Thermal Performance and Economic Effectiveness for Solar Air Heaters: Analysis and Expert System Developments

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Abstract

The present study involves presentation of an internet based Expert System for Solar Air Heater. The thermal performance was determined over a wide range of operating conditions and the optimum operating conditions were determined. It is found that for drying purpose the designed air flow rate should be in the range of 0.025 to 0.045 Kg/s and the recommended values ranges values of air flow depth are 0.025 to 0.035m for flat plate collector, 0.06 to 0.08m for V-groove absorber and 0.04 to 0.055m for lower duct in double flow double duct solar air heater. Comparison between predicted and experimental results indicates that the proposed mathematical model can be used for estimating the thermal performance of solar air heaters with reasonable accuracy. The results obtained, can be a helpful tool for a designer engineer to construct economical and efficient solar air heaters with technical dimensions.

Introduction

Solar air heaters are a type of solar collectors extensively used in many applications such as in industrial and agricultural fields without optical concentration. The solar air heaters occupy an important place among solar heating systems because of minimal use of materials, and the direct use of air as the working substance reduces the number of required system components [1]. In Malaysia the analysis of solar radiation in several main towns shows that, solar radiation has potential to be used for drying purposes and several other applications [2]. Typically, open air sun drying has been used to dry plants, seeds, fruits, meat, wood and other agricultural and forest products. But for large scale production, many limitations of open air drying have been appeared [3]. Thus in orders to reap the benefits from 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.

Several studies to determine the thermal performance of solar air heaters have been conducted, theoretically and/or experimentally, and different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air [4-8]. The optimum flow channel depth and mass flow rate in ten different designs of solar air heaters have been obtained by Ratna [9]. He found that there exists an optimum mass flow rate corresponding to an optimum flow channel depth [9]. Detailed theoretical parametric analysis on corrugated and flat plate solar air heaters of five different configurations have been made and mentioned in [10]. The analysis shows that increasing the air velocity of the air heaters will not only result in higher collection efficiency, but also it increased pressure drop [10]. Another study on corrugated solar air heater with and without cover was presented to obtain the optimum flow channel depth, at which the maximum heat is available at the lowest collector cost [11].

However, the availability of a tool to be used for supporting the designs of solar air heaters, application of mathematical models for the analysis of descriptive data from the domain experts would facilitate the task. Therefore, the knowledge and expertise gained from the said sources on solar collectors would be incorporated in an expert system given the code name Expert System for Solar Air Heaters (ESSAH). This expert system incorporates knowledge and calculates the important parameters to predict the thermal efficiency. As such, this study focuses on solar air heaters and subsequently on developing an internet based expert system, which could be used as a tool to predict the performance efficiency and the cost effectiveness for six different designs of solar air heaters. The use of the internet offers attractive features that are useful at the development and delivery stages, as well as expanding and sharing knowledge from any location in the world. The developed system is fully implemented to run on the web and provides an easy and attractive way to share knowledge.

The objective of this work is to develop an internet based expert system able to predict the thermal performance and the cost effectiveness of different designs of solar air heaters with flat or V-groove absorber, single double or triple glass cover, in single pass or double pass double duct with or without porous media in the lower duct

Material and Methods

This research is concerned with predicting the thermal performance for the six basic types of solar air heaters by mathematical simulation, via an internet based expert system that could be used as a tool to support the design of solar air heater. Initial work was based on determining the types and components of solar air heaters in Malaysia, its use, advantages and disadvantages. This involves the use of quantitative data from the field work along with qualitative information and knowledge from domain experts.

Data collection and knowledge acquisition

- Data and knowledge provide the problem statement. The main sources of such data are textual sources including books, Journals
- Data show the need for developing and using the solar energy as substantial energy source. The basic sources of these data are field survey and the domain experts.
- Knowledge assists to ESSAH knowledge base. The main sources of such knowledge are the domain experts, textual sources and the field work. The results of the field work were translated into a suitable form that could be used in ESSAH development.

Questionnaire and field survey

The field survey was performed during January to March 2003. A frequent visit to solar energy field in Universiti Kebengsaan Malaysia (UKM) was conducted. These visits were to determine the parameters and the range of using solar energy in Malaysia [12-16]. During the visit personal communication and interview was conducted with the researcher and professors as a domain experts to collect data. Table 1 is the result of the field survey in UKM solar energy field; it shows the components and the effective parameters for solar air heaters projects as stated by the researchers.

ESSAH development tool

Some of the various languages and shell, which had been developed and adapted on developing expert system, are PROLOG, LIPS, PASCAL, and CLIPS also expert system using conventional programming languages Such as, FORTRAN, BASIC and C.

CLIPS have been chosen firstly to be the developing tool for ESSAH, hence it is widely used and has many advantages over other tools but unfortunately, during the work it is found that it is difficult to create dynamic web pages by using CLIPS. So the search began for another tool able to create dynamic web pages. The alternative was Dreamweaver which was designed to develop pages for a variety of server platforms. To work with Dreamweaver for developing ESSAH, anther three main tools should be chosen [17].

- Web Server Application
- Extension Environment
- Scripting Language

Internet Information Services (IIS6) has been chosen to be the web server software application; it is turn the computer into a low-volume web server i.e. it is enable the developer to test the pages before publishing them. The Active Server Pages (ASP) that can communicate with databases has been chosen to be the extension environment. The programmatic code was written by VBScript as scripting language which is a particular syntax used to execute commands on a computer. VBScript's syntax is similar to Visual Basic's syntax. The system has been fully implemented to run on the web and can be access through the website at http://esrg.eng.upm.edu.my/BashriaSolarheaters/default.asp.

Table 1 Specification of solar system

System Components	**Specification**			
	Mufadal [13]	**El-Radi [14]**	**Salah [15]**	**Nazri [16]**
Project	Photovoltaic Assisted Solar Drying System	Pass Solar Air Collector with and without porous media	V-Groove Forced Convective Solar Dryer	Double pass photovoltaic/thermal (PV/T) solar collector
Solar radiation	513 -601 w/m^2	400-620 w/m^2	600-800 w/m^2	400-700 w/m^2
Mass flow rate	0.08 kg/sec	0.03-0.09 kg/sec	0.012-0.34 kg/sec)	0.01-0.2kg/sec
Outlet Temp.	50 $\pm$ 3^{o}c	< 64 ^{o}c	50 ^{o}c	35-65 ^{o}c
Absorber Characteristic				
Tilt angle	10^o facing sun	10^o	10^o	10^o (south)
Type of Collector	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	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	Flat Plate	49° and height 7.8cm.	Flat plate with fins attached
Collector area	234x198 cm^2	120x240cm^2	100x460 cm^2	122x85.5 cm^2
Cover Characteristics				
Material	Glass (one side tempered)	Ordinary glass (τ=0.85)	Glass one side tempered	Glass
Thickness	2.5mm	3mm	2.5mm	5 mm
Insulation Characteristics				
Material	Fiberglass wool	Fiberglass	Fiberglass wool	Glass wool
Thickness	2.5 cm	5 cm	2.5 cm	5 cm

ESSAH Development

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. It is composed of "If hypothesis THEN conclusion" [18]. Either hypothesis and or conclusion consist of one or more sentences. A typical example of a rule for the developed program is given in Fig. 1. The rule has two hypotheses and two conclusions and refers to the assignment of a value to Tpnew and Tfnew.

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If (Abs (dblTpnew -dblTplate) >= 0.001) Or  (Abs (dblTfluid- dblTfnew) >= 0.001) Then

            dblTplate = dblTpnew
            dblTfluid = dblTfnew

End If
```

Fig. 1 Example of a rule

The default page in the browser define the ESSAH for the user, it is also contain four main post linked to detailed pages in the system. The first link leads to a detailed page about the weather and climate in Malaysia, in addition to the range of incident of solar radiation. The second post linked to solar system page, this page presents a background of solar system, its classification and using. The third link focus on solar air heaters, its type, advantages and disadvantages. The expert system calculation's link leads to the choosing page which permits the user to select one of solar air heater types to find its thermal performance. These types are

- Single pass flat plate
- Single pass V-groove absorber
- Double pass double duct flat plate
- Double pass double duct V-groove
- Double pass flat plate with porous media
- Double pass V-groove absorber with porous media

After choosing the solar air heater type, General input data will be required to be entered. These required data are classified into three groups, the first group is the general input data concerns about meteorological condition, the second group is the collector characteristics contains all specific manufacture attributes related to the collector. The third group is the energy characteristic contains measured data about inlet temperature and mass flow rate related to the transfer media inside the collector. Also porous media characteristic will be requested if the chosen solar air heater used porous media. All entered data will be inserted to the input data file as a dynamic data-base and each solar air heater have a separate input data file. The dynamic database enriched during each execution of the program but the information is lost when the execution is terminated [19]. The static knowledge data base which represents the used equations in certain formalism is created once, when the system is being developed.

Validation

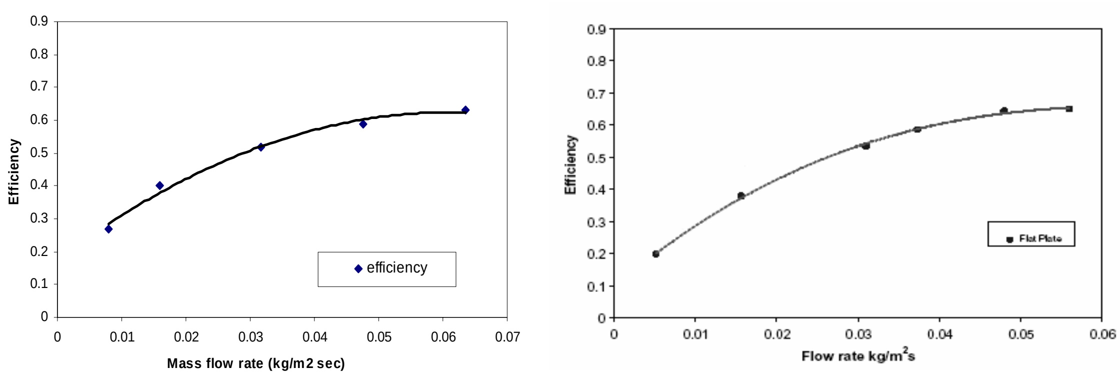
Validation and verification of ESSAH focus on the comparison between the predicted output and the experimental results for each solar air heater type listed in ESSAH program. The validation parameters for

Malaysian climate such as weather condition, collector specification, and collector tilt angle has been determined from personal communication, with researchers in the solar energy field in UKM [20].

The experimental results has been done by Karim and Hawlader [21] for single pass flat plate collector, single pass V-groove absorber, double pass flat plate collector and double pass V-groove absorber. El-Radi [14] has done an experiment on the double pass flat plate collector with and without porous media in the lower duct. The experimental results from [14] and [21] have been chosen to validate the ESSAH prediction results. The output from the mathematical simulation has been run according to same configuration and parameters done in experimental work [14] and [21] for different types of solar air heaters.

The experimental performance curves for the different solar air heaters are reproduced from [14] and [21] in order to compare them with theoretical predictions obtained by ESSAH.

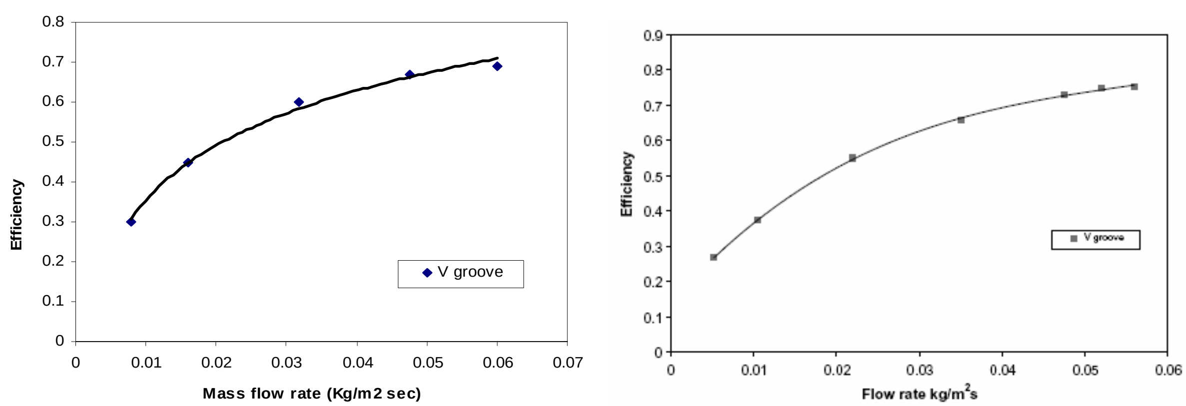
Figs. 2 to 5 show clearly that the efficiency is a function in mass flow rate hence it is increased by increasing the mass flow rate. While the outlet temperature decreased by increasing the mass flow rate as shown in Figs. 4 to 5.



ESSAH prediction output

Experimental work [21]

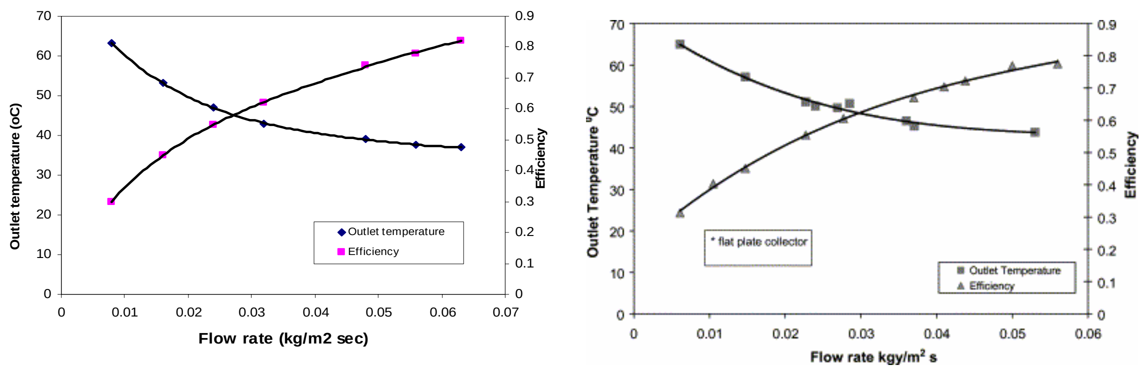
Fig. 2 Efficiency variations with mass flow rate for single pass flat plate collector



ESSAH prediction output]

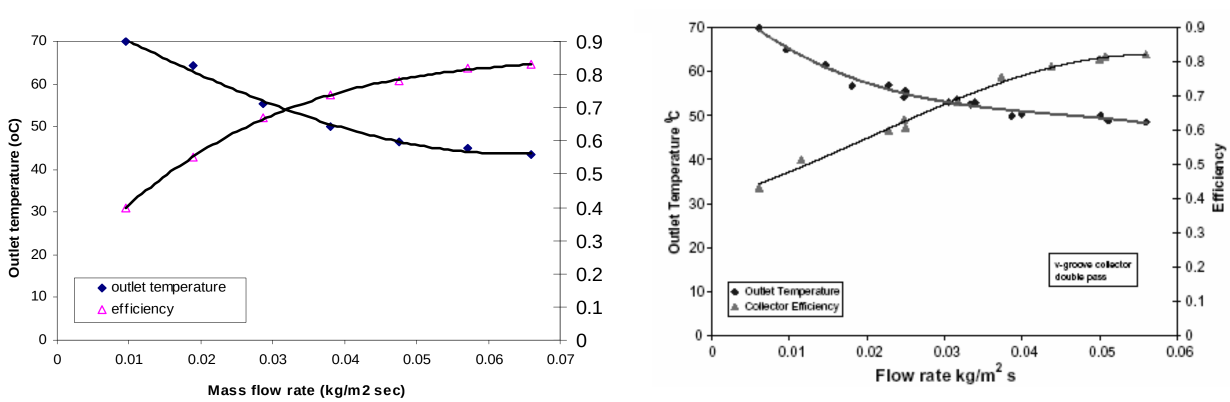
Experimental work [21

Fig. 3 Efficiency variations with mass flow rate for single pass V-groove absorber



ESSAH prediction Experimental work [21]

Fig. 4 Variation of efficiency and the outlet temperature with flow rate for double pass flat plate collector



ESSAH prediction Experimental work [21]

Fig. 5 Variation of efficiency and the outlet temperature with flow rate for double pass V-groove absorber

El-Radi [14] has find the effect of mass flow rates on temperature rise of double pass flat solar collector at 540W/m^2 solar radiation and 33^{o}C ambient temperature. At the same conditions the effect of mass flow rates on temperature rise of double pass flat solar collector has been predicted by ESSAH. The result is shown in Fig. 6, by comparing the experimental and predicted results it is found that, the temperature rise is decreased with the increased of mass flow rate, and there is an error deficiency occurred lies from 0.6 to 2.2% between the experimental and predicted results. The Figs. and analyses conducted in both methods experimentally and by the developed program show a great agreement with an error deficiency equal to 5% at maximum.

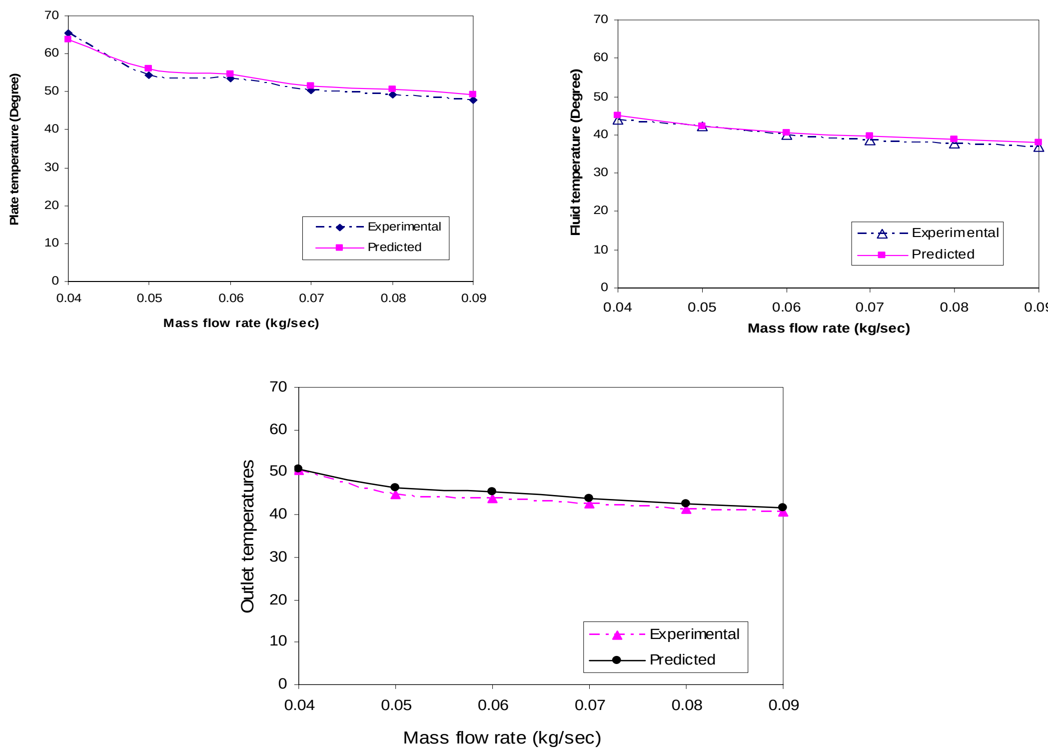


Fig. 6 Effect of mass flow rate on plate, fluid and outlet temperature experimentally and theoretically on Double pass flat plate collector with porous media (experimental work from [14])

The investigation study on double pass V-groove absorber with porous media has not been conducted before theoretically or experimentally. The theoretical study has been conducted by using ESSAH in this study, and the output results have been represented in Fig. 7.

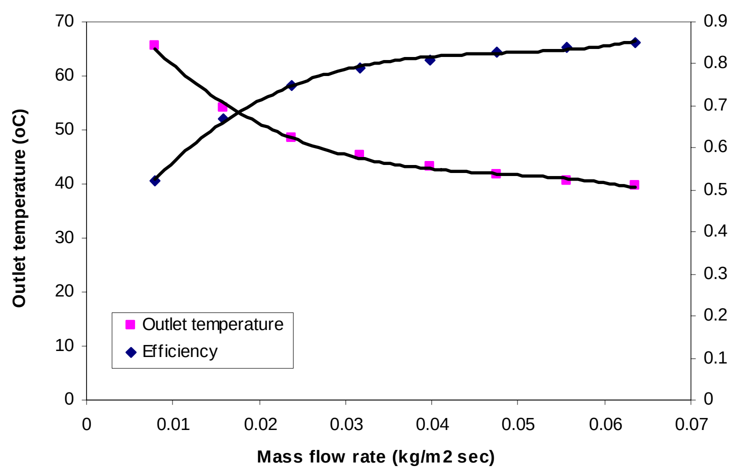


Fig. 7 Variation of efficiency and the outlet temperature with flow rate for double pass V-groove absorber with porous media

Results and Discussion

A development of an internet based expert system technique to help in predicting the thermal performance according to suitable cost for six types of solar air heaters is presented. From the study it is found that the parameters that have an affect on the thermal performance and the solar energy cost of the solar air heaters are mass flow rate, channel flow depth, collector length and the porous media. Their affective appears as follows:

a) Increasing the mass flow rate result in
   - Increasing the collector thermal efficiency
   - Decreasing the outlet temperature
   - Increasing the pressure drop, yet increase the cost of solar energy

b) Decreasing the flow depth cause the following
   - Increasing the collector thermal efficiency
   - Increasing the outlet temperature
   - Increasing the pressure drop which lead to an increase in the pumping expand in the collector thus increase the cost of solar energy

c) Increasing the collector length result in
   - Decreasing the collector thermal efficiency
   - Increasing the outlet temperature
   - Increasing the pressure drop

d) Using of porous media result in
   - Increasing the collector thermal efficiency
   - Increasing the outlet temperature
   - Increasing the pressure drop which lead to an increase in the pumping expand in the collector thus increase the cost of solar energy

Consequently, the following design range for the affective parameters has been predicted by the proposed program: The designed air flow rate for drying purpose which gives an outlet temperature suitable for most agricultural drying application with reasonable efficiency and pressure drop should be in the range of 0.025 to 0.045 Kg/s.

The optimum values of air flow depth which correspond to minimum annual cost per unit thermal energy gain are different for different duct lengths and air mass flow rate, therefore the recommended values ranges are:

- 0.025 to 0.035 m for flat plate collector
- 0.06 to 0.08 m for V-groove absorber
- 0.04 to 0.055 m for lower duct in double flow double duct solar air heater

The optimum collector length for reasonable thermal performance and minimum annual cost per unit thermal energy gain should be less than 3 m. By using the porous media in the lower duct in double flow double duct solar air heater the following output found

- In flat plate collector the efficiency increases by 8 % than double flow without porous media, and by 18% than the single flow pass. The outlet temperature increases by 3-6^{o}C than the double flow without using the porous media and by 10^{o}C than the single flow.
- In V-groove absorber the efficiency increases by 2-3% than double flow without porous media, and by 7% than the single flow pass. The outlet temperature increases by 2^{o}C than the double flow without using the porous media and by 5^{o}C than the single flow.
- In both types flat plate collector and the V-groove absorber the pressure drop increases by 4-25 Pa, thus increasing the pumping power by about 20 times.

Figs. 8 to 10 are direct comparisons of the outlet temperature, T_o, the pressure drop, Δp, and the cost benefit ratio, AC/ATEG, of the six types of solar air heaters investigated in this research under identical design and operational conditions. The outlet temperature is increased with an increase in the number of passes, corrugated absorber plate and the use of porous media. The highest outlet temperature is obtained in the double pass double duct V-groove absorber with porous media and the lowest in the single pass flat plate collector as shown in Fig. 8. On the other hand the increases in the outlet temperature for double pass double duct V-groove absorber with and without porous is only marginal, less than 2^{o}C.

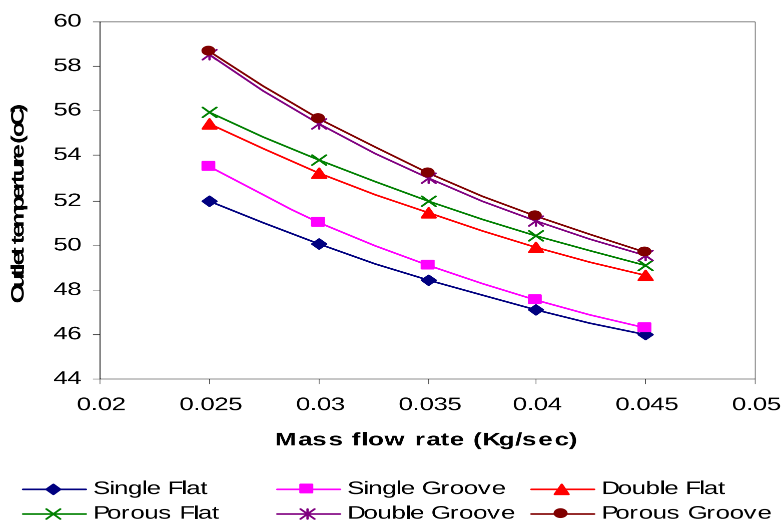


Fig. 8 The outlet temperature, T_o, as a function of mass flow rate for different types of solar air

In spite of increasing the mass flow rate through the air heater results in higher efficiency but also it is increased the pressure drop as illustrates in Fig. 9. It is obvious from Fig. 9 the value of the pressure drop in double flow mode is almost doubled the value of the pressure drop in single flow. At the same time the use of porous media in the lower duct for double flow increase the pressure drop from 3 to 25 Pa more than the pressure drop in double flow without the porous media.

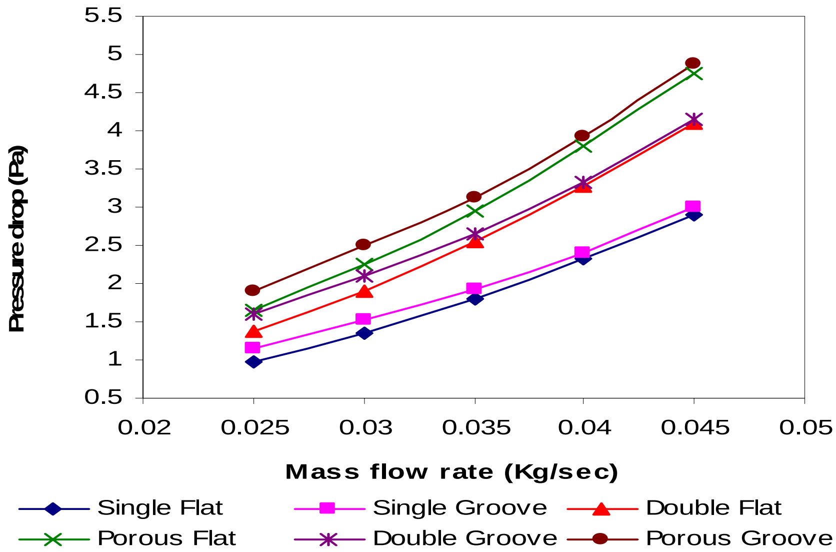


Fig. 9 The pressure drop, Δp, as a function of mass flow rate for different types of solar air

The corresponding values of the cost benefit ratio, AC/ATEG, in Fig. 10 shows the higher energy gain at lower cost (i.e. lower AC/ATEG) for each type of solar air heaters is at lower air mass flow.

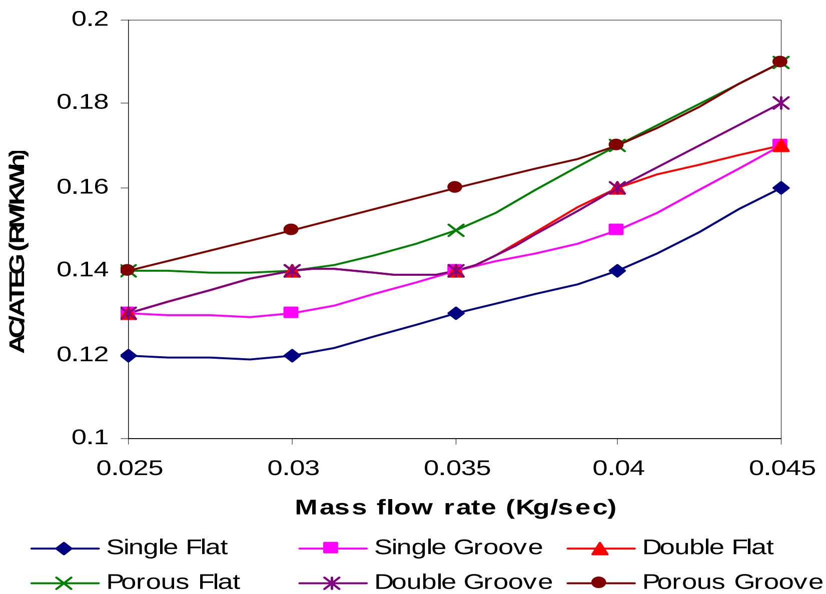


Fig. 10 The cost benefit ratio, AC/ATEG, as a function of mass flow rate for different types of solar air

By ranking the solar air heater types in order of high energy gain with reasonable cost and appropriate outlet temperature it is found that

- Double pass double duct V-groove absorber without porous media
- Double pass double duct flat plate collector with porous media
- Double pass double duct V-groove absorber with porous media
- Double pass double duct flat plate collector without porous media
- Single pass V-groove absorber
- Single pass flat plate collector

Conclusion

Finally and according to the previous points, the following remarks can be concluded.

i) The use of the aforementioned developed techniques to help the design of solar air heaters for drying agricultural products in Malaysia seems to be promising because of its capability to predict the collector performance according to chosen parameters with design rules that incorporate the human expertise in the field.

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

iii) The internet based computer program will help in sharing and distributing the knowledge.

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