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It is further certified that the student has satisfactorily fulfilled all the requirements of the Comprehensive examination, Candidacy, and SOTA for the award of the Ph.D. degree.

Dr. Rashmi Rekha Sahoo
(Supervisor)
Department of Mechanical Engineering
IIT(BHU), Varanasi

DECLARATION BY THE CANDIDATE

I, **Chandrmani Yadav,** certify that the work embodied in this thesis is my own bonafide work carried out by me under the supervision of **Dr. Rashmi Rekha Sahoo** for a period of 4 years and 6 months from July 2017 to December 2021 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 credits 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 at websites and have not included them in this thesis and have not cited as my own work.

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Dr. Rashmi Rekha Sahoo

(Supervisor)

Head of the Department

Mechanical Engineering Department, IIT(BHU), Varanasi

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Nomenclature

A	Area (m^2)
A_1	Area between PCMs/NEPCMs and the room temperature profile corresponds to the liquid state of PCMs/NEPCMs (m^2)
A_2	Area between PCMs/NEPCMs and room temperature profile corresponding to the phase change state of PCMs/NEPCMs (m^2)
A_3	Area between PCMs/NEPCMs and the room temperature profile corresponds to the solid-state of PCMs/NEPCMs (m^2)
B_1	Area between distilled water and room temperature profile corresponds to the liquid state of PCMs/NEPCMs (m^2)
B_2	Area between distilled water and room temperature profile corresponds to the phase change in the state of PCMs/NEPCMs (m^2)
c_p	Specific heat capacity (kJ/kg-K)
C	Heat capacity (kW/K)
d_o	Inner diameter of the inner tube (m)
D_o	Outer diameter of the outer tube (m)
Eu	Euler number
f	Liquid fraction
Fo	Fourier number
g	Gravitational acceleration (m/s^2)
G	Upstream velocity at minimum flow area (kg/m^2-s)
h	Coefficient of convective heat transfer (W-m^2/K)

k	Thermal conductivity (W/m-K)
l	Length of the tube (m)
LH	Latent heat (kJ/kg)
m	Mass (kg)
n	Number of tubes
N	Number of transverse rows
Nu	Nusselt number
P	Pressure (N/m^2)
Pr	Prandtl number
q	Heat transfer rate (kW)
Q	Amount of heat storage (kJ)
Q_{ex}	Heat transfer rate from exhaust gases (kW)
r	Radius (m)
Ra	Rayleigh number
S_l	Longitudinal spacing between tubes (m)
S_n	Normal spacing between tubes (m)
S_p	Parallel spacing between tubes (m)
S_t	Transverse spacing between tubes (m)
t	Time (s)
t_{ws}	Wall thickness of the outer tube (m)
t_{wt}	Wall thickness of the inner tube (m)
T	Temperature (K)
T_l	Temperature of liquid region of PCM (K)
T_m	Phase change temperature (K)
T_R	Temperature of the PCM at the axis (K)

T_s	Temperature of solid region of PCM (K)
T_w	Inner wall temperature (K)
U	Overall heat transfer coefficient (kW/m^2-K)
W	Weight (kg-m/s^2)

Greek symbols

α	Thermal diffusivity
β	Expansion coefficient
ε	Effectiveness
η	Energy efficiency
θ	Temperature Difference
μ	Dynamic viscosity
ρ	Density
ϕ	Volume concentration
χ	Correction factor
ψ	Exergy efficiency

Subscripts

a	Air
b	Bulk
ch	Charging
ex	Exhaust
f	Fuel
l	Liquid
np	Nanoparticles
o	Ambient

pcm	Phase Change Material
s	Solid
t	Tube
w	Water
∞	Free stream condition
1	Inlet
2	Outlet

Abbreviations

Al_2O_3	Aluminium Oxide
CA	Capric acid
CuO	Copper Oxide
CV	Calorific Value
EHE	Exhaust Heat Exchanger
HTF	Heat Transfer Fluid
IC	Internal Combustion engines
LA	Lauric acid
LHS	Latent heat thermal storage
LPM	Litres Per Minute
MWCNT	Multi-Walled Carbon Nanotubes
NEPCMs	Nano-enhanced phase change materials
PCM	Phase Change Material
PW	Paraffin wax
sfc	Specific Fuel Consumption
SA	Stearic acid

TES	Thermal Energy Storage
WHR	Waste Heat Recovery