NUMERICAL INVESTIGATION FOR HEAT TRANSFER ENHANCEMENT IN PARABOLIC TROUGH ABSORPTION TUBE USING TWISTED TAPE INSERTS

By

Mohamed Ahmed Abdelazim Abousabae

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE
In
MECHANICAL POWER ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

NUMERICAL INVESTIGATION FOR HEAT TRANSFER ENHANCEMENT IN PARABOLIC TROUGH ABSORPTION TUBE USING TWISTED TAPE INSERTS

Key Words:
Fluid Dynamics; Heat Transfer; Twisted Tape; Parabolic Trough Absorption Tube; Solar Energy

Summary:

In this work, the thermal performance of parabolic trough absorption tube with twisted tape inserts were analyzed numerically using ANSYS FLUENT 15.0 software. An optical modelling tool that uses Monte-Carlo ray tracing techniques (Soltrace) was used to obtain the non-uniform heat flux distribution on the parabolic trough absorber tube. The results show that the use of twisted tape inserts results in high heat transfer rates due to the increased turbulence intensity and the mixing of the heat transfer fluid from that part of the absorber tube which receive concentrated heat flux with the heat transfer fluid from the part which receive only direct solar heat flux and the heat transfer increases between 17 % and 84 % and friction factor increases between 117 % and 415 %

Acknowledgment

First, I would like to thank Almighty God for the gift of life, provision and protection. Without Him, I would not have come this far.

I would like to express my heartfelt gratitude to my supervisors Prof. Dr. Essam E. Khalil, Dr. Gamal Abd El-Moniem El Hariry and Dr. Ahmed El-Degwy Ahmed El-Degwy for their guidance and unremitting encouragement.

I am grateful to them, and to all my respectful teachers and professors, for mentoring me throughout my under graduate and postgraduate studies. I extend my gratitude to my dear colleagues for their valuable suggestions and noteworthy discussions.

I also would like to thank Dr. Kareem Awny and Eng. Waleed Ahmed for their unconditional support and help.

Finally, I cannot express in words my thanks and gratitude to my family for their motivation through finishing this thesis, their patience, and maintaining a perfect environment for study and research.

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NOMENCLATURE

Symbol	Quantity
K	Thermal conductivity, w/m.k
$A_{ap,r}$	Absorption tube aperture area, m^2
$A_{ap,c}$	Collector aperture area, m^2
L	Length of the trough, m
f	The focal length, m
a	The aperture width, m
C_G	Geometric concentration ratio
d_{ro}	Absorption tube outer diameter, m
d_{ri}	Absorption tube inner diameter, m
d_{gi}	Glass cover inner diameter, m
d_{go}	Glass cover outer diameter, m
Nu	Nusselt number
Nu_{en}	Nusselt number for enhanced absorber tube
Nu_p	Nusselt number for plain absorber tube
X	Thermal enhancement factor
H	Twist tape pitch, m
W	Twist tape width, m
Y	Twist ratio
T_{sky}	Sky temperature, K
h_w	Wind heat transfer coefficient, $w/m^2.k$
cp	Specific heat of fluid, J/kg.K
g_i	The component of the gravitational vector in the i^{th} direction, m/s^2
Gk	Turbulence kinetic energy generated due to the mean velocity gradients
K	Kinetic energy of turbulence, m^2/s^2
kp	Turbulence kinetic energy at point P, m^2/s^2
l	Length scale of Turbulence, m
Pr	Molecular Prandtl number, $Pr = Cp\ \mu / k$
$\dot{q}$	Wall heat flux, W/m^2
Su	The source term

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$S\varphi$	The source term
Ti	Inlet temperature, ºC
Tp	Temperature at the cell adjacent to wall, ºC
Tw	Temperature at the wall, ºC
$\vec{u}$	The flow velocity vector, m/s
$\vec{u}_g$	The grid velocity of the moving mesh, m/s
$\boldsymbol{u_i}$	The fluctuating velocity component, m/s
$\overline{\boldsymbol{u_i}}$	The mean velocity component, m/s
u_j	Mean velocity component, m/s
U_p	Mean velocity of the fluid at point *P* , m/s
Y_M	The contribution of the fluctuating dilatation to the overall dissipation rate
y_P	Distance from point to the wall, m
y_T^*	The non-dimensional thermal sublayer thickness

Greek Letters

ρ	Density of the fluid, kg/m^3
τ_{ij}	The stress tensor, N/m^2
ψ	Rim angle, degree
θ	Circumferential angle, degree
μ	Viscosity, kg/m.s
ε	Emissivity,
δ_{ij}	Kronecker delta
μ_{eff}	Effective turbulent viscosity
$\Gamma\varphi$	The diffusion coefficient
μ_t	Turbulent viscosity, kg.m/s
ϵ	Turbulence dissipation rate, m^2/s^3
β	Coefficient of thermal expansion, K^{-1}
δV_j	The volume swept out by the control volume face j
Φ_f	Value of Φ convected through face *f*
$\nabla\Phi$	Gradient of Φ
σ_ϵ	The turbulent Prandtl numbers for ϵ
σ_K	The turbulent Prandtl numbers for k
$-\rho\overline{u_i' u_j'}$	Reynolds stresses term

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ABBREVIATIONS

CFD	Computational Fluid Dynamics
CSP	Concentrated Solar Power Plants
DNI	Direct Normal Irradiance
EES	Engineering Equation Solver
FVM	Finite Volume Method
HCE	Heat Collection Element
HTF	Heat Transfer Fluid
IPH	Industrial Heat Process
LCR	Local Concentration Ratio
LVG	Longitudinal Vortex Generators
MCRT	Monte Carlo Ray Tracing Method
NREL	National Renewable Energy Laboratory
PTC	Parabolic trough Collector
RANS	Reynolds Averaged Navier-Stokes equations
RKE	Realizable K-ε Turbulence Model
RNG	Re-normalization Group K-ε Turbulence Model
SNL	Sandia National Laboratory
mtoe	Million Tonnes of Oil Equivalent

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ABSTRACT

Parabolic trough systems are one of the most commercially technologies for concentrated solar power. The main development efforts are concentrating on reducing the cost of this technology. The cost reduction options for parabolic trough systems include: (i) improving parabolic trough concentration ratio by increasing its sizes and (ii) improving the optical efficiency. However increasing the concentration ratio of parabolic trough system will cause more circumferential temperature difference on the absorption tube and will increase the system’s thermal losses. So the development of the absorption tube becomes very important to increase the concentration ratio.

In the present work, the thermal performance of parabolic trough absorption tube with twisted tape inserts at different inlet temperatures, twist ratios and Reynolds numbers are investigated.

In this work, the thermal performance of parabolic trough absorption tube with twisted tape inserts is analyzed numerically by solving the governing equations using ANSYS FLUENT 15.0 software. An optical modelling tool that uses Monte-Carlo ray tracing techniques (Soltrace) was used to obtain the non-uniform heat flux distribution on the parabolic trough absorber tube. These heat flux distributions were then coupled to the CFD code as a boundary condition by using MATLAB code to convert them to a readable data by the profile function in ANSYS FLUENT 15.0 for the analysis of the thermal performance of the receiver.

The results show that the use of twisted tape inserts for heat transfer enhancement in parabolic trough receivers results in high heat transfer rates due to the increased turbulence intensity and the mixing of the heat transfer fluid from that part of the absorber tube which receive concentrated heat flux with the heat transfer fluid from the part which receive only direct solar heat flux. As the results demonstrated that the heat transfer increases between 17 % and 84 % while friction factor increases between 117 % and 415 % and thermal enhancement factor at a constant pumping comparison with a plain receiver tube was in the range 0.83 - 1.12. Also the results showed that the improved heat transfer performance in the absorption tube due to the use of twisted tape inserts reduces the absorption tube's circumferential temperature difference.