THEORETICAL AND EXPERIMENTAL PERFORMANCE OF COMPOUND PARABOLIC CONCENTRATORS

By

Mohamed Hossam Mohamed Shehata Eldakamawy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE
in
MECHANICAL POWER ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2015

THEORETICAL AND EXPERIMENTAL PERFORMANCE OF COMPOUND PARABOLIC CONCENTRATORS

By

Mohamed Hossam Mohamed Eldakamawy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE
in
MECHANICAL POWER ENGINEERING

Under Supervision of

Abdalla Sayed Ahmed Hanafi

Professor
Mechanical Power Engineering Department
Faculty of Engineering,
Cairo University

Mahmoud Abdel-Wahab Kassem

Associate Professor
Mechanical Power Engineering Department
Faculty of Engineering,
Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2015

THEORETICAL AND EXPERIMENTAL PERFORMANCE OF COMPOUND PARABOLIC CONCENTRATORS

By

Mohamed Hossam Mohamed Eldakamawy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE
in
MECHANICAL POWER ENGINEERING

Approved by the
Examining Committee:

Prof. Dr. **Mahmoud Abdel-Fatah El-Kady**, External Examiner

Prof. Dr. **Abdel-Wahed El-Dib**, Internal Examiner

Prof. Dr. **Abdalla Sayed Ahmed Hanafi**, Thesis main Advisor

Dr. **Mahmoud Abdel-Wahab Kassem,** Thesis Advisor

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

Engineer: Mohamed Hossam Mohamed Shehata Eldakamawy
Date of Birth: 14/11/1990
Nationality: Egyptian
E-mail: m_eldakamawy@eng.cu.edu.eg
Phone: 00201285240291
Address: 19, Shawky st, sheikh rihan, talbia faisal, Giza


Registration Date: 01/10/2012
Awarding Date: / /
Degree: Master of Science
Department: Mechanical Power Engineering

Supervisors: Prof. Dr. Abdalla Sayed Ahmed Hanafi
Dr. Mahmoud Abdel-Wahab Kassem

Examiners: Prof. Dr. Mahmoud Elkady (El Azhar University)
Prof. Dr. Abdel-Wahed El-Dib
Prof. Dr. Abdalla Sayed Ahmed Hanafi
Dr. Mahmoud Abdel-Wahab Kassem

Title of Thesis: THEORETICAL AND EXPERIMENTAL PERFORMANCE OF COMPOUND PARABOLIC CONCENTRATORS

Keywords: Compound parabolic concentrator, Twisted tape inserts, Bare tubular absorber, Experimental, Swimming pool heating

Summary:

The compound parabolic concentrators (CPC) are promising low concentration non imaging solar collectors, with intermediate indicative working temperature range (60 - 300 ^{o}C), that can operate monthly, seasonally or annually without the need of continuous tracking. They show competitive performance with flat plate collectors when used in applications of temperatures slightly above the ambient. Likely, the CPC collectors have lower cost and smaller pumping power consumption. Thereby, the present work presents a rigorous study of the optical, geometrical and thermal characteristics of CPCs with bare tubular absorbers. This investigation covered also the effect of truncation, number of frequent tilt adjustments and usage of heat transfer enhancement (HTE) techniques like twisted tape insertion on the performance of CPC. In all cases, the CPCs are oriented as usual in an East-West direction and facing south. Moreover, a CPC test rig was set up at the Faculty of Engineering campus, Cairo University, which helped to validate the transient model and gave a clear indication for the CPC performance under Egypt's environmental working conditions. The designed CPC performed well as a solar water heater with a measured efficiency of around 46.7% during winter.

ACKNOWLEDGMENT

Firstly, I would like to thank Almighty ALLAH, whom I firstly owe everything, for his generousness and support through all my life. In our life, we rarely meet some respectful people doing their best, exerting great efforts to share their experience, knowledge and lead us to the right way. I'd like to thank ALLAH for helping me to meet such great professors: Prof. Abdalla Hanafi and Assoc. Prof. Mahmoud Abdel-Wahab, who guided me to finish this work in the most suitable form.

Further thanks go to Prof. Adel Khalil, Prof. Elgamil, Dr. Essam Elhanoony, Eng. Ahmad Abo-Elmagd, Eng. Ahmad Elmelih and Eng. Mostafa Gamal for helping and supporting me with very useful experimental instrumentation and measured data.

Special thanks and gratitude are for my father Eng. Hossam Eldakamawy for his great technical support, and my family for their patience to provide me with the most suitable conditions to finish my work.

Finally, I'd like to thank my colleagues, Eng. Ahmad Hamed, Eng. Mohamad Zidan, Eng. Mohamad Mortada, Eng. Osama Selim and Eng. Ahmad Ibrahim, also technicians in the Mechanical Power Department who encouraged and helped me to finish this work in an appropriate form.

Table of Contents

List of Tables

List of Figures

List of Symbols

A	Area, m^2
$\bar{A}$	Altitude, km
α	Absorptivity
a_o, a_1 and k	Constants for standard atmospheric conditions
a_0^*, a_1^* and k^*	Corrected constants for Hottel model
β	Tilt angle, degrees
C	Concentration ratio
δ	Declination angle, degrees
ϵ	Emissivity
f_{end}	End losses factor
f	Friction factor
f_{rat}	Ratio between heat transfer coefficients
F	Control function
F’	Ratio between thermal resistances
g	Gap distance between reflector and absorber, m
γ_s	Solar azimuth angle, degrees
Gr	Grashof number
H	Full collector height, m
H_t	Truncated collector height, m
h	Heat transfer coefficient, $W/m^2.K$
H^*	Characteristic length, m
h_{tot}	Overall heat loss coefficient, $W/m^2.K$
η_o	Optical efficiency
η	Instantaneous efficiency
I_b	Normal beam radiation, W/m^2
I_d	Diffuse radiation on horizontal surface, W/m^2
I_o	Normal extraterrestrial radiation, W/m^2
I_{sc}	Solar constant, W/m^2
I_{tot}	Total incident radiation, W/m^2
I_u	Useful gained radiation, W/m^2
k	Thermal conductivity, W/m.K
L	Collector length, m
m	Air mass
m^*	Corrected air mass
$\dot{m}$	Mass flow rate, kg/s
M	Arc length, m
$\overline{n_\iota}$	Average number of internal reflections within θ_c
$\overline{n_o}$	Average number of internal reflections outside θ_c
n	Day number
Nu	Nusselt number
υ	Kinematic viscosity, m^2/s