SIMULATION AND ANALYSIS OF A FLAT PLATE SOLAR AIR HEATER WITH AND WITHOUT INTERNAL RECYCLE

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DEDICATION

Dedicated to my beloved mother and father And my siblings

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In the name of Allah, Most Gracious, Most Merciful.

First and foremost I am grateful to ALLAH on His blessing in completing this thesis.My sincere thanks go to my supervisor Prof. Amer Nordin Darus. I am ever grateful to my family, for their support and encouragement from psychological and financial. and the very genuine appreciation goes to my father and mother whom I owe my very existence to the world, whom always gave me motivation and courage to look on the bright side every time I felt unmotivated, whom that never let me down and whom I respect the most in my heart.

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ABSTRACT

In this thesis, a mathematical model to analyze the heat exchanges in two different types of solar air collectors was developed. The effect of placing a barrier inside a flat plate solar air heater was also investigated and all of them were simulated in two and three dimensions using the commercial software FLUENT. When building the thermal mathematical model it was shown that for each collector, at quasi steady state, the energy balance equations of the components of the collector cascade into a single first-order non-linear differential equation that is able to predict the thermal behavior of the collector. The heat transfer model clearly demonstrates the existence of an important dimensionless parameter, referred to as the thermal performance of the collector, which compares the useful thermal energy which can be extracted from the heater to the overall thermal losses of that collector for a given set of input parameters. An analysis of the thermal models was performed for the most significant input parameters such as the incident solar irradiation, the air mass flow rate, the depth of the fluid channel, in order to measure the impact of each of these parameters on the model. It was shown that the optimal barrier location for maximum collector efficiency is the center line of the collector. The numerical modeling was successfully validated as computed parameters such as thermal performance, efficiency, outlet temperature and Nusselt number matched closely to the available experimental data.

ABSTRAK

Dalam kajian ini model matematik digunakan untuk menganalisis perubahan suhu dalam beberapa jenis pengumpul haba daripada telah dibangunkan.Kesan daripada meletakkan halangan di dalam plan rata pengumpul haba daripada solar juga dikaji dan kesemua bahan tersebut dirangsang dalam dua dan tiga dimensi menggunakan perisian komersial FLUENT.Apabila model matematik haba dibina,ia akan ditunjukkan pada setiap pemungut,pada tahap kuasai yang stabil,persamaan keseimbangan tenaga pada komponen pemungut cascade kepada perintah tunggal pertama bukan linear,persamaan pembeza yang boleh digunakan untuk menjangkakan kesan perubahan haba pada pemungut .Model pemindah haba penunjukkan dengan jelas satu parameter tanpa dimensi merujuk sebagai pemungut haba,dimana jika dibandingkan dengan menggunakan tenaga haba yang boleh diekstrak daripada pemaras ke semua haba yang hilang daripada pemungut tersebut kepada satu set input parameter.Satu analisis model haba telah dijalankan bagi input parameter paling penting seperti kejadian sinaran solar,kadar aliran jisim udara,kedalaman saluran cecair untuk mengukur kesan daripada setiap parameter pada model.Ia menunjakkan lokasi halangan yang optima untuk pemungut yang paling cekap terletak pada jalur tengah pemungut.Permodelan berangka Berjaya disahkan sebagai parameter dikira seperti prestasi haba ,kecekapan,suha outlet dan nombor Nusselt dipadankan menghampiri kepada data ujikaji yang sedia ada.

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LIST OF SYMBOLS

English Symbols			**UNIT**
A	-	Collector area	[m^2]
A_c	-	Collector area	[m^2]
C_P	-	Specific heat	[J/kg K]
D_h	-	Hydraulic diameter	[m]
e	-	Thickness	[m]
e_{mb}	-	Water vapour pressure	[Pa]
E_u	-	Useful energy gain	[J]
F'	-	Collector effiiciency factor	[]
G	-	Mass flow rate per unit collector area	[kg/s/m^2]
h_c	-	Convection heat transfer coefficient	[W/m^2/K]
h_r	-	Radiation heat transfer coefficient	[W/m^2/K]
h_{ap}	-	Heat transfer coefficient between absorber and fluid	[W/m^2/K]
h_b	-	Heat transfer coefficient between back plate and fluid	[W/m^2/K]
h_o	-	Overall convection coefficient	[W/m^2/K]
h_b	-	Radiative heat transfer coefficient between absorber and back plate	[W/m^2/K]
h_a	-	Heat transfer coefficient between ambient and the glass	[W/m^2/K]
h_{fc}	-	Heat transfer coefficient between the glass cover and working fluid,	
I	-	Incident solar radiation	[W/m2]
I_T	-	Incident solar radiation on collector plane	[W/m2]
$K_{\tau\alpha}$	-	Incidence angle modifier	
L	-	Collector length	[m]
L_c	-	Characteristic length	[m]
L_s		Characteristic length	[m]
m	-	Mass per unit collector area	[kg/m^2]

$\dot{m}$	-	Mass flow rate through collector	[kg/s]
$\dot{m}_f$	-	Air mass flow rate	[kg/s]
Nu	-	Nusselt number	[-]
Pr	-	Prandtl number	[-]
Q_u	-	Useful thermal power	[W]
Re	-	Reynolds number	[-]
t_r	-	Iistant of sunrise	[s]
t_s	-	Instant of sunset	[s]
T_a	-	Ambient temperature	[K]
T_c	-	Transparent cover temperature	[K]
T_f	-	Fluid temperature	[K]
T_p	-	Blackened back plate temperature	[K]
T_s	-	Selective absorber temperature	[K]
T_{ap}	-	Temperature of absorber	[K]
T_b	-	Temperature of absorber channel back plate	[K]
U_b	-	Bottom loss coefficient	[W/m2/K]
U_L	-	Overall loss coefficient	[W/m2/K]
U_b	-	Collector bottom and edge loss coefficient	[W/m2/K]
U_t	-	Collector top loss coefficient	[W/m2/K]
V_a	-	Wind speed	[m/s]
x	-	Space coordinate	[m]

Greek Letters

α_p	-	Absorptance of blackened back plate	[-]
K	-	Thermal conductivity	[W/m/K]
α_s	-	Absorptance of selective absorber plate	[-]
ℓ	-	Collector width	[m]
ε_p	-	Emittance of blackened back plate	[-]

ε_s	-	Emittance of selective absorber plate	[-]
η	-	Collector thermal efficiency	[-]
ρ_c	-	Transparent cover reflectance	[-]
ρ_f	-	Fluid density	[kg/m3]
σ	-	Stefan–Boltzmann constant	$[W/m^2/K^4]$
θ	-	Dimensionless collector capacitance rate	
$(\tau\alpha)_n$	-	Transmittance-absorptance product for normal incident radiation	
α_c	-	Absorptivity of glass cover,	
τ_c	-	Transmittance of cover for short wavelength radiation	[-]
τ_{ir}	-	Transmittance of cover for thermal IR radiation	[-]
Ω	-	Thermal performance factor	[-]
T_a	-	Ambient temperature	[K]
T_f	-	Local fluid temperature	[K]
S	-	Absorbed solar irradiation per unit area	[-]
U_L	-	Overall collector heat loss coefficient	[-]

LIST OF ABBREVIATIONS

SAH	-	Solar air heater
SPFDSAH	-	Single pass with front duct
SPRDSAH	-	Single pass with rear duct
SPDDSAH	-	Single pass with double duct
DPSAH	-	Double pass Solar air heater
TOPSIS	-	Single pass with front duct
GH	-	Total horizontal solar radiation for the heating season [Kwh/m2]
DD	-	Heating degree days to base 200C for the heating season[Kd]
SSI	-	Solar Similarity Index

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CHAPTER 1

INTRODUCTION

1.1 Overview

The increased costs during the past decade for fossil fuels used for drying crops led to a search for methods of drying crops that consume less energy (Brooker et al. 1974).Solar energy is one of the most promising renewable energy sources in the world. Compared to non-renewable source such as fossil fuels, the advantages are clear: it is totally nonpolluting, has no moving parts to break down, and does not require much maintenance, Nidal (2003).

Solar air heaters are employed in many applications requiring low to moderate temperatures (below 60 centigrade), such as crop drying and space heating. The principal types of these heaters are: the single pass with front duct (SPFDSAH), rear duct (SPRDSAH), double duct (SPDDSAH) and double-pass (DPSAH) Forson et al. (2002).

The main applications for solar air heaters are space heating, drying and generate a new energy. Air as a heat transfer fluid is advantageous to liquid transfer fluids in solar thermal energy systems, as small leaks in air circuits are acceptable, phase changes do not occur in the usual temperature range, and corrosion is less critical, although air systems involve lower volumetric heat capacity and lower corresponding heat transfer coefficients, Ammari (2002).

1.2 Applications of Solar Energy

With the rapid rise in the population and the living standards, the world seems to engulf into major crisis, called energy crisis. If this growth continues with the same pace the condition would go from bad to worse. The reverse of conventional sources of energy like coal, petroleum and natural gas are depleting at a very fast rate to fulfill the demand of the growing population. So there is a need to look for some other energy sources that could meet this growing demand. One such source is solar energy, which is cheap available in abundance. Solar energy has been utilized in many ways. Some of its thermal applications are as follows:

1. Water heating
2. Space heating
3. Power generation
4. Space cooling and refrigeration
5. Distillation
6. Drying, and
7. Cooking

1.3 Background of The Study

There is an old saying: “There is nothing new under the sun” and that is certainly true for solar air heaters. In the U.S.A. in the 1890’s E.S. Morse took out the first patent for a solar air heater design. Over the next century, the technology has developed to meet the challenges of a varying energy source matched to a varying demand in a system designed to be efficient, reliable and cost effective, Hastings et al (2000).

In 1948 a school in Arizona was heated using an unglazed double skin roof. The fan-forced system raised the temperature of ventilation air by 5 to 10°C and supplied 80% of the heating requirements. Around 1980, CSIRO built an experimental house at Highett, Victoria that included a roof-integrated solar air heater and a rock bed below the concrete floor slab, Wooldridge and Welch (1980). Solar air heating systems in commercial or industrial applications are not as widely used as liquid systems although the advantages connected with air based systems can be numerous.

They include: any need for freeze or boiling protection, no objectionable toxicity characteristics of the working fluid, reduced corrosion problems, and lower maintenance costs. Furthermore, the comparatively low fluid temperatures at collector inlet, due to highly stratified thermal storage or direct feed of ambient air, enhance the thermal efficiency of the collectors, Duffie et al. (1980). Disadvantages involved are bulkier systems resulting from wide ducts and large storage volumes, significant pumping costs due to high fluid velocities and thus high friction losses, and system efficiency losses caused by leakage in collectors and ducts, Lof (2003).

For industrial and commercial applications where heated air is required, solar air heating systems with conventional auxiliary heaters are a convenient way to combine the marginal profit that a properly designed system provides along with the important environmental benefits of solar energy, Misra (2005).

1.4 Problem Statement

Determining thermal performance and the effect of different parameters on the efficiency of solar air heaters is of great importance. Since doing experiment is time consuming, expensive and not always possible, simulation is a good tool for studying the behavior of the solar air heater. Among the simulation studies, some of the researchers developed a computer code employing finite deference method, Naphon (2005) or matrix inversion method, Ong (1995). But, few of them have used the FLUENT Software for simulation.

The goal of this project is to perform simulation of a flat plate solar air heater and comparison of the results with experimental results. The effect of the air mass flow rate inside the collector and collector height on the collector efficiency will be covered. For solving this problem below questions has been assumed.

I. What is the main application of solar energy?
II. How to get high efficiency in solar air heater?

1.5 Objectives

The objectives of this study are as follows:

- To perform simulation of solar air heater to determine the thermal efficiency and outlet air temperature.
- To investigate a solar air heater with an inside barrier and comparing with a single pass solar air heater.
- To investigate thermal efficiency and output temperature with respect to changes of mass flow rate and the fluid channel depth.

1.6 Scope

In order to achieve the objectives above, the following scopes has been considered:

- Steady-State condition prevail.
- Working fluid is air with constant thermal properties as an ideal gas.
- Study will be done by simulation using commercial software package FLUENT 6.3.
- Solar radiation will be considered variable in a day.

1.7 Significance of the Study

In this research, one of the most important renewable energy, i.e. solar energy as a reverse of conventional sources like coal, petroleum and natural gas has been investigated. This can be used as a design guide to make a proper unit for the special required purpose.

1.8 Summary

This chapter discussed the main ideas of the research. First of all, the backgrounds of solar air heater and applications were briefly explained. Next, the statements of the problems were defined. Then, the objectives and scopes of the project were defined to achieve the goals and indicate borders of the study. Finally, the significance of the study was discussed.

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