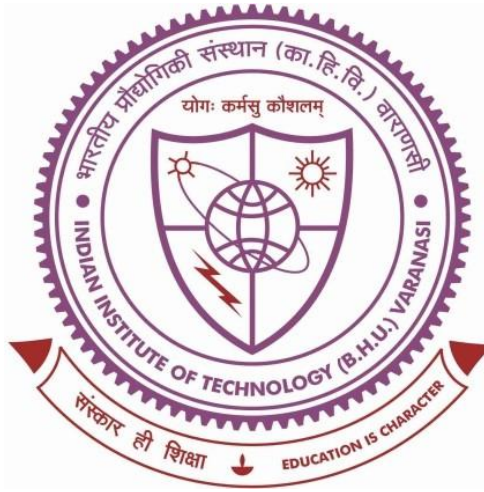


LOW GRADE WASTE HEAT RECOVERY ENHANCEMENT METHODS USING THERMOELECTRIC GENERATORS



Thesis submitted in partial fulfillment for the
Award of Degree

Doctor of Philosophy

By

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CERTIFICATE

It is certified that the work contained in the thesis titled "Low grade waste heat recovery enhancement methods using thermoelectric generators" by Kartik Srivastava has been carried out under my supervision and that this work is not submitted elsewhere for any degree.

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DECLARATION BY THE CANDIDATE

I, **Kartik Srivastava**, certify that the work embodied in this thesis is my bonafide work carried out by me under the supervision of **Dr. Rashmi Rekha Sahoo** for a period of 3 years and 9 months from July 2021 to March 2025 at IIT(BHU) Varanasi. The material contained in this thesis has not been submitted for the award of any other degree. I declare that I have faithfully acknowledged and given credit to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any others' work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports, dissertations, theses, etc., or available on websites, and have not included them in this thesis and have not cited them as my work.

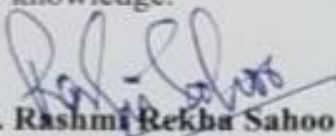
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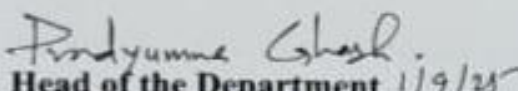

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Date: 23/04/2025

Place: IIT (BHU), Varanasi


(Kartik Srivastava)

Dedicated
to
the loving memory
of
Maa & Papa

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List of Symbols

Nomenclature

A	Area (m ²)
A, B	Viscosity enhancement coefficients
A_a	Outer surface area of the absorber (m ²)
A_e	Effective heat absorption area of the absorber (m ²)
A_r	Cross-sectional area of the computational domain (m ²)
A_t	Cross area of the tube (m ²)
Be	Bejan number
C	Conductivity enhancement coefficient
C_p	Specific heat capacity (J/kgK)
D	Distance between consecutive vortex generators (m)
D/H	Distance to height ratio
D_h	Hydraulic diameter (m)
ΔP	Pressure drop (Pa)
ΔT	Temperature difference (K)
D_h	Hydraulic diameter (m)
d_{SC}	Inner absorber tube's outer diameter (m)
d_{tube}	Outer diameter of the inner absorber tube (m)
Ex	Exergy rate (W)
f	Friction factor
F'	Collector efficiency factor
F_R	Heat removal factor
G	Incident solar radiation (W/m ²)

h	Heat transfer coefficient (W/m ² K)
H_c	Channel height (m)
$h_{f,I}$	Heat transfer coefficient at the fluid-tube wall interface (W/m ² K)
i	Control unit number
I	Current (A)
I_{rr}	Irreversibility rate (W)
k	Thermal conductivity (W/mK)
K	TEG power factor (W/K ²)
k_{Al}	Thermal conductivity of aluminum (W/mK)
k_{pn}	TEG thermal conductivity (W/mK)
L	Length (m)
L_{SC}	Inner absorber tube's effective length (m)
\dot{m}	Mass flow rate (kg/s)
n	Number of channels
N	TEG computational unit number
Nu	Nusselt number
$Power$	TEG power (W)
Pr	Prandtl number
\dot{Q}	Heat rate (W)
q_{flux}	Heat flux (W/m ²)
R	Thermal resistance (m ² .K/W)
R^2	Coefficient of determination
Re	Reynolds number
Req	Equivalent electrical resistance (Ω)

R_{pn}	TEG electrical resistance (Ω)
S/N	Signal-to-noise ratio
\dot{S}_{gen}	Entropy generation rate (W/K)
t	Heat sink base thickness (m)
t_p	Heat exchanger plate thickness (m)
T	Temperature (K)
U_f	Uncertainty
U_m	Mean velocity (m/s)
\dot{V}	Volume flow rate (m^3/s)
V	Voltage (V)
W	Width (m)
w_c	Channel width (m)
w_w	Wall width (m)
x	x-direction
x^*	Dimensionless thermal entry length
y	y-direction
z	z-direction
ZT	Figure of merit

Greek letters

α	Channel aspect ratio
α_a	Absorbing coating's absorptivity capacity
α_{pn}	Seebeck coefficient (V/K)
β	Width ratio of the fin to channel
η_{conv}	TEG conversion efficiency

η_{fin}	Fin efficiency
γ	Aspect ratio
μ	Dynamic viscosity (kg/ms)
φ	Volume fraction
ρ	Density (kg/m ³)
ρ_{pn}	TEG resistivity (m/S)
τ	Outer glass's light transmittance
Γ	Diffusion coefficient

Subscripts

0	Reference case
amb	Ambient
avg	Average
bf	Base fluid
c	Cold
ch	Channel
cap	Capacitive
co	Coolant
$cond$	Conductive
$conv$	Convective
ex	Exhaust
h	hot
hnf	Hybrid nanofluid
hs	Heat sink
in	Inlet

<i>m</i>	Intermediate
<i>nf</i>	Nanofluid
<i>out</i>	Outlet
<i>w</i>	Wall of the heat sink

Abbreviation

ANN	Artificial neural network
ANOVA	Analysis of variance
CFD	Computational fluid dynamics
DMSO	Dimethyl sulfoxide
DVG	Delta vortex generator
EG	Ethylene glycol
EUSWH	Evacuated u-tube solar water heater
FVG	Fishtail vortex generator
GHG	Greenhouse gas
HTC	Heat transfer coefficient
HTF	Heat transfer fluid
HX	Heat exchanger
LHSCS	Latent heat storage and cooling system
LVG	Longitudinal vortex generator

MVG	Envelope vortex generator
MVS TEG	Multistage variable shape TEG
MWCNT	Multi-wall carbon nano tube
ORC	Organic Rankine cycle
RTG	Radioisotope thermoelectric generator
RWVG	Rectangular winglet vortex generator
STEG	Solar thermoelectric generator
TEF	Thermal enhancement factor
TEG	Thermoelectric generator
TES	Thermal energy storage
VG	Vortex generator
WHR	Waste heat recovery