UNIVERSITI PUTRA MALAYSIA

COMPUTATIONAL FLUID DYNAMICS ANALYSIS ON THERMAL PERFORMANCE OF SOLAR AIR HEATER WITH INCLINED FINS

BOOTAN SHERZAD QADER

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to all people around me especially for those who involved and contributed a lot of expenses in completing the thesis. First, I dedicate this work to my beloved wife and my family. Second, to my supervisory committee Dr. Eris Elianddy Bin Supeni, Professor Ir. Dr. Khairol Anuar bin Mohd Ariffin and Associate Professor Ir. Dr. Abd. Rahim Abu Talib who have guided me during the projects period. Lastly, I dedicate this thesis to all my friends who gave me their real friendship and advices, and motivated me to complete this thesis.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

COMPUTATIONAL FLUID DYNAMICS ANALYSIS ON THERMAL PERFORMANCE OF SOLAR AIR HEATER WITH INCLINED FINS

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Chairman : Eris Elianddy Bin Supeni, PhD
Faculty : Engineering

The depletion of fossil fuel reserves and rise in price instability of fossil fuels and also the impacts of global warming have accelerated the development of renewable energy sources as a reliable alternative energy source. The solar energy is a clean, sustainable, abundant and renewable energy source that has attracted the interest of various researchers across the world for solar energy with related applications. Similarly, solar irradiance can be absorbed by the solar collectors from the sun and thereafter, it is converted to convenient heat needed for heating air. The design of solar air heater is simple and commonly used in different areas of application. The thermal performance of the conventional solar air heater is found to be poor due to low convective heat transfer coefficient between heat collecting surface and working fluid. The main objective of this research is to increase the convection heat transfer coefficient in order to increase the performance of thermal system. In this study, a numerical evaluation was carried out on the heat transfer and the flow friction processes in a solar air heater coupled with inclined fins located underneath the absorber plate. With the constant heat flux application, the average Nusselt number and friction factor as well as the thermo-hydraulic performance parameter (THPP) were comprehensively investigated. The research covered various length of fin in the range of 1.5-2.5 mm, different slant angle (α) of fin in the range of 30°-60°, different pitch (P) of fin in the range of 15-25 mm, and a range of 4,000-24,000 for the Reynolds numbers. For the current computational fluid dynamic (CFD) evaluation, (ANSYS FLUENT v16.1) with renormalization group $k-\varepsilon$ turbulence model is selected for analysis computational domain.

In general, a significant improvement of the heat transfer in a solar air heater having inclined fins has been achieved. The maximum value of 174.05 was observed for the average Nusselt number which corresponds to a length of fin e=2.5mm, slant angle

α=60˚ and pitch P=15mm at a Reynolds number of (24,000) for the of parameter range investigated. While, the maximum friction factor of 0.046 was observed which corresponds to a length of fin e=2.5mm, slant angle α=60˚ and pitch P=15mm at a Reynolds number of (4,000).

Moreover, the quadratic model created by the response surface methodology (RSM) for computation of the THPP was found so that it is applied to a high degree of accuracy to quantify the operating performance of the solar air heater. Based on results of the model, the optimized values of design parameters for the optimal operation of solar air heater to provide the optimal THPP of 1.928 were found to be; length of fin = 1.52 mm, the pitch of fin = 19.04 mm, slant angle = 49° and Reynolds number of 18243.5. According to the optimized values of design parameters, the enhancement ratio of Nusselt number, friction factor and the THPP were found to be 2.53, 2.22 and 1.928, respectively. These correspond to the improvement of the Nusselt number by 153%, the friction factor by 122% as well as the THPP by 92.8% compared to the smooth duct. Finally, the thermal performance of the proposed inclined fin in terms of THPP was compared to other roughness geometries, such as circle (THPP=1.65), square-sectioned (THPP=1.80) and L-shaped (THPP=1.90). Accordingly, a better THPP of 1.928 was observed for the current study.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS DINAMIK CECAIR PENGIRAAN TERHADAP PRESTASI TERMA PEMANAS UDARA SURIA DENGAN SIRIP CONDONG

Oleh

BOOTAN SHERZAD QADER

Julai 2018

Pengerusi : Eris Elianddy Bin Supeni, PhD
Fakulti : Kejuruteraan

Penurunan rizab bahan api fosil dan ketidakstabilan harga bahan api fosil dan juga kesan pemanasan global telah mempercepatkan pembangunan sumber tenaga boleh diperbaharui sebagai punca tenaga alternatif yang boleh diharap. Tenaga suria ialah suatu tenaga yang bersih, mampan, banyak dan boleh diperbaharui yang telah menarik minat ramai penyelidik di seluruh dunia untuk mengkaji tenaga suria dan penggunaannya. Sinaran suria contohnya, boleh diserap oleh pengumpul suria dan sesudah itu, ditukar kepada haba sesuai yang diperlukan untuk memanaskan udara. Reka bentuk sebuah pemanas udara adalah mudah menyebabkannya banyak digunakan dalam pelbagai bidang kegunaan. Bagaimanapun, kecekapan terma pemanas udara suria biasa agak rendah disebabkan pekali pemindahan haba olakan yang rendah antara permukaan pengumpul haba dan bendalir kerja. Objektif utama bagi penyelidikan ini adalah untuk meningkatkan pekali pemindahan haba olakan bagi meningkatkan prestasi sistem terma. Dalam kajian ini, penilaian berangka dijalankan ke atas proses pemindahan haba dan aliran geseran dalam sebuah pemanas udara suria yang dipasang dengan sirip condong di bawah plat penyerap. Dengan penerapan fluks haba malar, nombor Nusselt purata dan faktor geseran serta parameter prestasi terma-hidraulik (THPP) diselidik dengan menyeluruh. Penyelidikan ini meliputi pelbagai panjang sirip 1.5-2.5 mm, sudut condong sirip (α) berbeza 30°-60°, junaman sirip (P) berbeza 15-25 mm, dan julat 4,000-24,000 bagi nombor Reynolds. Bagi penilaian Dinamik Cecair Pengiraan (CFD) ini, model gelora (ANSYS FLUENT v16.1) dengan kumpulan penormalan $k - \varepsilon$ dipilih untuk domain pengiraan analisis.

Secara umum, penambahbaikan yang signifikan telah dicapai bagi pemindahan haba dalam sebuah pemanas udara suria dengan sirip condong. Nilai maksimum 174.05 telah diperolehi bagi nombor Nusselt purata bagi panjang sirip e=2.5 mm, sudut

condong sirip α=60˚ and junaman sirip P=15 mm pada nombor Reynolds (24,000) untuk julat parameter yang dikaji. Sementara itu, faktor geseran maksimum 0.046 pula diperolehi bagi panjang sirip e=2.5 mm, sudut condong sirip α=60˚ and junaman sirip P=15 mm pada nombor Reynolds (4,000).

Tambahan lagi, model kuadratik yang dicipta RSM untuk pengiraan THPP dicari supaya dapat digunakan dengan darjah kejituan yang tinggi bagi mengukur prestasi kendalian pemanas udara suria tersebut. Berdasarkan keputusan model, nilai optimum parameter reka bentuk bagi kendalian optimum pemanas udara suria untuk mendapat nilai optimum THPP 1.928 ialah; panjang sirip = 1.52 mm, junaman sirip = 19.04 mm, sudut condong = 49° dan nombor Reynolds = 18243.5. Berdasarkan nilai optimum parameter rekaan, catuan penambahan bagi nombor Nusselt, faktor geseran, dan THPP didapati sebanyak 2.53, 2.22, dan 1.928 masing-masing, iaitu bersamaan dengan meningkatkan nombor Nusselt, faktor geseran, dan THPP sebanyak 153%, 122%, dan 92.8% berbanding saluran licin. Akhir sekali, prestasi terma bagi sirip condong yang dicadangkan berdasarkan THPP telah dibandingkan dengan geometri tidak rata lain seperti bulatan (THPP=1.65), seksyen empat segi (THPP=1.80) dan bentuk-L (THPP=1.90), di mana THPP lebih baik bagi kajian ini dapat diperhatikan iaitu 1.928.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Eris Elianddy Bin Supeni, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Khairol Anuar bin Mohd Ariffin, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Abd. Rahim Abu Talib, PhD PE
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name and Matric No: Bootan Sherzad Qader, GS45642

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature: ____________________
Name of Chairman of Supervisory Committee: Dr. Eris Elianddy Bin Supeni

Signature: ____________________
Name of Member of Supervisory Committee: Professor Dr. Mohd Khairol Anuar bin Mohd Ariffin

Signature: ____________________
Name of Member of Supervisory Committee: Associate Professor Dr. Abd. Rahim Abu Talib

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LIST OF NOMENCLATURE AND ABBREVIATIONS

C_P	Specific heat of air, J/kg K
D	Equivalent or hydraulic diameter of duct, mm
e	Fin length, mm
h	Heat transfer coefficient, W/m^2 K
H	Depth of duct, mm
I	Turbulent intensity/intensity of solar radiation, W/m^2
K	Thermal conductivity of air, W/mK
L	Length of duct, mm
$L1$	Inlet length of duct, mm
$L2$	Test length of duct, mm
$L3$	Outlet length of duct, mm
m	Mass flow rate, kg/s
ΔP	Pressure drop, Pa
P	Pitch, mm
U	Velocity of air in the duct, m/s
W	Width of duct, mm
SAH	Solar air heater
CFD	Computational fluid dynamics
RSM	Response surface methodology
CCD	Central composite design
ANOVA	Analysis of variance
$x_1, x_2 \ldots x_n$	Independent input variables

Dimensionless parameters

F	Friction factor
f_s	Friction factor for smooth surface
Nu	Nusselt number
Nu_s	Nusselt number for smooth duct
Pr	Prandtl number
Re	Reynolds number
$THPP$	Thermo-hydraulic performance parameter
$THPPs$	Thermo-hydraulic performance parameter for smooth duct
W/D	Duct aspect ratio

Greek symbols

M	Dynamic viscosity, Ns/m^2
μ_t	Turbulent viscosity, Ns/m^2
P	Density of air, kg/m^3
A	Angle of attack, (˚)
K	Turbulent kinetic energy, m^2/s^2
Γ	Molecular thermal diffusivity, m^2/s
Γ_t	Turbulent thermal diffusivity, m^2/s

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The modern world of today and tomorrow is undergoing an uncertain period with respect to the provision of energy and power as a result of fossil fuel shortages which lead to increased costs and worldwide economic instability. Therefore, it is more vital now than ever to search for alternate means of power generation i.e. sustainable energy in order to fulfill our requirements. As a result, a large number of nations are exploring various technologies centered on using the power of the Sun as the primary source and improving the efficiencies of solar thermal systems (Gawande *et al*., 2016a).

A particular system used for heating purposes is the solar air heater that works on the basis of solar power. It is utilized in various functions such as crops drying of industrial products as well as for heating in various residential schemes. In this system, heat is transformed from the plate that absorbs to air by the way of convective heat transfer (El-Sebaii *et al*., 2011a).

Since this system uses the fluid all around us (air) as its transfer material its complexity is much lower than other alternative heating systems and result in simple design and low maintenance requirements (Ammari, 2003). On the contrary, air type solar collectors have two disadvantages i.e. low thermal air capacity and a low absorber to air heat transfer coefficient (Fudholi *et al*., 2011).

More recently, these solar air heaters operating through forced convection have been the subject of many extensive types of research and scrutiny. Various methodologies have been proposed to improve the operating and economic potentials of the solar air heater which seek the improvement in coefficient of the heat transfer and thus improve the efficiency of the system. It has been shown as a result of these developments that the artificial surface roughness provided on the duct of the solar air heaters, such as fins, ribs, and baffles lead to heat transfer augmentation and superior thermo-hydraulic performance (Lahori *et al*., 2016).

Since this is still an active research area, the recommended design upgrades of using fins to enhance roughness were introduced in relatively recent times. The fins increase heat transfer area as well as allow for larger turbulence and vortices in the flow which results in improved thermal efficiency.

1.2 Problem Statement

It is a common conversation in today's time that the population of our world is increasing gradually with an alarming rate mainly due to human activities. It is well understood that to do any work everyone needs energy. But, one day the non-renewable energy resources which give us energy like fossil fuels (coal, gas, oil) will run out with the passage of time. Burning fossil fuels release carbon dioxide when they burn, which not only adds to the greenhouse effect and also increases global warming. As the energy demands are increasing day by day with the increase in population by the next few coming years, it would not be possible to address concerns about such fossil fuels. Nowadays, with this concern, it becomes compulsory to find an alternative resource to meet demands by contributing to the replacement of fossil fuel energy production in order to meet future energy needs and consider the natural environment. Out of all sources of renewable energy, solar energy has many advantages over others (Sachin *et al*., 2012). It is the cheapest and easily available source having in abundant. This energy can run nearly equal to every application and can be used in any field of life such as; cooking, washing, electricity, in water equipment and on running heavy machinery as well. The best possible way to harness solar energy is to convert it into thermal energy and utilized for desired purposes (Lanjewar *et al*., 2015). Conventional solar air heater is one of the basic equipment through which solar energy is converted into thermal energy for further usage. Due to the simplicity of the device, they are low-cost and widely used to harness the solar energy available. The development of these devices allows consumers to rely less on conventional energy sources such as fossil fuels for the provision of thermal energy. A highly promising application of solar air heater is in assisting in the drying process of agricultural products and maintaining comfortable internal temperatures of greenhouses and buildings when required. The simplistic structure of the solar air heater also reduces maintenance time and costs. Despite these great advantages, the thermal performance of the solar air heater is found to be poor due to two reasons: the low thermal capacity of air and a low heat transfer coefficient between the absorber plate and air flow through the duct (Kumar *et al*., 2010). Therefore, it is vital to improving this coefficient of heat transfer so that the effectiveness of the system under consideration is economically justifiable. It has been observed from the literature review that different modifications have been suggested and applied to improve the heat transfer coefficient between the absorber plate and the air and several designs are discussed. However, the importance of having inclined fins on the underside of the absorber plate of solar air heaters has not much been identified and studied. Therefore, there is a need to study the influence of inclined fins arrangement on heat transfer and friction factor in a solar air heater by using a novel CFD study.

1.3 Objectives

The main objective of this research is to increase thermal performance of solar air heater with using inclined fins on the underside of the absorber plate. Towards achieving the main objective, the related aims associated with are identified as follows:

1. To propose a new design of solar air heater with inclined fins in order to improve thermal performance.
2. To determine the optimum parameters for achieving improved thermal performance in terms of thermo-hydraulic performance parameter (THPP) of the proposed solar air heater by using Design of Experiments (DOE).
3. To compare the optimum thermo-hydraulic performance parameter (THPP) results with previous work.

1.4 Scope of the Study

This study covers the generation of a two-dimensional solar air heater model in order to numerically analyze the effect of geometric parameters in order to achieve the maximum THPP. The geometric parameters consist of length of fin (e) which is varied in between values of 1.5mm, 2mm and 2.5mm, slant angle of the inclined fins (α) which is varied between 30°, 45° and 60°, pitch of the fins (p) which is varied in between 15mm, 20mm and 25mm and the Reynolds number which is varied in between the values 4000, 8000, 12,000, 16,000, 20,000 and 24,000. These ranges were selected on the basis of common ranges for the SAH (Rajneesh *et al*., 2017; Pandey and Bajpai, 2016; Tamna *et al*., 2014; Yadav and Bhagoria, 2013). The governing equations are formulated considering the fluid flow as a single-phase, incompressible, no radiation heat transfer and fully developed flow (steady-state condition). The solar air heater duct operating on air was used as the working fluid while aluminum was used to develop the absorber plate. The thermo physical characteristics of air as well as the material used for the absorber plate were anticipated to stay constant at a mean bulk temperature. Whilst a 1000 W/m^2 steady heat flux was sustained on the top wall of the test section to represent the best value of heat flux for solar air heater investigation, and bottom wall is insulated, the inlet section was subjected to a homogenous velocity boundary state and the exit section was subjected to a fixed pressure outlet boundary state (Yadav and Bhagoria, 2013; Yadav & Bhagoria, 2014a; Gawande et al., 2016b).

1.5 Thesis Structure

The research thesis is divided into five main chapters that cover systematically the whole work. Chapter 1 focuses on the research background, problem statement, objectives and scope of the study. Chapter 2 provides a scientific literature review and previous dealing with the issue of enhancing of solar air heater. Chapter 3 presents the methodology adapted, numerical study and software used. Chapter 4 presents in details the analysis results, validation, discussions. Chapter 5 presents the conclusions and recommendation for future work.

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