Declaration

I hereby declare that the work presented in this Thesis titled "*Two-Phase Flow and Boiling Heat Transfer Analysis of Macro and Mini-channels at Atmospheric and Subatmospheric System Pressure*" submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work carried out under the supervision of *Dr. Hardik B. Kothadia*. The contents of this thesis, in full or in parts, have not been submitted to, and will not be submitted by me to any other Institute or University in India or abroad for the award of any degree or diploma.

Arvind Kumar
P19ME014

Certificate

This is to certify that the thesis titled "*Two-Phase Flow and Boiling Heat Transfer Analysis of Macro and Mini-channels at Atmospheric and Subatmospheric System Pressure*", submitted by *Arvind Kumar* (*P19ME014*) to the Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Dr. Hardik B. Kothadia
Ph.D. Thesis Supervisor

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Arvind Kumar
Ph.D. Student

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Nomenclatures

Symbol	*Description*
C_p	Specific Heat at Constant Pressure (J/kgK)
D	Helical Coil Diameter (mm)
G	Mass Flux (kgm^2s)
H	Enthalpy (J/kg)
I	Electric Current (A)
L	Length (mm)
P	Pressure (kPa)
Q	Useful Heat (kW)
T	Temperature ($°C$, $°K$)
V	Voltage (V)
X	Lockhart Martinelli Parameter
ΔP	Pressure Drop (kPa)
ΔT	Temperature Difference ($°C$, $°K$)
ΔT_{ONB}	Wall Superheat required for ONB
ΔT_{sub}	Temperature Difference between Fluid Temperature and corresponding Saturation Temperature
ΔT_{sat}	Wall Superheat
d	Tube Inner Diameter (mm)
f	Friction Factor
f_c	Friction Factor for Helical Coil
f_s	Friction Factor for Straight Tube
g	Gravitational Constant (m/s^2)
h	Heat Transfer Coefficient (W/m^2K)
k	Thermal Conductivity (W/mk)
$\dot{m}$	Mass Flow Rate (kg/s)
p	Pitch (mm)
q''	Heat Flux (kW/m^2)
$\dot{q}$	Heat Generation (W/m^3)
x	Vapor Quality
z	Local Length from Inlet (mm)

Greek Symbols

ρ	Density
μ	Dynamic viscosity
σ	Surface tension
ε	Emissivity
α	Void fraction
β	Coefficient of volume expansion
ν	Kinematic viscosity
∞	Ambient
$\emptyset^2$	Two-phase multiplier

Subscripts

acc	Acceleration
c	Curved
ch	Characteristics
conv	Convection
cr	Critical
f	Bulk fluid
fg	Liquid to gas
fri	Frictional
g	Gas

go	Gas-only
gra	Gravitational
h	Homogeneous
in	Inlet
L	Local
l	Liquid
lo	Liquid-only
loss	Heat loss to atmosphere
out	Outlet
rad	Radiation
s	System
sa	Surface area
sat	Saturated
sb	Subcooled
sp	Single-phase
sub	Subcooling
tp	Two-phase
trans	Transition
tt	Turbulent - Turbulent
w	Wall

List of Abbreviations

DAS	Data Acquisition System
CHF	Critical Heat Flux
DPT	Differential Pressure Transmitter
DSG	Direct Steam Generator
H	Horizontal Flow
HTC	Heat Transfer Coefficient
L-M	Lockhart Martinelli
MI	Matlab Image
NIST	National Institute of Standards and Technology
NVG	Net Vapor Generation
ONB	Onset of Nucleate Boiling
PD	Pressure Drop
PT	Pressure Transmitter
RTD	Resistance Temperature Detector
SFB	Subcooled Flow Boiling
SSP	Subatmospheric System Pressure
Temp	Temperature
TI	Thermal Image
VD	Vertical Downflow
VU	Vertical Upflow

Dimensionless Number

Bd	Bond number, $\frac{g(\rho_f-\rho_g)d^2}{\sigma}$
Bo	Boiling number, $\frac{q''}{GH_{fg}}$
Dn	Dean number, $Re\sqrt{\frac{d}{D}}$
Fr	Froude number, $\frac{G^2}{\rho_f^2 gd}$
Gr	Grashoff number, $\frac{g\beta(T_w-T_\infty){L_{ch}}^3}{\nu^2}$
Ja	Jacob number, $\frac{C_p(T_w-T_{sat})}{H_{fg}}$

Nu	Nusselt number, $\frac{hd}{k_f}$
Pr	Prandtl number, $\frac{\mu C_p}{k_f}$
Ra	Rayleigh number, $Gr \times Pr$
Re	Reynolds number, $\frac{4\dot{m}}{\pi d\mu}$
We	Weber number, $\frac{G^2 d}{\sigma \rho}$