



**AIN SHAMS UNIVERSITY**  
**FACULTY OF ENGINEERING**

**EXPERIMENTAL STUDY OF THE THERMO-HYDRAULIC  
PERFORMANCE OF A SINGLE-PASS SOLAR AIR HEATER WITH  
POROUS MEDIUM**

A Thesis Submitted in Fulfillment of The Requirements of The Degree of  
Master of Science in Mechanical Engineering

Submitted by

**Ashraf Hussien Abd Alhamed Mislem**

B. SC Mechanical Engineering, Power dept., 2011

Supervised by

**Professor Dr. Gamal Mosaad  
Hennes**

Mechanical Power Engineering  
Department  
Faculty of Engineering, Ain Shams  
University

**Professor Dr. Eldesouki Ibrahim  
Saleh Eid**

Mechanical Engineering Department  
Faculty of Industrial Education, Suez  
University

**Dr. Ehab Mouris Mofid Mina**

Mechanical Power Engineering Department  
Faculty of Engineering, Ain Shams University

2020



**AIN SHAMS UNIVERSITY**  
**FACULTY OF ENGINEERING**

**EXPERIMENTAL STUDY OF THE THERMO-HYDRAULIC  
PERFORMANCE OF A SINGLE-PASS SOLAR AIR HEATER WITH  
POROUS MEDIUM**

Submitted by

**Ashraf Hussien Abd Alhamed Mislem**

Master of Science in Mechanical Engineering

Examiners' Committee

Name and Affiliation	Signature
<b>Professor Dr. Tarek Abdel Malak Mikhail</b> Power Engineering, Aswan University	.....
<b>Professor Dr. Raouf Nassif Abdel Messih</b> Mechanical Power, Ain Shams University	.....
<b>Professor Dr. Gamal Mosaad Hennes</b> Mechanical Power, Ain Shams University	.....
<b>Professor Dr. Eldesouki Ibrahim Saleh Eid</b> Mechanical Engineering Department, Suez University	.....

## **Preface**

This dissertation is submitted for the degree of master of science in mechanical engineering for the faculty of engineering of Ain shams university, Cairo.

The work distinguished in the dissertation was executed at the Department of Mechanical Power Engineering, Faculty of Engineering, Ain Shams University, Cairo.

No part of this thesis was submitted for an academic degree or qualification at any other university or institution.

Under supervision and guidance of:

- **Professor Dr. Gamal Mosaad Hennes**
- **Professor Dr. Eldesouki Ibrahim Saleh Eid**
- **Dr. Ehab Mouris Mofid Mina**

Name : **Ashraf Hussien Abd Alhamed Mislem**

Signature :

Date : / / 2020

## **Researcher Data**

Name:	Ashraf Hussien Abd Alhamed Mislem
Date of birth:	8/4/1988
Place of birth:	Dammam, Saudi Arabia
Last academic degree:	Bachelor of Engineering
Field of specialization:	Mechanical Power Engineering
University issued the degree:	Higher Technological Institute (10 <sup>th</sup> of Ramadan city)
Date of issued degree:	2011
Current job:	Teaching Assistant at H.T.I

## Acknowledgement

My greatest thanks to **Allah** for giving me the will power and strength

first, I would like to thank my supervisors **Prof. Dr. Gamal Mosaad Hennes, Prof. Dr. Eldesouki Ibrahim Saleh Eid** and **Dr. Ehab Mouris Mofid Mina** for their continuous guidance, encouragement, invaluable assistance and patience. I learned so many valuable things from them, but above all, they taught me how to be devoted to scientific research.

Very warm and special gratitude to my **beloved Mother** who supported me with the greatest possible care and encouragement.

I wish to express my deepest appreciation and gratitude to my beloved **father, my brothers, my wife, and the whole family** for their endless love through my life.

I would like also to thank **Dr. Ahmed Samy El-Adl** and **Eng. Mohamed Abd Ellatif** for supporting and the encouragement during a certain stage of the research.

Special thanks to laboratory operator; **Mr. Nabil Samak** for his sincere support during my experiments either in the construction of the test rig or in the preliminary runs.

## **Abstract**

Enhancing the thermo-hydraulic performance of solar air collectors (SACs) can be achieved by various ways, some of which are; fins, ribs, baffles, porous medium and grooves. So far, diverse attempts have been established to enquire the effects of these ways on the heater performance. Consequently the performance of a single pass SAC (SPSAH) employing Porous Medium (PM) with various density and porosity has been experimentally investigated. Several porous packings made of compressed aluminum scraps with different packing density and filament size were utilized. A SAC fitted with a solar simulator was designed to apply a uniform heat flux ( $q''$ ) of about  $700 \text{ W/m}^2$ , where the solar simulator generates irradiance similar to that coming from the sun. It is utilized to run experiments under constant heat flux conditions without the demand for natural solar radiation. Noting that solar simulator utilized in this study is designed and constructed of scrape which is mentioned in details. The distribution of the flux generated from the constructed solar simulator was measured and reported in the results.

This study aims to improve the temperature lift in an SPSAH with a minimum possible increase in pressure drop ( $\Delta P$ ). Locally available metal packings are used as a PM to accomplish this aim. Two types of packing are employed in experimental work. The first type is made of compressed aluminum

swarf with different wire size and packing density. The porosity in this type ranges from 0.60 to 0.96. The second type is made of packed steel wire mesh with varied mesh density. The porosity of this second type ranges from 0.60 to 0.92.

- The thermal efficiency ( $\eta_{th}$ ) is used to evaluate the heater performance. The pressure drops ( $\Delta P$ ) associated with each packing is employed to assess the exergy loss from the solar heater, and the packing is compared accordingly. Additionally, a Computational Fluid Dynamic (CFD) analysis is executed to analyze the SPSAH performance.
- The results illustrate that employing compressed aluminum swarf as a porous medium increases the thermal efficiency ( $\eta_{th}$ ) of SPSAH and preserves the temperature inside the heater for longer running periods. Additionally, the results indicate that increasing the air mass flow rate ( $\dot{m}$ ) will decrease the temperature difference ( $\Delta T$ ) between the inlet and the exit sections of the heater, but also, will cause an increasing in  $\eta_{th}$  of the system.
- The packed SPSAH (packed with aluminum swarf) enhanced the  $\eta_{th}$  by 50 - 60% compared to empty SPSAH for the same dimensions and air mass flow rate. The maximum temperature incurred from the packed SPSAH is 62 °C for a temperature difference of 34 °C. The experimental data validated the CFD results with a maximum deviation between both results within  $\pm 2\%$ .

## Nomenclature

Symbol	Name	units
A	area	$\text{m}^2$
I	solar radiation intensity	$\text{W}/\text{m}^2$
$\dot{m}$	Mass flow rate	$\text{kg}/\text{s}$
Pr	Prandtl number	$\text{m}^2 \text{ s}^{-1}$
$\Delta P$	pressure difference	pa
Q	volume flow rate	$\text{m}^3/\text{s}$
$q''$	Heat flux	$\text{W}/\text{m}^2$
Q	useful heat gain	W
S	Absorbed radiation from the sun	$\text{W}/\text{m}^2$
T	inlet temperature	K
$\Delta T$	temperature difference	K
U	loss coefficient	$\text{W}/\text{m}^2 \cdot \text{K}$
$U_L$	Heat transfer coefficient	
V	air velocity	$\text{m}/\text{s}$

### Greek symbols

$\alpha$	Absorptivity	
H	Efficiency	
$\rho$	density of air	$\text{kg}/\text{m}^3$
$\tau$	Transmissivity	
$\Phi$	Porosity	

### Subscripts

A	Ambient
b	Beam
C	Collector
d	Diffuser
$F_R$	Heat removal factor
g	Ground
I	Inlet

O	Outlet
R	Removal factor
T	Top
th	Thermal
u	Useful

### **Abbreviations**

CFD	Computational Fluid Dynamics
PM	Porous medium
SAC	Solar air collector
SAH	Solar air heater
SPSAH	Single pass solar air heater

# Table of Contents

<b>Preface .....</b>	<b>ii</b>
<b>Researcher Data .....</b>	<b>iii</b>
<b>Acknowledgement.....</b>	<b>iv</b>
<b>Abstract .....</b>	<b>v</b>
<b>Nomenclature.....</b>	<b>vii</b>
<b>Table of Contents.....</b>	<b>ix</b>
<b>List of Tables.....</b>	<b>xii</b>
<b>List of Figures .....</b>	<b>xiii</b>
<b>CHAPTER 1 INTRODUCTION.....</b>	<b>2</b>
<b>1.1 General .....</b>	<b>1</b>
<b>1.2 Solar Air Heaters (SAHs) .....</b>	<b>3</b>
<b>1.3 Advantages and disadvantages of solar air system.....</b>	<b>4</b>
<b>1.3.1 Advantages .....</b>	<b>4</b>
<b>1.3.2 Disadvantages .....</b>	<b>4</b>
<b>1.4 Thesis Objectives and Organization .....</b>	<b>5</b>
<b>1.5 The main objectives of the thesis.....</b>	<b>7</b>
<b>1.6 The plan of the thesis.....</b>	<b>7</b>
<b>CHAPTER 2 LITERATURE REVIEW .....</b>	<b>1</b>
<b>2.1 Introduction .....</b>	<b>9</b>

2.2 Using multiple glazing.....	9
2.3 Implementing extended surface .....	9
2.4 Solar air collector with storage medium.....	12
2.5 The use of solar simulator.....	14
<b>CHAPTER 3 THE TEST RIG .....</b>	<b>9</b>
3.1 Solar Air Collector with Various Arrangements.....	17
3.2 SAC apparatus building.....	18
3.2.1 Solar collector .....	18
3.2.2 Solar simulator.....	22
3.3 Experimental Measurement Devices .....	27
3.3.1 Pyranometer.....	27
3.3.2 Temperature Measuring Sensor.....	27
3.3.3 Digital Anemometer .....	27
3.3.4 Differential pressure gauge.....	27
3.4 Experimental Procedure .....	28
3.4.1 SAC without packing (empty) .....	29
3.4.2 Solar air collector with packings.....	29
<b>CHAPTER 4 EXPERIMENTAL RESULTS.....</b>	<b>30</b>
4.1 Introduction .....	30
4.2 Single pass solar air heater investigations.....	30

4.3	Results of the experimental work.....	33
<b>CHAPTER 5 NUMERICAL SIMULATION .....</b>		<b>38</b>
5.1	Solar simulator investigations .....	38
5.1.1	Modelling and numerical results.....	38
5.1.2	Absorbed radiation from the sun:.....	45
5.2	Theoretical Procedure.....	46
5.3	Setup .....	47
5.4	Results.....	51
<b>Chapter 6 Conclusions and future work .....</b>		<b>54</b>
6.1	Solar simulator .....	54
6.2	Solar collector .....	54
<b>REFERENCES .....</b>		<b>56</b>
<b>APPENDICES .....</b>		<b>62</b>
<b>APPENDIX (A) .....</b>		<b>62</b>
Working drawing of the frame.....		62
<b>APPENDIX (B) .....</b>		<b>68</b>
Tables of parameters readings .....		68
<b>APPENDIX (C) .....</b>		<b>83</b>
Measurement Instruments.....		83

## List of Tables

Table 2. 1 Some of latest work of researchers and their achievements.....	15
Table 3.1 Different experimental setups for packings of the SAC.....	18
Table 3. 2 inlet air changing periods .....	28
Table 4. 1 Results of 5.5 kg packing with 66% porosity and 3mm wire thickness .....	33
Table 4. 2 results of 4.5 kg packing with 72% porosity and 3mm wire thickness .....	34
Table 4. 3 results of 4.5 kg packing with 72% porosity and 2mm wire thickness .....	35
Table 5. 1 Setting used in Zemax Software .....	39
Table 5. 2 Results of irradiance against elevation .....	41
Table 5. 3 Different numerical setups for packings of the SAC .....	50

## List of Figures

Fig. 1. 1 Classification of solar energy applications.....	2
Fig. 3. 1 The schematic of the manufactured solar air collector .....	19
Fig. 3. 2 Wooden frame of the air heater .....	19
Fig. 3. 3 Disassembly view of the collector.....	20
Fig. 3. 4 heater double layer glass cover .....	20
Fig. 3. 5 Air Pre-heating Section .....	21
Fig. 3. 6 Inverted View of The Solar Simulator .....	22
Fig. 3. 7 diagram showing the basic form of a solar simulator.....	23
Fig. 3. 8 Designed Solar Simulator .....	24
Fig. 3. 9 The schematic of the solar air collector with different solar simulator heights.....	25
Fig. 3. 10 Pictorial view of the SAC with solar simulator .....	25
Fig. 3. 11 Pictorial view of the SAC with inlet air pre-heater.....	26
Fig. 3. 12 Pictorial views of the SAC with solar simulator illustrating packing insertion port .....	26
Fig. 4. 1 Example of the readings logged for about 12 minutes to produce one data point on the characteristic curve (taken from the readings of a heater with no packing) .....	31
Fig. 4.2 The curve associate with the heater with no packing .....	32
Fig. 4. 3 The curve associate with the heater with 5.5 kg packing with 66% porosity and 3mm wire thickness.....	34
Fig. 4. 4 The curve associate with the heater with 4.5 kg packing with 72% porosity and 3mm wire thickness.....	35

Fig. 4.5 The curve associate with the heater with 4.5 kg packing with 72% porosity and 2mm wire thickness .....	36
Fig. 4. 6 The experimental apparatus of solar simulator.....	36
Fig. 4.7 The irradiance measured results obtained on the centerline of the solar heater .....	37
Fig. 5. 1 Sketch of the Simulator on Zemax A) without the rays B) with the 100 rays originated from each tube sketched .....	38
Fig. 5. 2 Rays from tube to the detector surface shown on 2-D view of the setup, rays missing the surface are not extended in this view .....	40
Fig. 5. 3 the detector view obtained from ray tracing with spacing 30 cm between the tube and the detector with the detector resolution 11X13 pixels .....	41
Fig. 5. 4 the detector view obtained from ray tracing with spacing 25 cm between the tube and the detector with the detector resolution 11X13 pixels .....	42
Fig. 5. 5 the detector view obtained from ray tracing with spacing 35 cm between the tube and the detector with the detector resolution 37X31 pixels .....	42
Fig. 5. 6 Radiation distribution on Detector surface for source above the detector by 25cm (up) – 30cm (middle) - 35 cm (lower) .....	43
Fig. 5.7 The irradiance numerical results obtained on the centerline of the solar .....	44
Fig. 5.2 comparison between the irradiance results obtained on the centerline of the solar heater (red circles) numerical, (black diamonds) measurements .....	45
Fig. 5. 9 Heater Geometry in SOLIDWORKS.....	47
Fig. 5.10 Illustration of boundary conditions .....	48
Fig. 5.11 mesh metrics.....	49