Journal of Energy & Environment 3 (2004) 91 - 101

Expert System Based Prediction of the Performance of Solar Air Collectors in Malaysia

Bashria A. A. Yousef*, N. M. Adam*, M. Daud*, H. Omar*, M. H. M. Ahmad* and Elradi A. Musa **

**Faculty of Engineering, Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor D.E. Malaysia*

***Faculty of Engineering, Department of Mechanical and Material Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor D.E. Malaysia*

Email: bashria@yahoo.com

(Received on 19 Jan 2004, revised on 12 Apr 2004)

Abstract

A mathematical model for predicting thermal efficiency, useful energy and outlet air temperature of a flat plate collector, used for drying agricultural products under the tropical climate condition of Malaysia was developed to be an internet based expert system. The developed program is capable of handling the ambient conditions, collector characteristics, and thermal properties of collector material. The criteria and parameters of solar energy usage in Malaysia were used as the input in the program to simulate the performance of the solar air collector. The model was validated through a comparison of the predicted output with the results from experimental studies. It is found that the adoption of expert system techniques to help the design of flat plate solar collector for drying in Malaysia seems to be promising.

Nomenclature

A	area of collector that absorbs solar
C	520*(1-.000051 β^2)
C_p	specific heat of working fluid, J/kg K
D_h	hydraulic diameter, m
E	0.43*(1 – (100/Tpm))
F'	the collector efficiency factor
F_R	heat removal factor
F	(1+0.089 hw – 0.1166 hw εp)*(1+0.07866 N)
H	collector height, m
H	fluid heat transfer coefficient, W/m^2 K
h_r	radiation heat transfer coefficient, W/m^2 K
h_w	wind convective heat transfer coefficient, W/m^2 K
I	solar radiation, W/m^2
K	fluid thermal conductivity, W/m K
K_b	back insulation conductivity, W/m K
K_e	edge insulation conductivity, W/m K
L	collector length, m
$\dot{m}$	collector flow rate, kg/s
N	number of glass cover
Nu	Nusselt number
Qu	rate of useful energy gain, W
Ta	ambient air temperature, K

Ti	fluid inlet temperature, K
Tfm	mean fluid temperature, K
T_{Pm}	mean absorber plate surface temperature, K
T_o	outlet temperature, K
U	overall heat loss coefficient, $W/m^2 K$
U_t	top loss coefficient, $W/m^2 K$
U_b	back loss coefficient, $W/m^2 K$
U_e	edge loss coefficient, $W/m^2 K$
W	collector width, m
x_b	back insulation thickness, m
x_e	edge insulation thickness, m
β	collector tilt angle, degree
ε_p	emittance of absorber plate
ε_c	emittance of glass cover
α	aolar absorptance of collector plate
σ	$5.669*10^{-8}$, W/m^2K^4
τ	solar transmittance of glazing
a	ambient
b	back
c	convective
e	edge
f	fluid
u	useful
h	hydraulic
m	mean
p	plate

Introduction

Energy is a subject of vital importance because of our great dependence on them in all aspects of human life. However, the total demand for energy in the world is increasing year by year. Therefore, the reserve of the fossil fuel, which is an important source of energy, is depleting in an alarming way. On the other hand, due to increasing demand of energy with the inefficient way of consuming it we have directly or indirectly polluted our environment. To prevent this from becoming a global disaster it is inevitable to strengthen our efforts on the energy generation and utilization in a sustainable way, and progressively substitute the fossil fuel by the renewable energy.

The solar radiation level in Malaysia is high, ranging from 6.6 kWh/m^2 in January to 6.0 kWh/m^2 in August, which is ideal for several applications [1]. Solar drying is a traditional method to process food like coffee, pepper, paddy; to store fish and fruits, and to process tobacco. The farmers dry their products under the sun on cement or on trays. The consumers accept the quality and taste of such products. However, for large-scale production open air-drying have limitations [2]. In order to reap benefits from the abundant and free solar energy, numerous attempts have been made in recent years to develop simple solar drying systems mainly for drying agricultural and forest products.

One of the most important components of solar drying system is the solar collector. In order to achieve an optimum design, the determination of the thermal performance for a flat plate collector using an internet based expert system is addressed in this paper.

Design Process for Flat Plate Collector Using Expert System

An expert system is an interactive computer based decision tool that uses both facts and heuristics to solve difficult decision problem based on knowledge acquired from an expert [3]. What is expected from an expert system is to deal with problems of scientific or commercial nature, to provide solutions in a reasonable time and to be right about them, as a human expert does. An expert system usually consists of a knowledge base, an inference mechanism and a user interface. The knowledge base contains two different data bases, a static and a dynamic one [4].

The knowledge for developing an expert system in the present work has been acquired by conducting an interview with domain experts in the field of solar energy to get the parameters and criteria for solar energy use in Malaysia. The solar research group at Universiti Kebangsaan Malaysia (UKM) in Malaysia has been established in 1980 with a view to maintaining sustainable energy resources of the nation, and making Malaysia the world leader in clean and efficient energy technologies through research and development [5].

A prototype internet based computer program was developed to support the design of flat plate collector used for drying agricultural products in Malaysia. Dreamweaver combined with the Active Server Pages (ASP) as an extension environment, has been chosen as a development software tool. The programmatic code was written by VBScript as scripting language to execute commands on a computer. In order to exploit and represent the knowledge for design, rules have been used to specify a set of action performed for a given situation, where rule-based programming is one of the most commonly used techniques for developing expert systems. It is composed of “If hypothesis THEN conclusion” [6]. Either hypothesis and or conclusion consist of one or more sentences. Moreover, the conclusion of a rule can be the hypothesis of another, so that multiple level rule dependencies can be created. A typical example of a rule for the developed program is given in Fig. 1. The rule has two hypotheses and four conclusions and refers to fluid properties in a certain temperature range.

```
If (dblTfluid > 303) And (dblTfluid <313) Then
                    dblViscosity = 1.888*10^-5
                    dblCp =1006.6
                    dblKair = .0267
                    dblPr = .711
  End If
```

Fig. 1 Example of a rule

The required data are classified into three groups, the first group named general input data concern about meteorological condition (ambient temperature, global solar radiation and wind velocity) the second group named collector characteristics contains all specific manufacture attributes related to the collector. (Collector dimensions tilt angle, absorber, cover and insulation characteristics,). The third group, energy characteristic contains measured data about inlet temperature and mass flow rate related to the transfer media inside the collector. All the entered data related to the parameters which are needed for the calculation of total heat transfer coefficient of the system, collector efficiency factor, collector flow factor, heat removal factor and Reynolds number. Then the result was used to determine flow type, final useful energy, system thermal efficiency, out put temperature, final plate temperature and final mean fluid temperature as shown in Fig. 2. The internet based computer program is still under development, but it can be access through the website http://esrg.eng.upm.edu.my/BashriaSolarheaters/default.asp .

Simulation Methodology

The aim of the mathematical simulation is the determination of the performance characteristic of the flat plate collector used for agricultural products in Malaysia.

Under steady state conditions, the useful energy output is defined as the difference between the solar radiation reaching the absorber plate and the thermal loss [7-9].

$$Q_u = A[(\tau\alpha)_e I - U(T_{Pm} - T_a)] \tag{1}$$

The mean absorber plate temperature is difficult to calculated or measure, since it is a function of the collector design, the incident solar radiation and the entering fluid conditions [9]. So equation 1 is reformulated in terms of the inlet fluid temperature and the collector hear removal factor as shown below

$$Q_u = AF_R[(\tau\alpha)_e I - U(T_i - T_a)] \tag{2}$$

The factors that affected on the solar collector efficiency are as:

a. The absorption of radiant energy, which requires the highest possible transmission coefficient for the transparent cover and the highest possible absorption coefficient for the absorber plate [7]. Thus effective parameter will be the product $(\tau\alpha)_e$ and it is larger than the direct product of the cover transmittance and absorber absorptance, because some of the radiation reflected from the absorber is returned to the absorber due to cover reflectance, the increase is about 5 percent [10].
b. The total loss of energy and is controlled by the overall heat transfer coefficient (U) and the mean plate temperature (T_{pm}). U is the summation of three separate components, the top loss coefficient, the bottom loss coefficient, and the edge loss coefficient. The empirical relations for these coefficients are as follows[9-11]

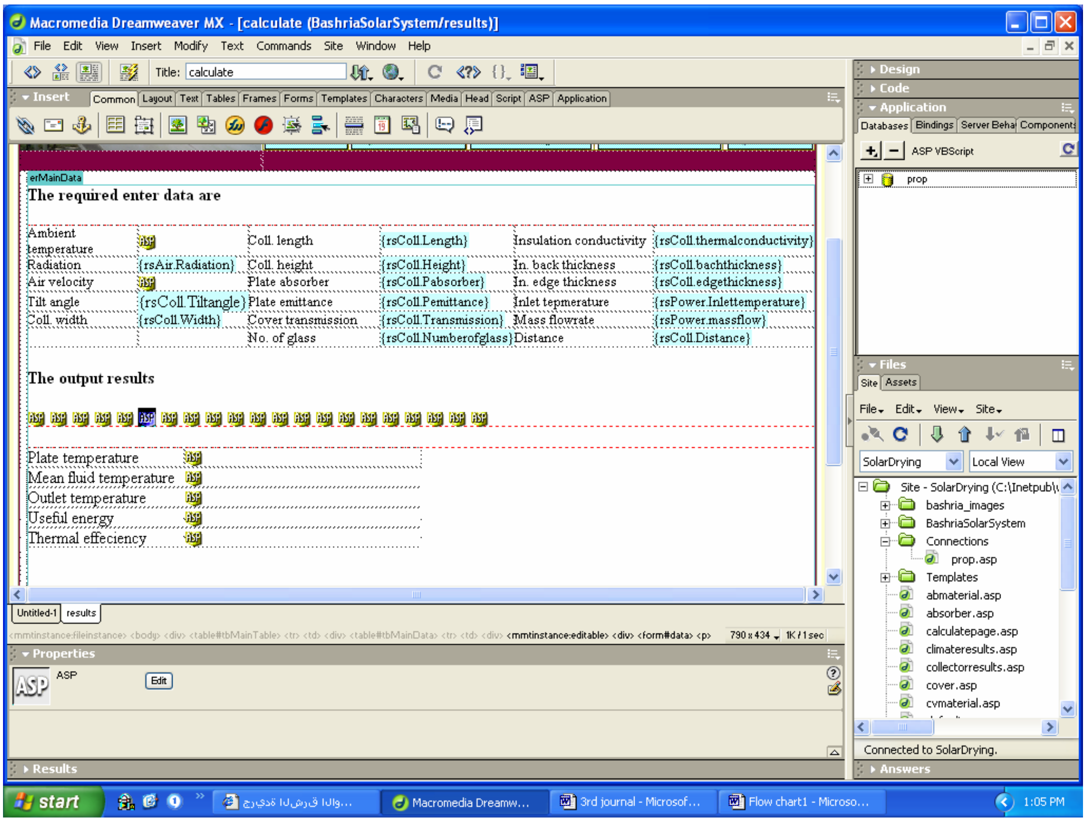

Fig. 2 The designed page for the developed expert system

$$U_t = \left\{ \frac{N}{\frac{C}{T_{Pm}}\left[\frac{T_{Pm}-T_a}{N+f}\right]^e} + \frac{1}{h_w} \right\}^{-1} + \frac{\sigma\left(T_{Pm}+T_a\right)\left(T_{Pm}^2+T_a^2\right)}{\left(\varepsilon_P + 0.00591Nh_w\right)^{-1} + \frac{2N+f-1+0.13\varepsilon_P}{\varepsilon_c} - N} \tag{3}$$

$$U_b = \frac{k_b}{x_b} \tag{4}$$

$$U_e = \frac{k_e}{x_e} * \left[\frac{2*\left(L+W\right)*H}{L*W}\right] \tag{5}$$

$$U = U_t + U_b + U_e \tag{6}$$

The mean plate temperature is solved in an iterative manner with equation 3, with an initial assumption for plate temperature equal to inlet fluid temperature + 20^{o}C [9], from which the total heat transfer coefficient is calculated. The heat removal factor which influenced by the heat transfer resistance between the heated absorber surface and the collector fluid calculated as below

$$F_R = \frac{\dot{m}C_p}{AU}\left[1 - e^{\frac{-AUF'}{\dot{m}C_P}}\right] \tag{7}$$

The collector efficiency factor is affected by the design of the absorber plate and the properties of the collector fluid. To determine the collector efficiency factor the radiation coefficient and the heat transfer coefficient between the air and the duct walls must be obtained. In our calculation the radiation coefficient between the two air duct surfaces is calculated by assuming the mean radiant temperature equal to the mean fluid temperature. The first value of the mean fluid temperature is assumed. The heat transfer coefficients between the air and the two duct walls (the cover and absorber) are assumed to be equal. The used relations are shown below

$$F' = \frac{2h_r h + hU_t + h^2}{\left(U_{t+}h_r + h\right)\left(U_b + h + h_r\right) - h_r^{\ 2}} \tag{8}$$

$$h_r = \frac{4\sigma\overline{T}_{fm}^{\ 3}}{\left(1/\varepsilon_P\right) + \left(1/\varepsilon_C\right) - 1} \tag{9}$$

$$h = Nu\frac{k}{D_h} \tag{10}$$

The collector flow factor F'' equal to

$$F'' = \frac{F_R}{F'} \tag{11}$$

With the calculated values of collector efficiency factor, collector flow factor and heat removal factor, the useful energy gain is determined according to equation 2. Then the assumed mean plate temperature and mean fluid temperature are checked using equation 12 & 13. The process is repeated until the absolute difference between the assumed and calculated temperatures are less than 0.1. From the most accurate absorber plate mean temperature, the useful energy gain is calculated from where the thermal efficiency and the output temperature are determined by using equations 14 & 15 respectively.

$$T_{Pm} = T_{fi} + \frac{Q_u / A}{F_R U} * (1 - F_R) \tag{12}$$

$$T_{fm} = T_{fi} + \frac{Q_u / A}{F_R U} * (1 - F'') \tag{13}$$

$$\eta = \frac{Q_u}{AI} \tag{14}$$

$$T_o = T_i + \frac{Q_u}{\dot{m} C_P} \tag{15}$$

The flow chart in Fig. 3 illustrates the developed mathematical model.

Validation

The validation parameters such as weather condition, collector specification, and collector tilt angle have been taken from the experimental studies [12-15] made in the area of solar dryer/collector at UKM, as shown in Table 1. It is found that the average daily solar radiation in Malaysia lies between 400 to 800 W/m^2. The program was run according to these parameters.

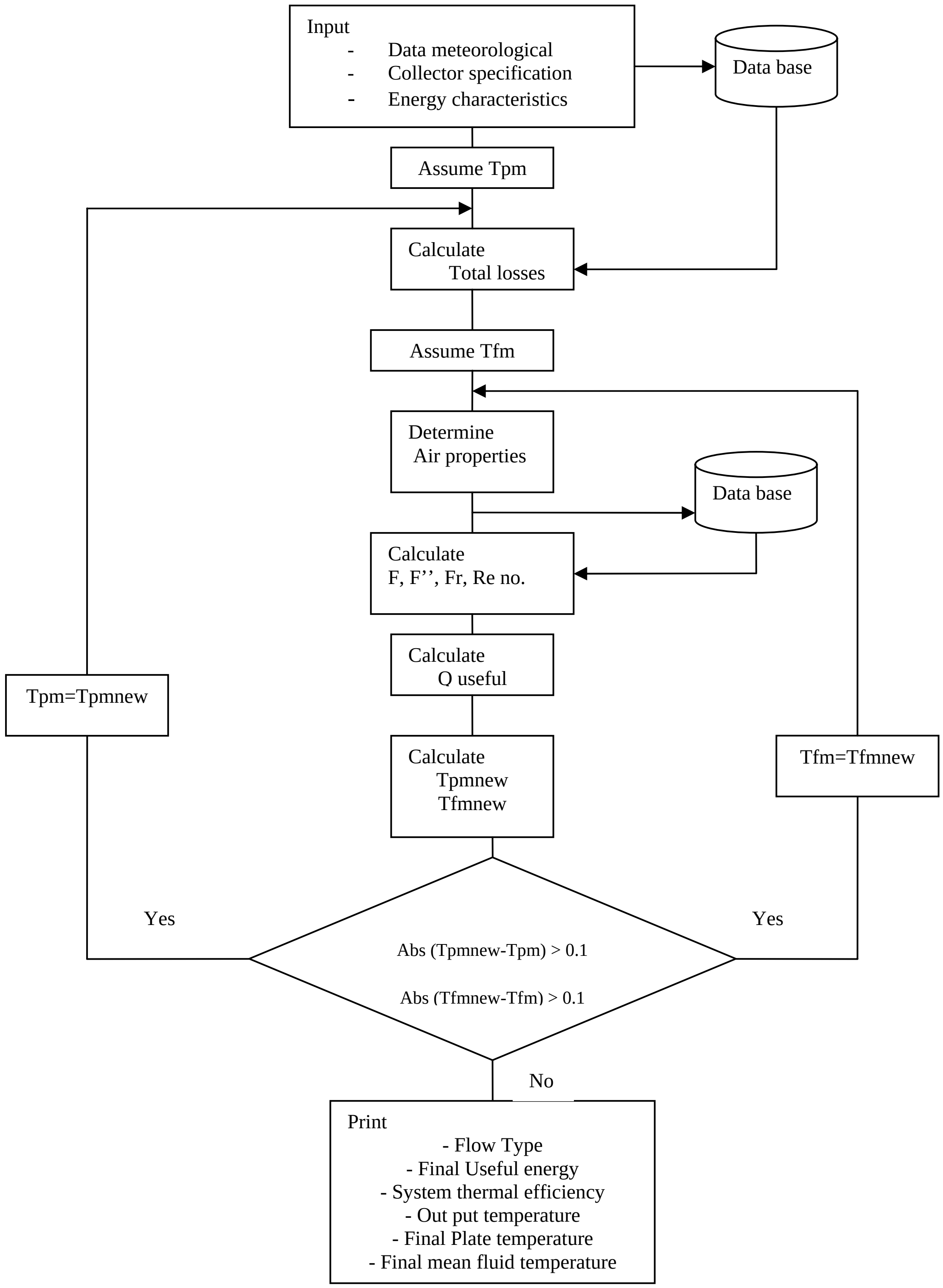

Fig. 3 Flow chart of the developed mathematical model

Table 1 Specification of different solar dryer systems

System Components	Specifications			
	Model-1 [12]	**Model-2** [13]	**Model-3** [14]	**Model-4** [15]
Collector				
Solar radiation	513-601 W/m^2	400- 620 W/m^2	600- 800 W/m^2	400-700 W/m^2
Tilt angle	10^o facing sun	10^o	10^o	10^o (south)
Type of absorber	V-groove single pass	Double pass	V-groove back pass	Double pass PV/T collector
Absorber plate	Folded aluminum sheet SWG22	Black painted mild steel of 0.8mm thickness (α= 0.9)	Folded aluminum sheet SWG22: 244cm x 112cm.	Aluminum of 0.2mm thickness paint flat black
Angle of groove	29^o and height 7.8 cm	-----------------	49° and height 7.8cm.	------------------
Collector area	234x198 cm^2	120x240cm^2	100x460 cm^2	122x85.5 cm^2
Cover				
Material	Glass (one side tempered)	Ordinary glass (τ=0.85)	Glass one side tempered	Glass
Thickness	2.5mm	3mm	2.5mm	5 mm
Insulation				
Material	Fiberglass wool	Fiberglass	Fiberglass wool	Glass wall
Thickness	2.5 cm and density 46kg/m^3	5 cm	2.5 cm	5 cm

In the studies [12-15] a range of mass flow rate between 0.04 to 0.25 kg/sec have been used, and it was concluded that the outlet temperature of the flowing air decreased with the increase of mass flow rate, as illustrated in Fig. 4. However, after a flow rate of about 0.1 Kg/sec, the rate of outlet temperature drop became lower, and from 0.2 to 0.25 kg/sec the drop became insignificant.

Complete measured experimental results from [13] have been chosen for comparing the developed expert system output. The experimental results were measured during the determination of thermal performance of double pass solar air collector with and without porous media. In that project the solar incidence was varied between 400 and 620 W/m^2 and the mass flow rate was varied between 0.04 to 0.09 kg/sec [13]. The average measured temperature distribution at solar radiation 500 W/m^2 with different values of mass flow rate, as obtained in [13], is shown in Table 2.

The predicted output was calculated by using the developed program, the entered data of solar radiation, tilt angle, ambient and inlet temperature and collector specification were typical to that mentioned in [13]. A great agreement has been occurred between the experimental results [13], and the predicted output when comparison has been achieved as shown in Figs. 5-7.

Fig. 6 confirmed the aforementioned researcher’s conclusion shown in Fig. 4, that the outlet temperature of the flowing air through the collector decreased with the increased of mass flow rate.

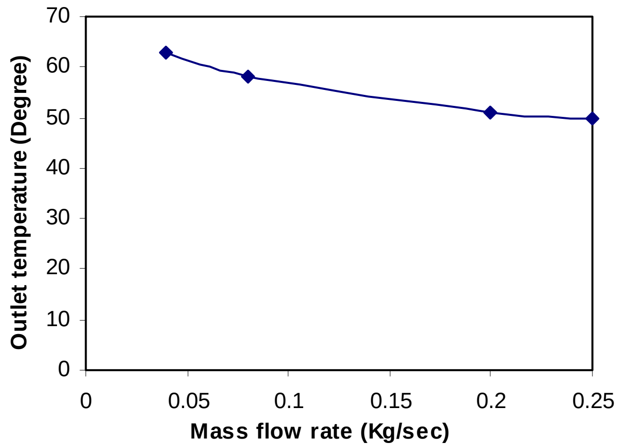

Fig. 4 Outlet temperature variation with mass flow rate

Table 2 Average temperature distribution at the collector (at solar radiation 500 W/m^2) [13]

Mass (Kg/sec)	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**
$T_{ambient}$	33.7	33.5	33.8	33.6	33.1	33.8
T_{inlet}	38.68	35.28	35.55	35.02	34.64	34.12
T_{outlet}	50.48	44.72	43.97	42.62	41.38	40.66
T_{plate}	65.37	54.3	53.38	50.43	49.1	47.7
T_{fluid}	44.02	39.92	42.2	38.5	37.62	36.98

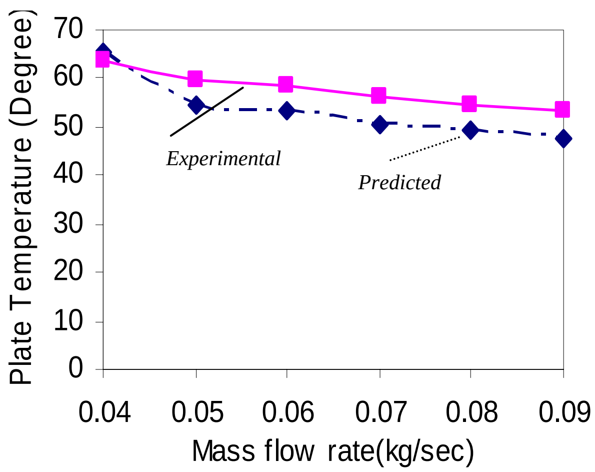

Fig. 5 Effect of mass flow rate on the plate temperature

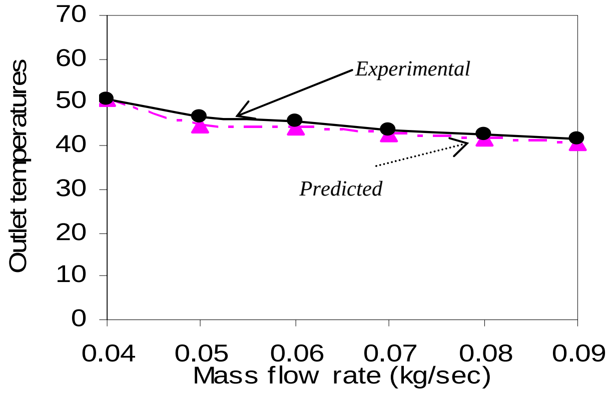

Fig. 6 Effect of mass flow rate on outlet temperature

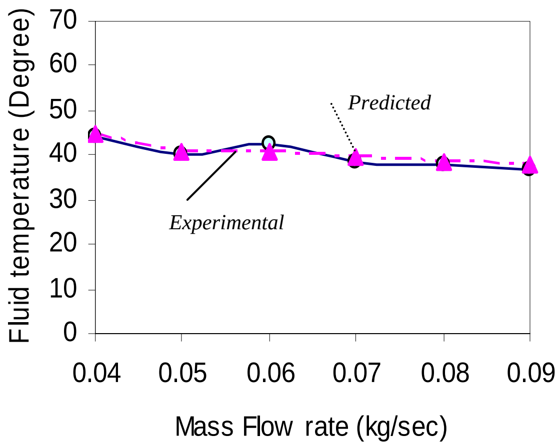

Fig. 7 Effect of mass flow rate on the fluid temperature

Conclusions

This paper has presented the development of an internet based expert system to predict the performance of a flat plate solar air collector in the context of Malaysia. The results have been compared with those from an experimental study. The achievements of the present work can be summarized as follows.

1. The use of expert system techniques to help the design of flat plate solar collector for drying agricultural products in Malaysia seems to be promising because of its capability to predict the collector performance with design rules that incorporate the human expertise in the field.

2. This system can accelerate, improve and optimize the quality of the final design.

3. The internet based computer program will assist in sharing and disseminating the knowledge.

4. The aforesaid application of expert system to assist in the design of flat plate solar collector is a preliminary proposal. In the near future the expert program will be upgraded to accommodate

designs for other types of solar air collectors such as finned, V-groove and double pass solar air heaters. collectors such as finned, V-groove and double pass solar air heaters.

References

[1] Y. H Mohd., B. Yatim and W. R. W. Daud, "Concept model of a 100 KWP PV village in Malaysia," Commercialization of Malaysian R&D, Kementeriam Sams, Teknologi dam Alam Sekitar,(1), 1999 pp 206- 211.

[2] K. Sopian, Supranto, W. R. W. Daud, M. Y. Othman and B. Yatim, "Design of a solar assisted drying system using the double pass solar collector," in Proc., World Renewable Energy Congress, Malaysia, 1999, pp 89-93.

[3] Adedeji B. Badiru, "Expert systems application in engineering and manufacturing," Prentice-Hall, Inc. New Jersy, 1992, pp 436.

[4] S. Panteliou, A. Denisoras and A. Daskaloulos, "Use of expert system for the selection and the design of solar domestic hot water systems," Solar Energy, ;(57), 1996, pp 1-8.

[5] http://pkukmweb.ukm.my/~pkt/mekanik/thermofluid_research.htm, January, 2004.

[6] H. Omar and A. A. Azlan, "Clips for expert systems," in Proc., 1st seminar on UPM, EIA Reports, Malaysia, 1996, pp 11-13.

[7] G. Begli, "Performance of solar energy converters," Thermal collectors and photovoltaic cells, Holland, D. Reidel publishing Company, 1982.

[8] J. F. Kreider, J. H. Charles and F. Kreith, "Solar design components, systems, economics," Hemisphere Publishing Corporation, USA, 1989.

[9] J. A. Duffie and W. A. Beckman, "Solar engineering of thermal processes," 2nd ed., Wiley-Interscience publication, Canada, 1991.

[10] C. S. Charles and A. W. Thomas, "Design application of the Hotel Whiller- Bliss equation," Solar energy, (19), 1977, pp 109-113.

[11] S. A. Al-Ajlan, H. Al-Faris and H. Khonkar, "a simulation modeling for optimization of flat plate collector design in Riyadh, Saudi Arabia," Renewable Energy, (28), 2003, pp 1325-1339.

[12] I. A. Mufadal, "Photovoltaic assisted solar drying system," M. Sc. Thesis, Faculty of Science and Technology, Universiti Kabangsaan Malaysia, 2003.

[13] Elradi A. Musa, "Thermal performance of the double pass solar air collector with and without porous media," M. Sc. Thesis, Faculty of Engineering, Universiti Kebangsaan Malaysia 2001.

[14] Salah Ahmed Eltief, "Drying bin performancy of V-groove forced convective solar dryer," M. Sc. Thesis, Faculty of Science and Technology Universiti Kabangsaan Malaysia 2003.

[15] M. N. A. Bakar, B. Yatim, M. Y. Hj Othman and K. Sopian, "Double pass photovoltaic/thermal (PV/T) solar collector with advanced heat transfer features," in Proc., International Symposium on Renewable Energy: Environment Protection and Energy solution for Sustainable Development, Kuala Lumpur, 2003; pp 14-17