transfer state

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ETHANOL STILL PERFORMANCE ESTIMATION BASED ON UTILIZABILITY

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ABSTRACT- Measured daily still productivity strongly depends linearly on daily total solar radiation. Hourly productivity's calculation based on heat-transfer model confirms this relation. Utilizability was used to find the long-term performance of the ethanol still. This performance was compared to that of heat-transfer model. Utilizability function developed in this study is based on daily total solar radiation.

1. INTRODUCTION

Ethanol as a substitute of fuel oil is now very interesting. It can improve air quality in transportation system. Villagers usually produce 10% alcohol from rice, cassava, corn, and palm. To raise concentration of this alcohol needs a solar still. Solar energy can heat the solution temperature up to 70 ^{O}C in basin solar still. Calculation of long-term performance of this still based on hourly calculation is more expensive. The objective of this study was to develop an effective and economical technique to predict long-term performance of solar ethanol 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 and 1.62 x 0.54 m absorbing 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. Solution depth in the still is 2 cm and kept constant by the supply tank during experiment. Solutions of 10, 20, 30, 40 percents by volume were distilled. 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

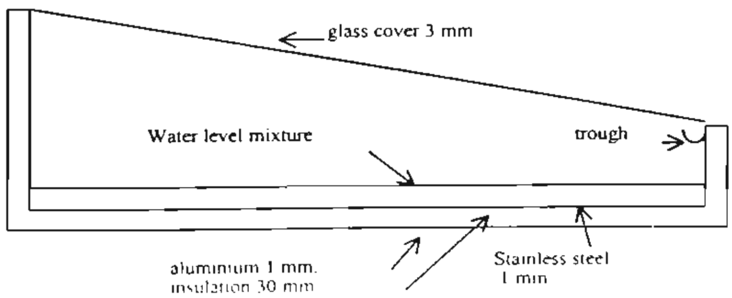

Fig.1 A horizontal basin solar still

used as equipment and materials in this out-door test. Experimentation is done from 8.00 a.m. up to 5.00 p.m.

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 [1,2,3]. 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 X_C. 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

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

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

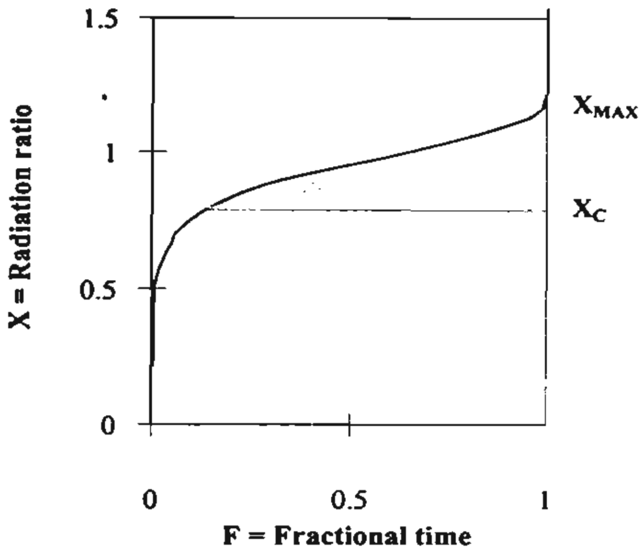

Fig. 2 Cumulative radiation frequency curve in January 1979-1988 (KMUTT, Bangkok)[4].

Table 1. Values of constants a, b, c and d in eqn (3)[4]

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

4. EFFECT OF VARIOUS PARAMETERS ON PERFORMANCE

It was concluded that ambient temperature and wind speed varied linearly to solar radiation[4]. Calculated productivity strongly depends on daily solar radiation [5]. In this study, measured daily production rate has very important effect of daily solar radiation as shown in Fig. 3. Therefore, it can be concluded that daily solar radiation is the most important climatic parameter affecting production rate.

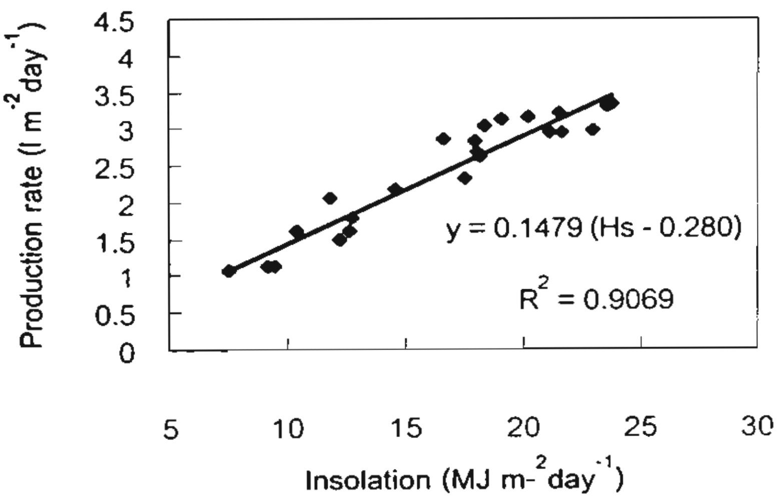

Fig. 3 Production rate as a function of daily total solar radiation obtained from this study for the month of May 1999 for 10% solution.

5. PERFORMANCE ESTIMATION BASED ON UTILIZABILITY

The daily production rate in Fig.3 can be approximately calculated from the fitted equation:

$$P_t = a(H_{Si} - H_C), \quad \text{for } H_{Si} > H_C \tag{5}$$

$a = 0.1479, \quad H_C = 0.2800,$

Where P_i is daily production rate, a is a constant, H_{si} is daily total solar radiation and H_c is a threshold insolation at which a still starts to produce yield. Daily mean production rate then can be calculated from:

$$\frac{\sum_N P_i}{N} = \frac{a\sum_{N'}(H_{Si} - H_C)}{N} = \bar{P} \tag{6}$$

and

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

or

$$\bar{P} = a\,\bar{H}_S\,\phi \tag{8}$$

Where N are 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 (H_C) is 0.2800 MJ $m^{-2}day^{-1}$. Therefore critical radiation ration (X_C) is 0.2800/15.9 = 0.0176. Utilizability (ϕ) calculated from eqn (3) is 0.9819. Then from eqn (8) we obtain monthly mean daily production rate:

$$\bar{P} = 0.1479 \times 15.9 \times 0.9819 = 2.31\ l\ m^{-2}day^{-1}.$$

The monthly mean daily production rates all the year are compared between hourly calculation based on heat-transfer model [5] and that of utilizability concept from eqn (8) as shown in Table 2. The two annual production rates are slightly different showing that the first one is higher than the second one within 11 %.

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 [5] 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	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02
P utilizability	2.31	2.84	3.16	3.11	2.95	2.65	2.77	2.62	2.37	2.27	2.30	2.53
P model	2.48	3.27	3.75	3.66	3.42	2.98	3.16	2.94	2.57	2.41	2.46	2.81

6. CONCLUSIONS

The performances based on heat-transfer model [5] and utilizability is slightly different. The advantage of utilizability concept is that it uses only solar energy, which can produce corresponding yield. Around 969 litters of product per square meter of solar still can be obtained annually. The efficiency is approximately 38 % (Fig. 3). Twenty percents alcohol output can be produced in 10%-solution still. It is recommended that P (utilizabity) for October should be used in finding still area on an industrial scale.

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NOMENCLATURE

a,b,c,d	constants in eqns (3) and (5)
F	fractional time
F_C	fractional time at X_C
H_C	critical daily total solar radiation on a horizontal surface, MJ $m^{-2}day^{-1}$
$\bar{H}_s$	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
$\bar{P}$	monthly mean daily production rate, l $m^{-2}day^{-1}$
P_i	daily production rate, l $m^{-2}day^{-1}$
X	ratio of daily total solar radiation to monthly mean daily total solar radiation
X_C	critical radiation ration
X_{MAX}	maximum radiation ration
ϕ	utilizability function based on daily total solar radiation

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