Simulation of Fast Response Thermocouple for Nuclear Reactor

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Outline of the presentation

- Description of the subjective system
- Problem definition/identification
- Strategy of modeling thermocouple
- Boundary conditions
- Simulation
- Analysis of the simulation data
- Selection of optimal configuration

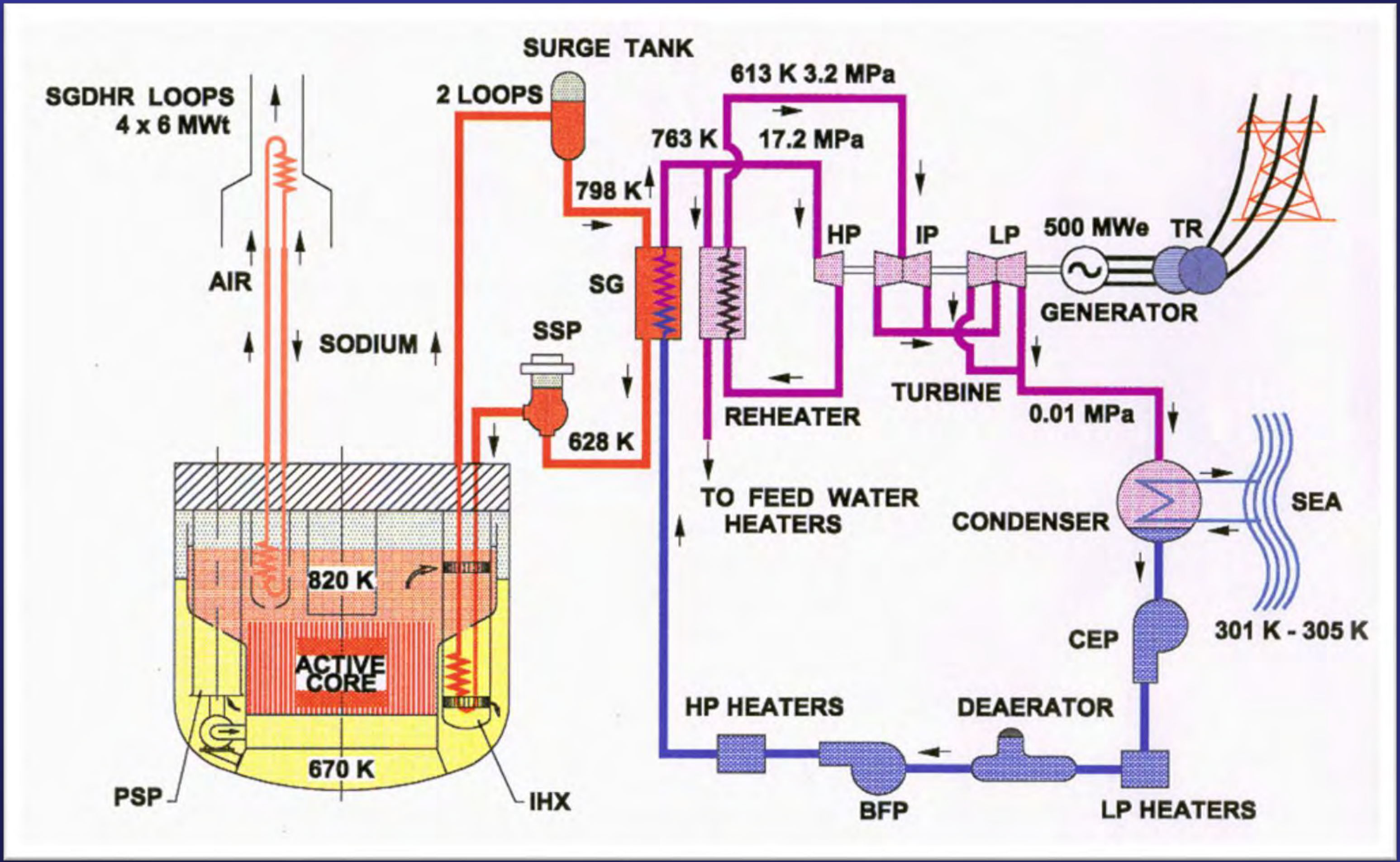
Introduction

About Nuclear Reactor, INDIA's contribution, Scope of sensors in nuclear reactor,

Nuclear Energy:

- ✓ The viable energy resource.
- ✓ India has got abundant Nuclear fuel resources.
  Uranium(50,000t),Thorium(5,00,000t).
- ✓ Presently commercial nuclear electricity generation through PHWReactors and as a part of efficient fuel utilization FBReactors are introduced.
- ✓ FBR is a successfully running environmental friendly technology.
- ✓ Presently in IGCAR, Kalpakkam, a Prototype FBTR is launched.
- ✓ Role of SENSORS in improving the efficiency of nuclear plant.

Sensors For PFBR application



Schematic Representation of Nuclear Plant

Requirements in Reactor Core

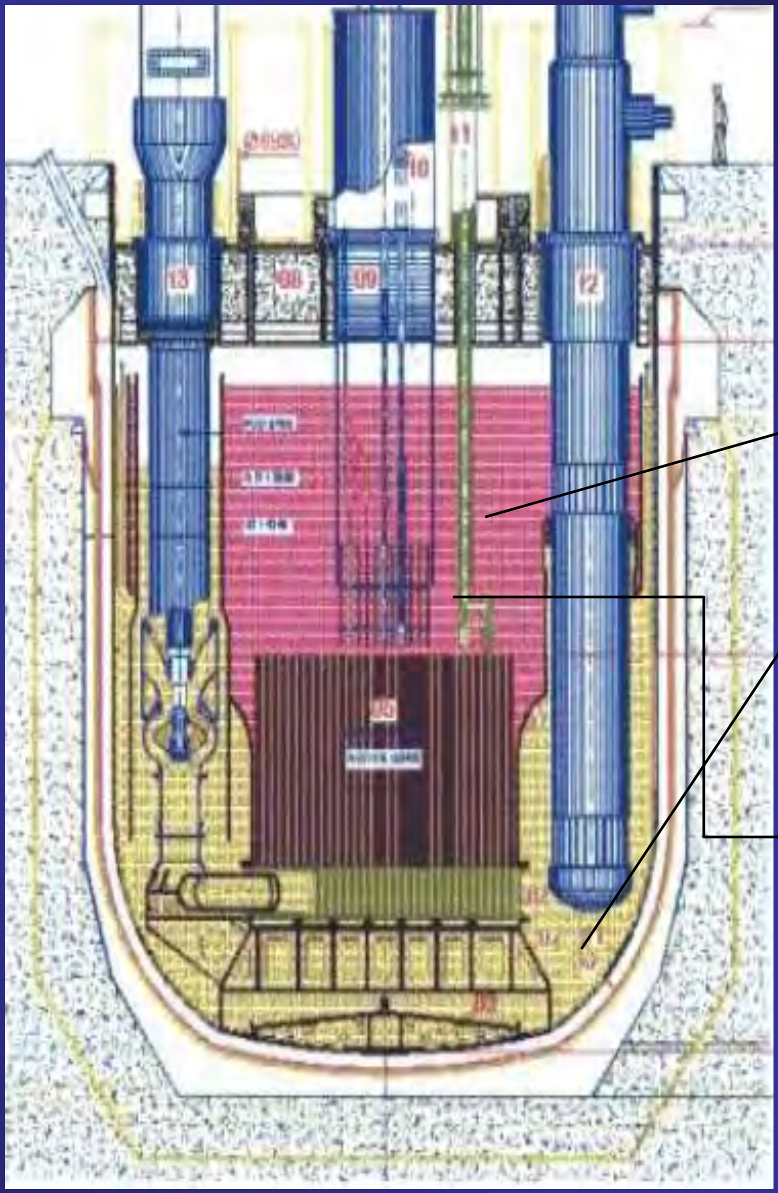
Core temperature monitoring is provided for detection of core anomalies

- It provides signals for protection of the reactor from various incidents. The safety actions prevent the clad hot spot and fuel temperature reaching the limits.
- Temperatures at the outlets of 211 core subassemblies (SA) are measured.
- Redundant TC are provided at the outlet of SA. These signals are used for the reactor protection
- The sensors are to be easily replaceable and withstand high radiation at the outlet of the core SA

Thermocouple	Time response(Sec's)
1mm Thermocouple	0.3
2mm Thermocouple	0.3
5mm Thermo well	6

Reactor Core

- In fast reactors, TC used for measurement of temperature in various locations.
- Some of these installation locations like the outlet of the fuel subassemblies require that the response time of the thermocouple should be less so that better control and safety can be achieved in a fast reactor



Objective

- To Model the Thermocouple which has the faster response than the present.
- Various thermocouple models and the response times has to analyze.
- Based on the analysis best model has to select for the requirement.

Design Features

- ✓ Mineral Insulated, SS sheathed, ungrounded junction, Chromel-alumel thermocouple of overall diameter 1mm are used for core temperature monitoring.
- ✓ TC except at the central SA are installed in thermo wells fixed on the core cover plate.
- ✓ The TC for the central SA are fixed in the central canal plug and are directly in contact with sodium.
- ✓ The values of temperature measured by each thermocouple at the SA outlet and the TC at the reactor inlets are displayed on the control consol.

Thermocouple Specifications

Chromel-Alumel thermocouples are selected for core temperature monitoring as they have

- ✓ Very good radiation resistance,
- ✓ an almost linear temperature-emf characteristic over the required range of temperature
- ✓ proven operating experience in all the fast reactors.

The characteristics of the TC are as follows

range : 400 to 1100 K

- » accuracy : ± 2.3 K at nominal operating
- » temperature of 843 K
- » (channel accuracy : ± 3 K)
- » time constant : 6±2 s (Except for the TC for central SA)

  : 300 ms for the TC for central SA

REQUIRED THERMOCOUPLE MODEL

- ✓Thermocouple Physics.
  - Sensing principle.
  - Theory behind the sensing.
- ✓Factors affecting the response time of the thermocouple.
  - Conducting medium
  - Thermocouple bead size.
  - Insulation and Sheath of the thermocouple.

CONTINUATION………

- ✓Heat Transfer Phenomenon

  conduction

  convection

- ✓ Modelling considerations

  The require study of heat transfer takes place inside the thermocouple so examine the effects of heat transfer inside the thermocouple as a conduction phenomenon.

  Suitable measures can be taken to decrease the response time without compromising on other aspects like mechanical strength and electrical insulation

CONTINUATION.....

The selection of a particular type of thermocouple depends upon the application or the process requirement.

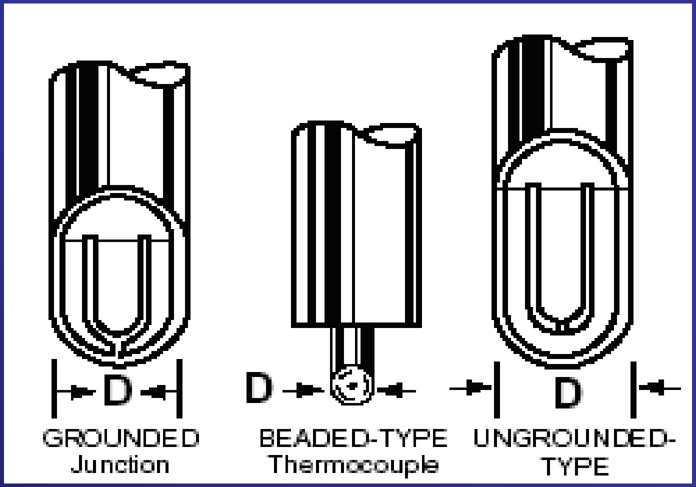
Since it is time consuming to fabricate thermocouples of different dimensions and materials and to obtain their response time experimentally, a numerical modeling approach has been followed.

By using the COMSOL Multi Physics, a finite element based software Various designs of thermocouples have been analyzed and their response times has been calculated.

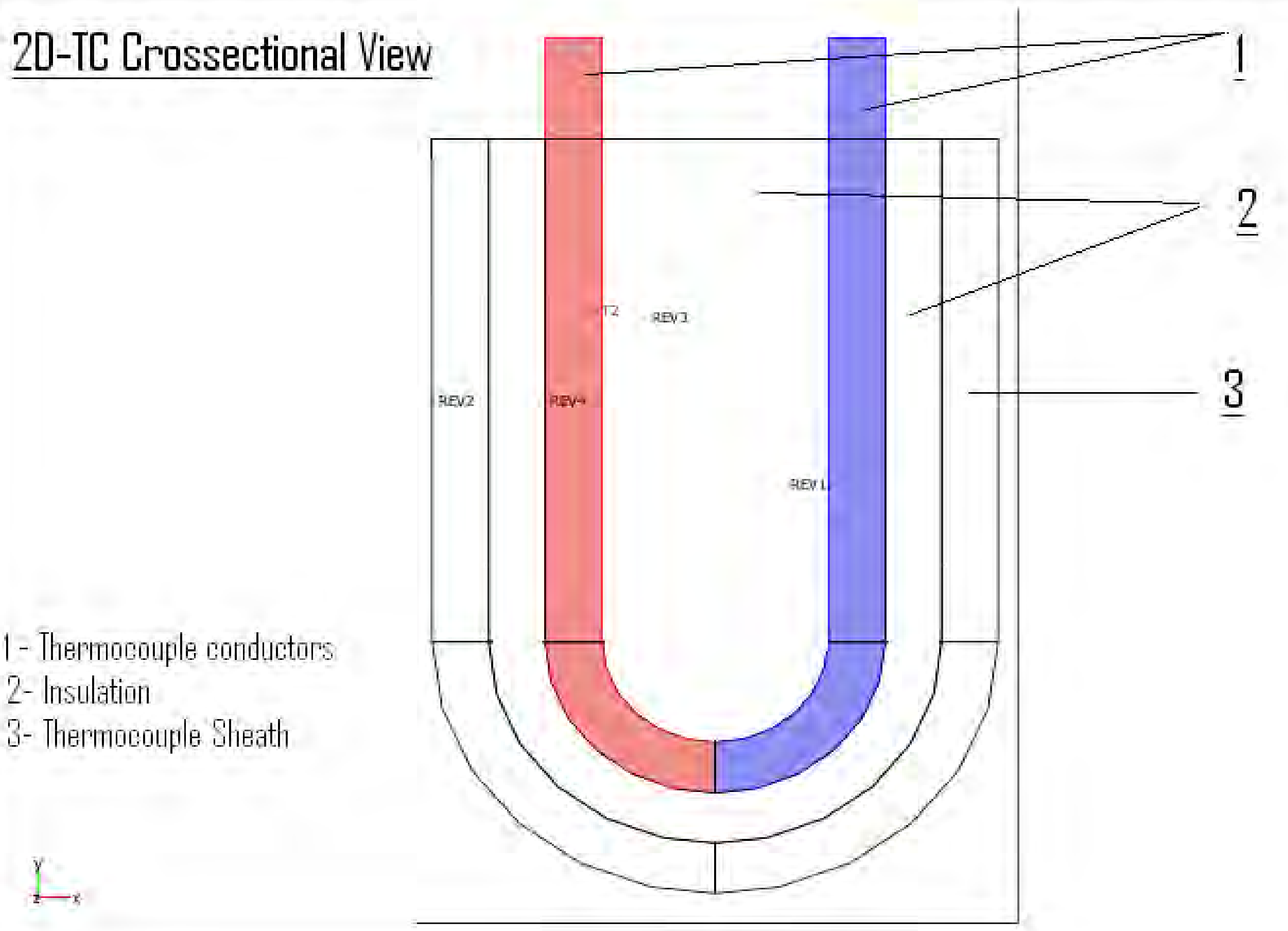
Modelling of Thermocouple

- Simulation of the thermocouple heat transfer @ hot junction.

  Simulation of Central core SA thermocouple(Which is immersed in Hot Liquid sodium).
- Simulation of Central core SA thermocouple fixed in thermo well.



Model Geometry

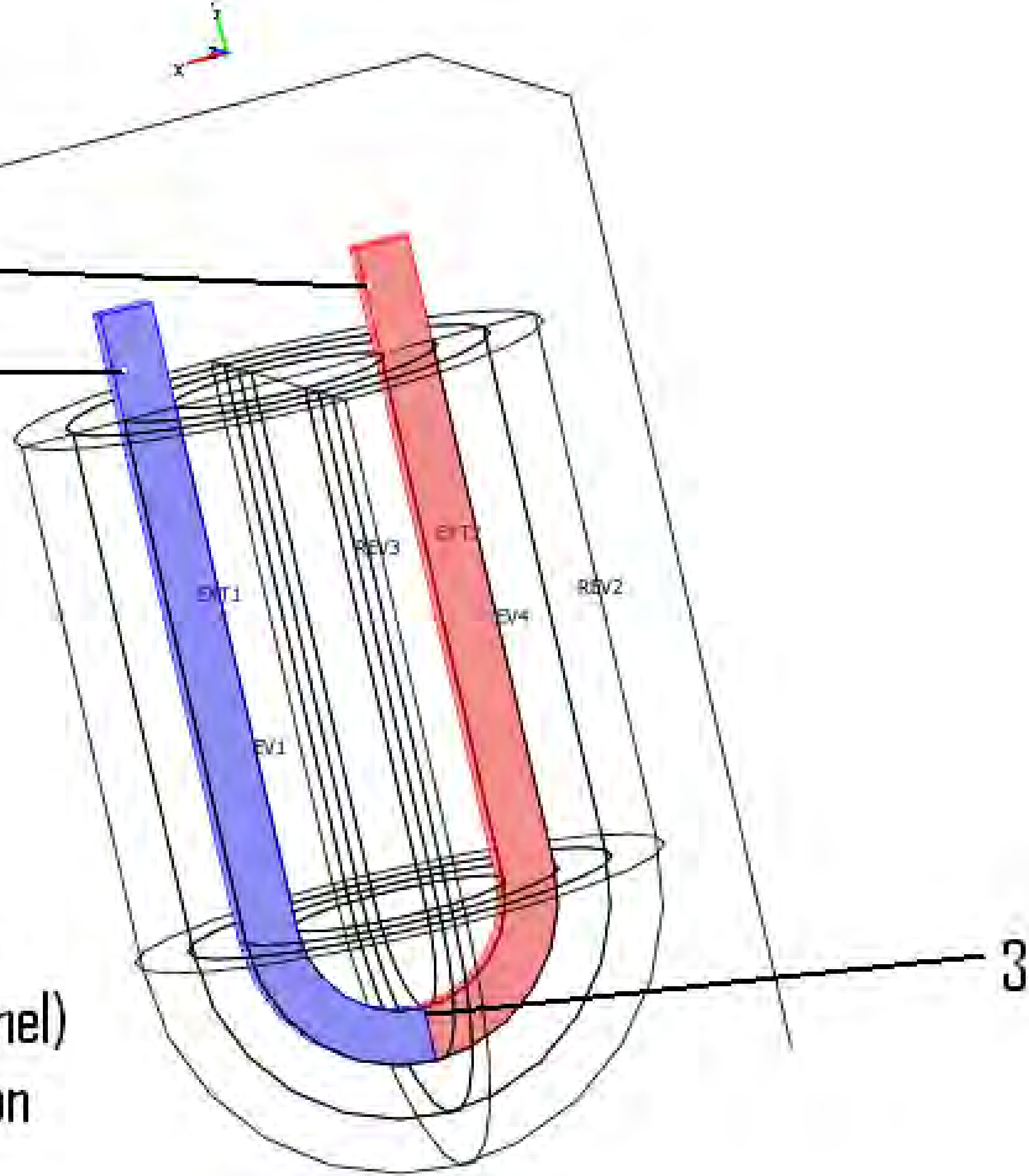


1 - Thermocouple conductors
2- Insulation
3- Thermocouple Sheath

Conductor sideview

1

2



1,2 - Thermocouple wires
K-Type(Chromel-Alumel)

3 - Thermocouple Junction

MODELLING METHODOLOGY

The response time of the thermocouple depends upon a number of parameters. A parametric analysis has been done with respect to these parameters and its effect on the response time has been obtained. The parameters varied in the analysis are:

Diameter of the thermocouple wire (a)

Thickness of the sheath (b)

Position of the hot junction (h)

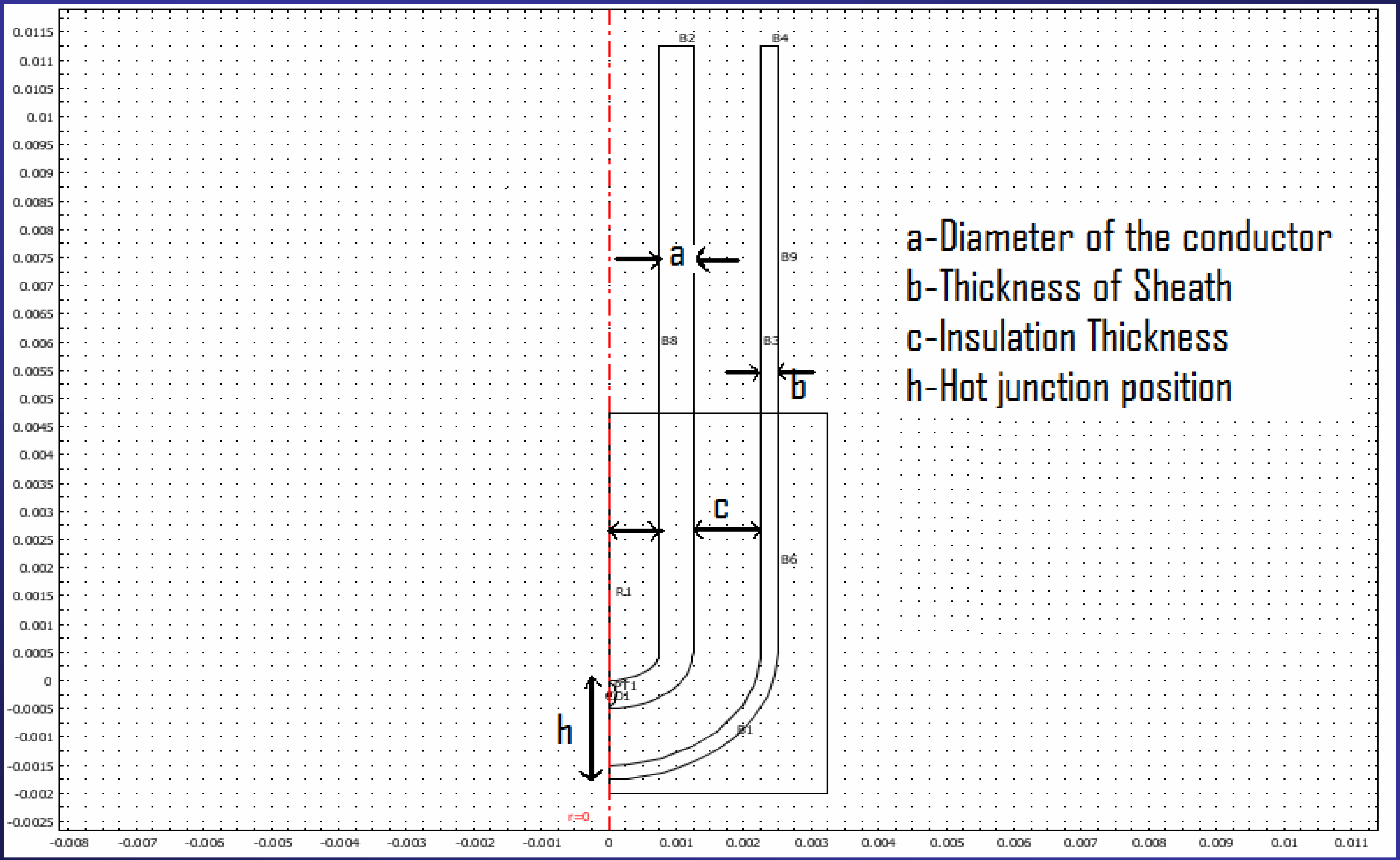
Insulation thickness (c)

Bead diameter.

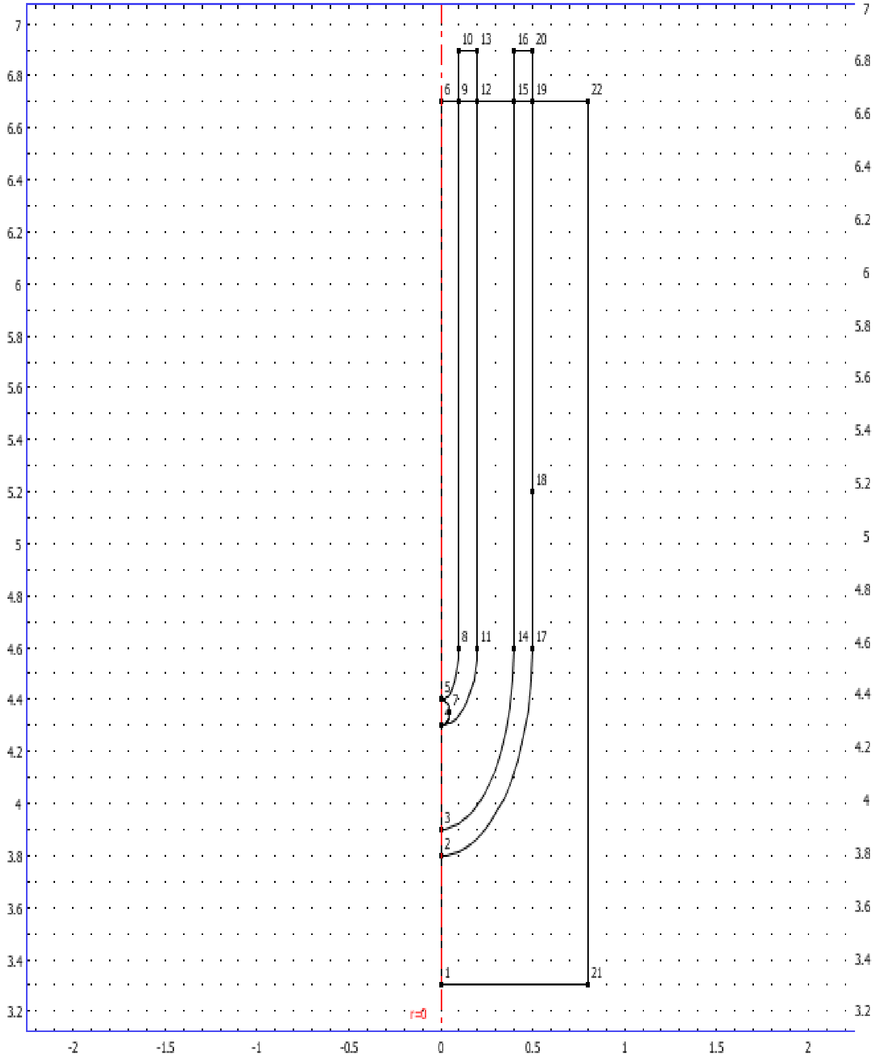
Since a number of combinations are possible out of these 4 parameters, a coding representation (a-b-h-c) to refer to each configuration has been used

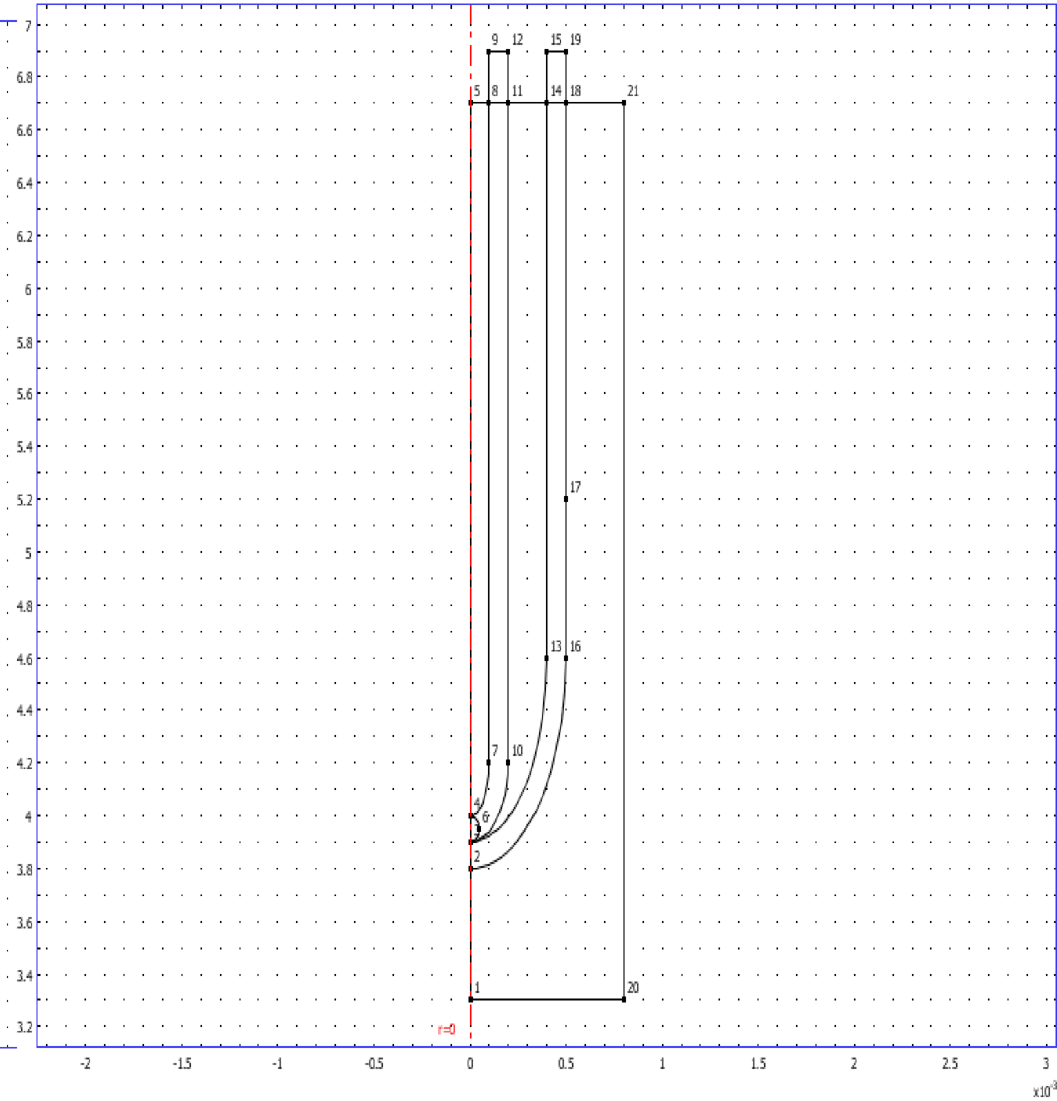
e.g. (Ex: 0.5-2.5-2-5) in mm.

Reference Dimensions of the Thermocouple Model

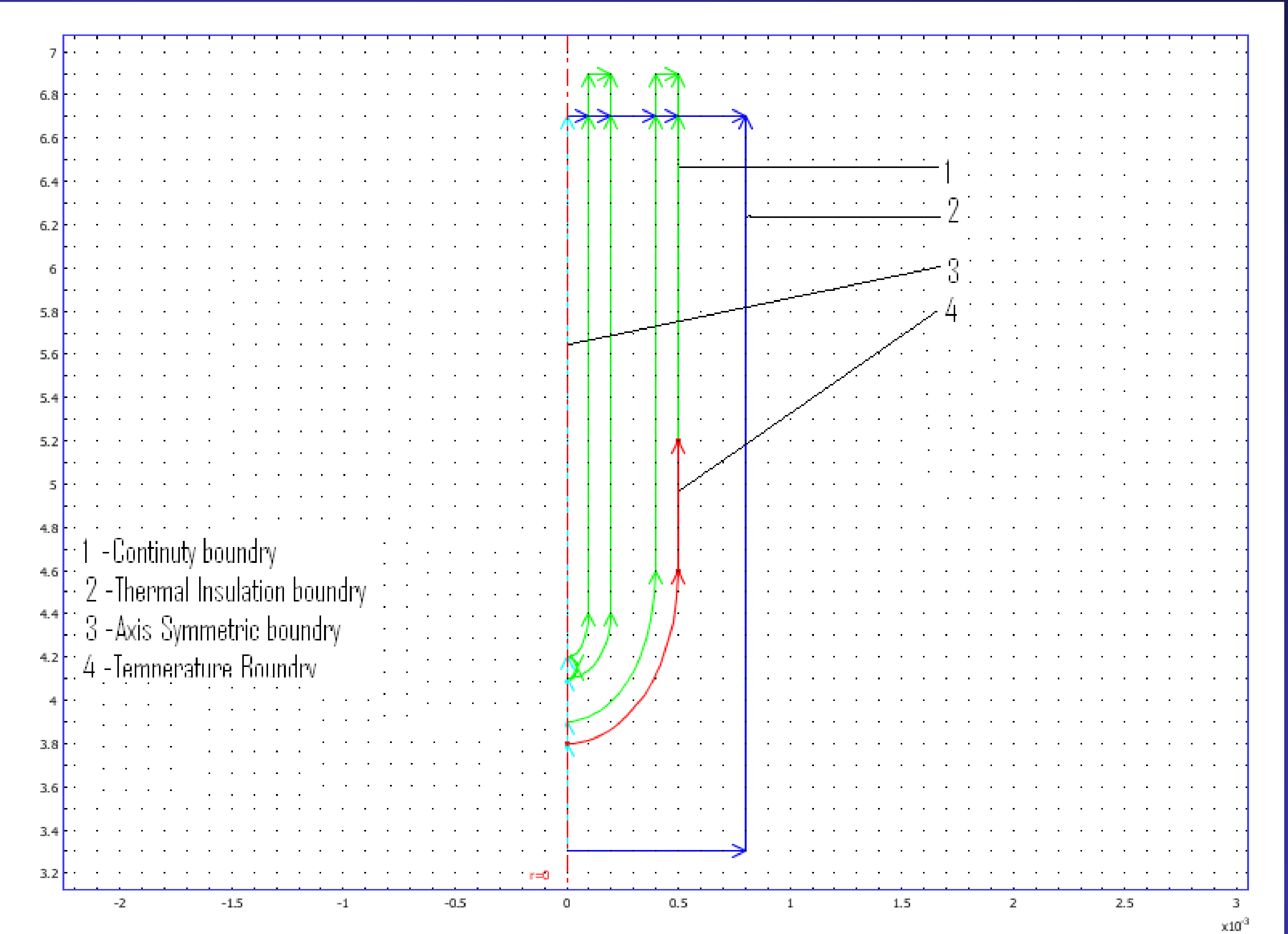


Grounded and Ungrounded Thermocouple Models

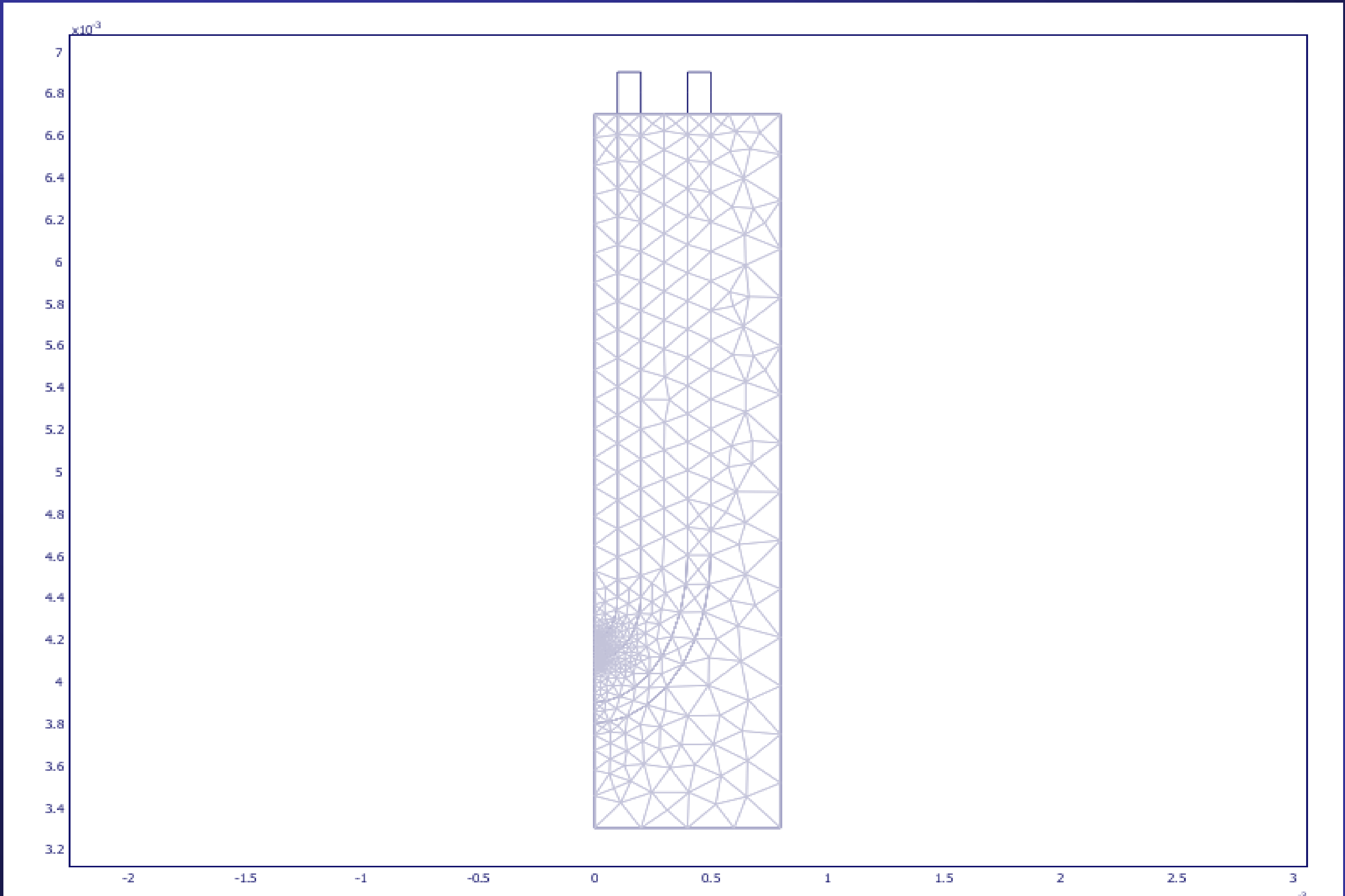




Thermocouple Model Boundaries



Thermocouple Model Mesh



Equations governing the Heat tranfer

Conduction:

Equation

$$\delta_{ts}\rho C_p \partial T/\partial t + \nabla\cdot(-k\nabla T) = Q, \ T = \text{temperature}$$

Convection:

Equation

$$\delta_{ts}\rho C_p \partial T/\partial t + \nabla\cdot(-k\nabla T) = Q - \rho C_p \mathbf{u}\cdot\nabla T, \ T = \text{temperature}$$

k	- Thermal conductivity
Rho(ρ)	- Density
C_p	- Heat Capacity
Q	- Heat source
T	- Temperature
U	- Velocity of the fluid

Material Properties For TC Simulation

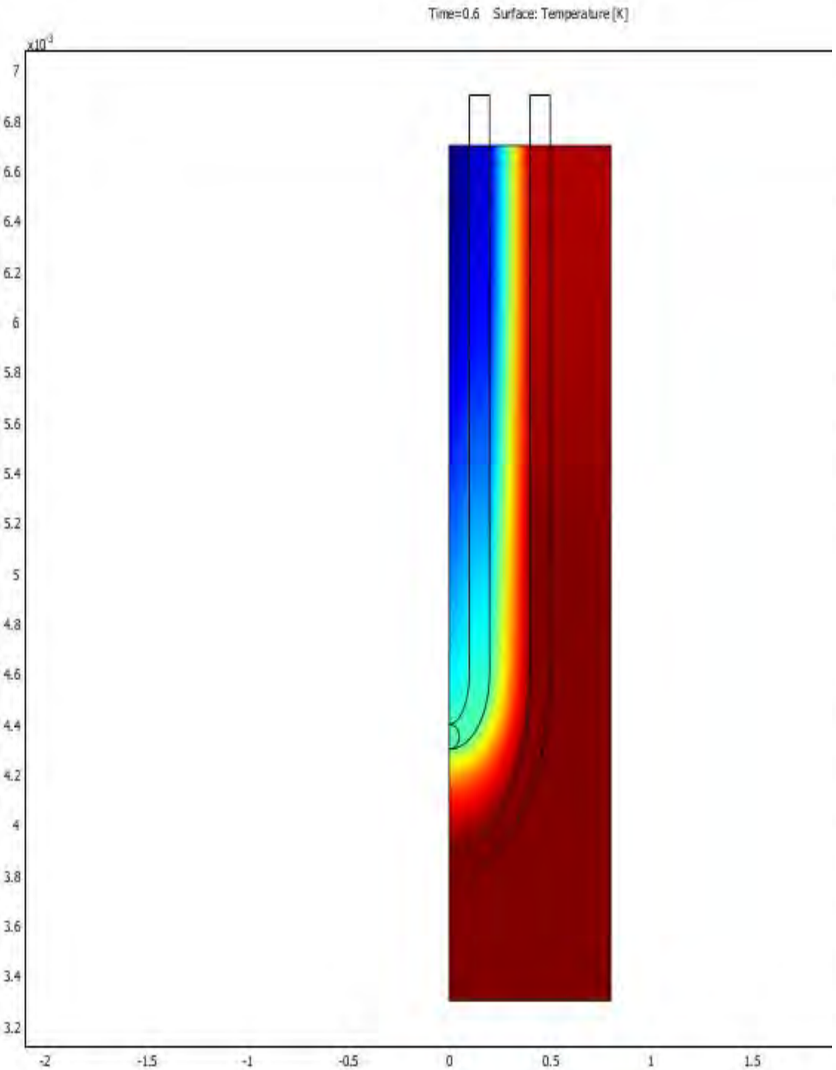
Material	K (w/m.k)	Rho(kg/m3)	Cp (j/kg.k)
Chromel	19.2	8730	448
Alumel	29.7	8610	523
Liquid sodium	107	860	1280
MgO	1.44	2848	940
Stainless Steel	21.4	8030	475

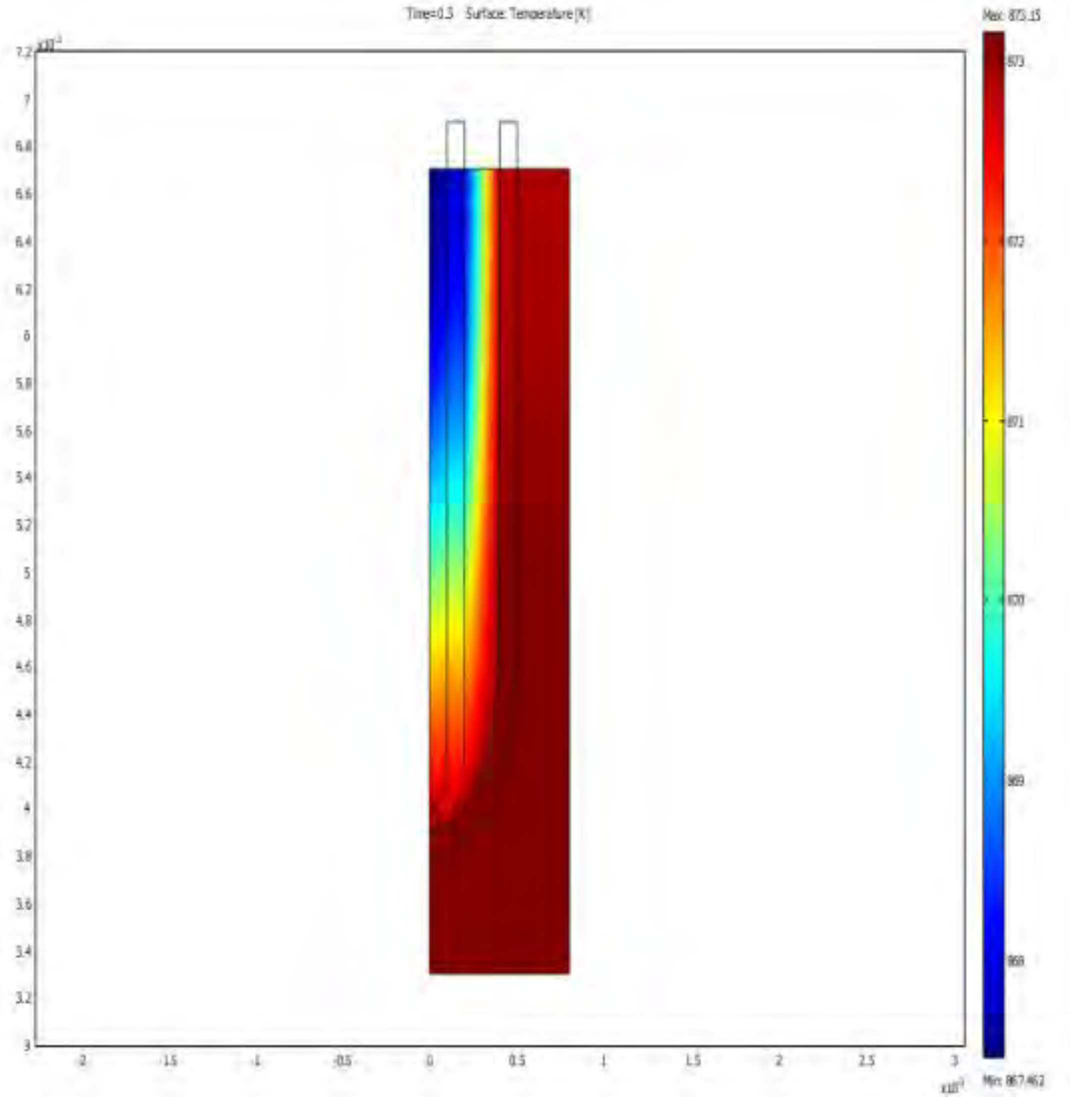
Simulation of Models

- ✓ Specified thermocouple for simulation are 1mm and 2mm.
- ✓ Simulation of 5mm Thermo well.
- ✓ Various ungrounded and grounded models of 1mm and 2mm.
- ✓ Dimensions for 1mm ungrounded 0.1-0.1-0.6-1 mm

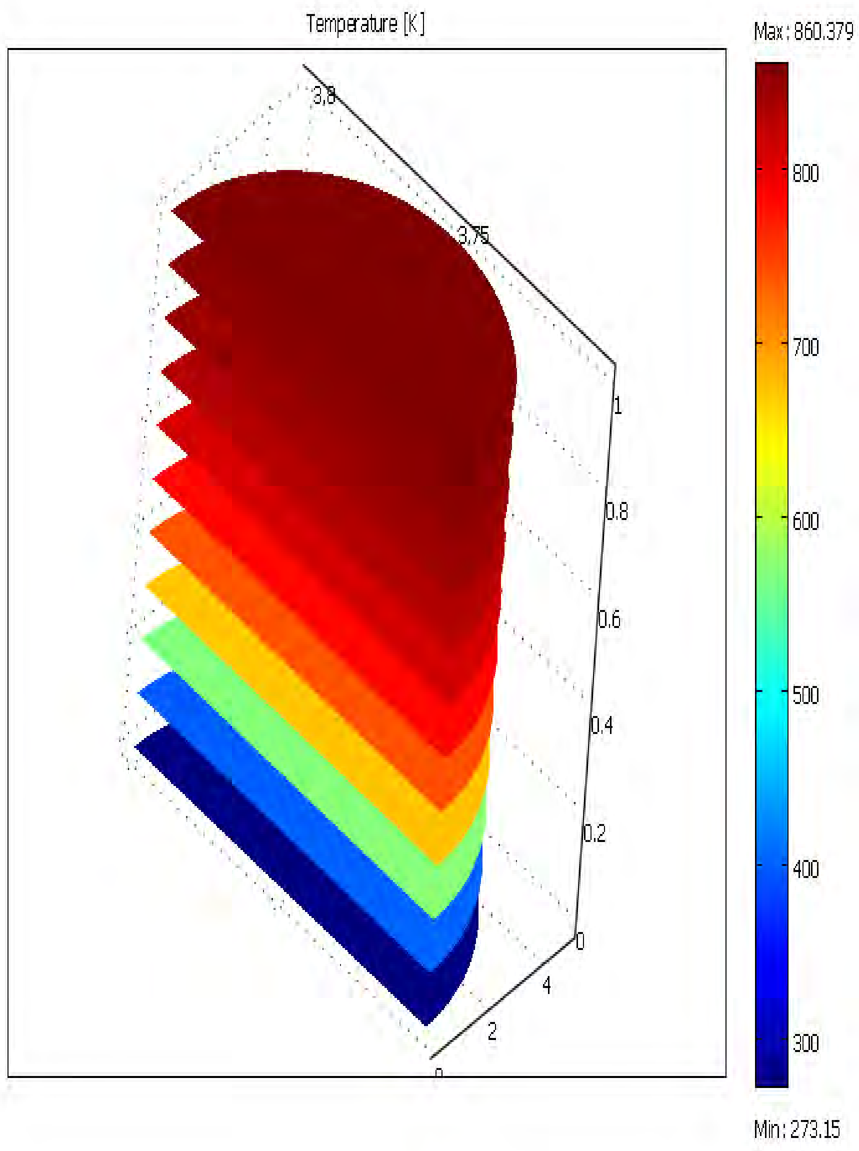
  1mm grounded 0.1-0.1-0.2-1 mm
- ✓ Dimensions for 5mm thermo well 0.5 - 0.25 - 4.5 -5 mm and 0.5mm wall thickness.

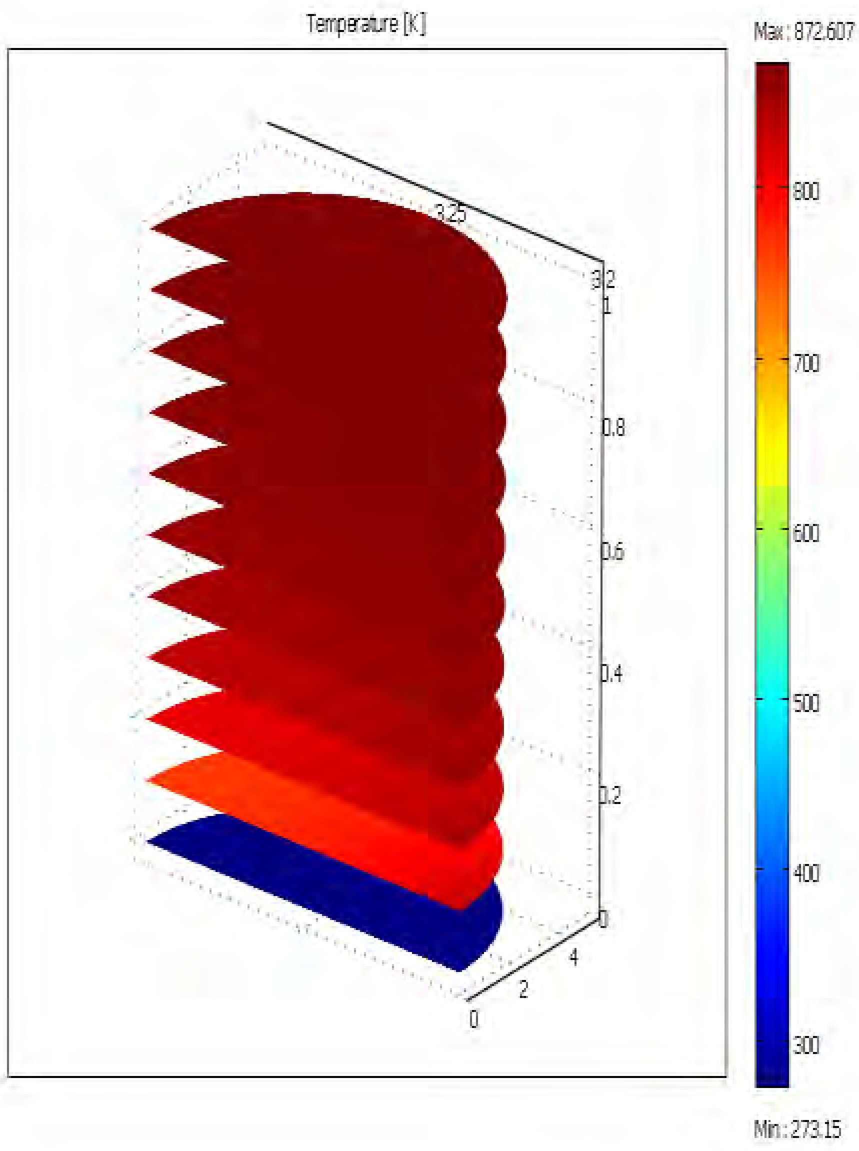
Steady state heat transfer



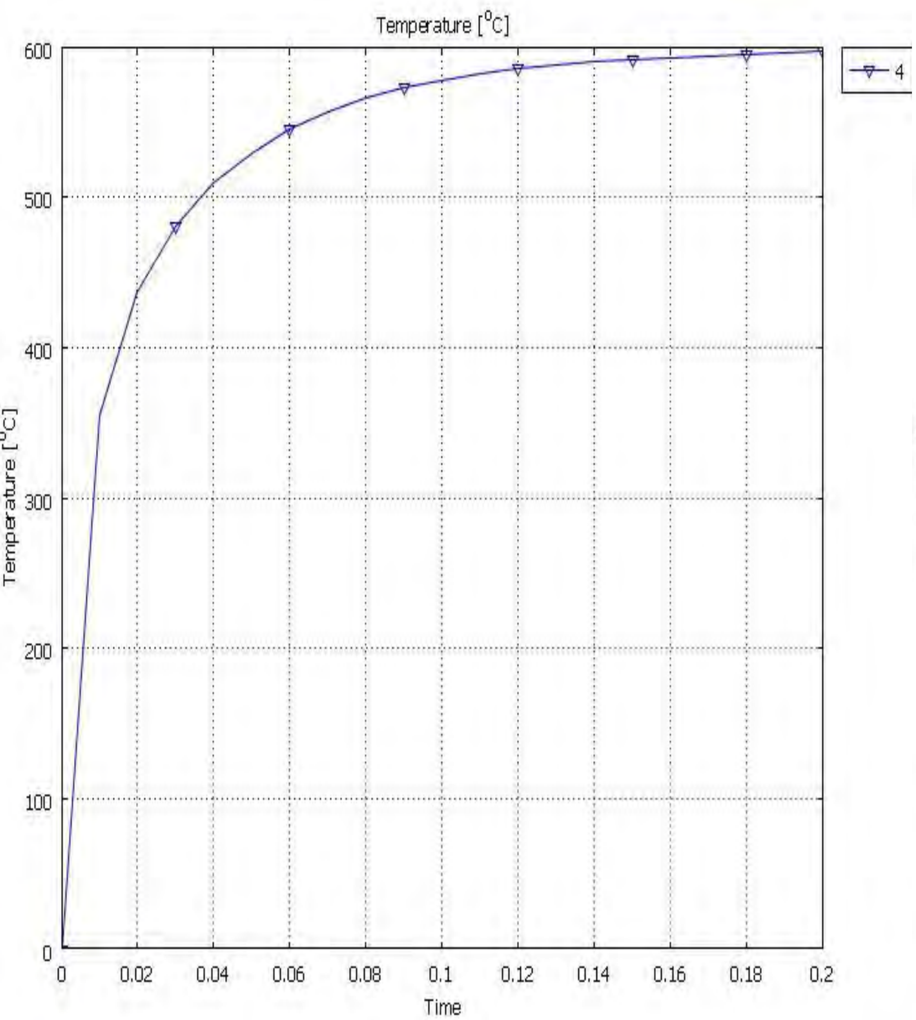


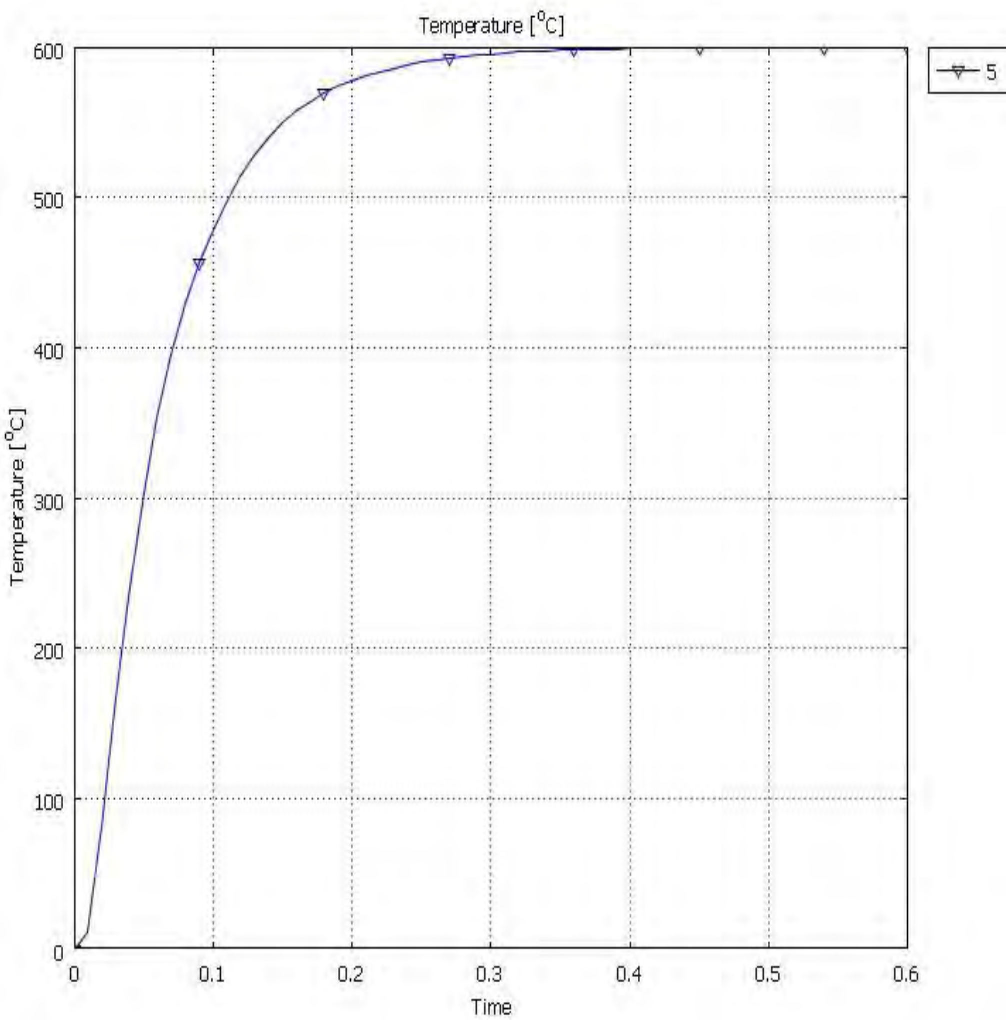
Hot Junction Temperature Distribution



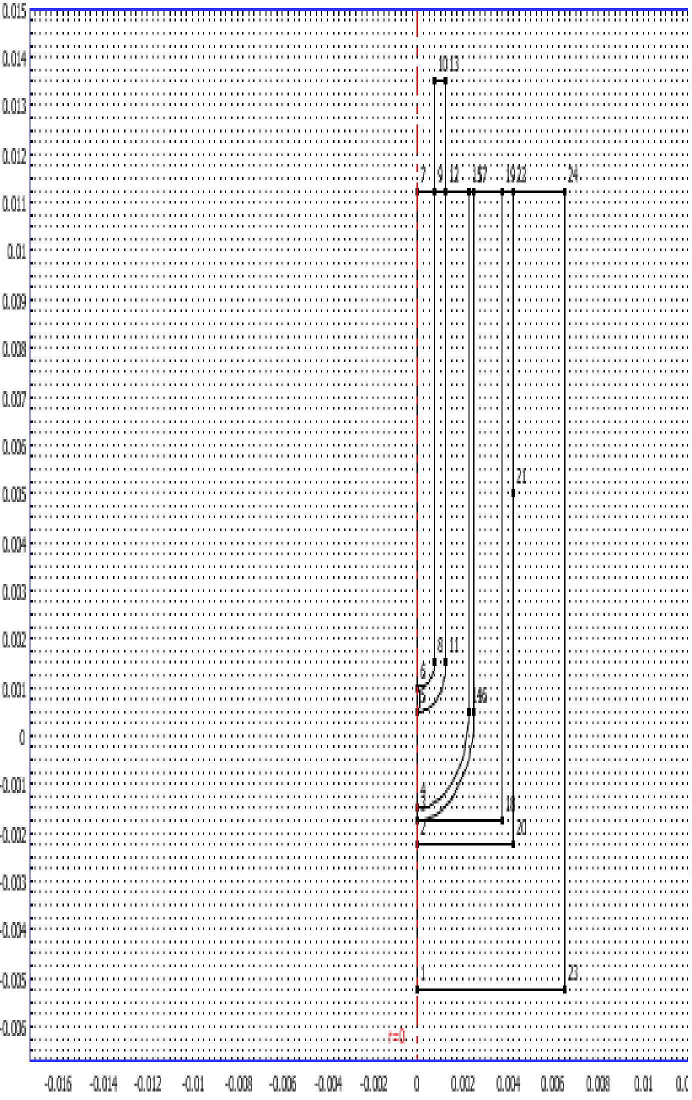


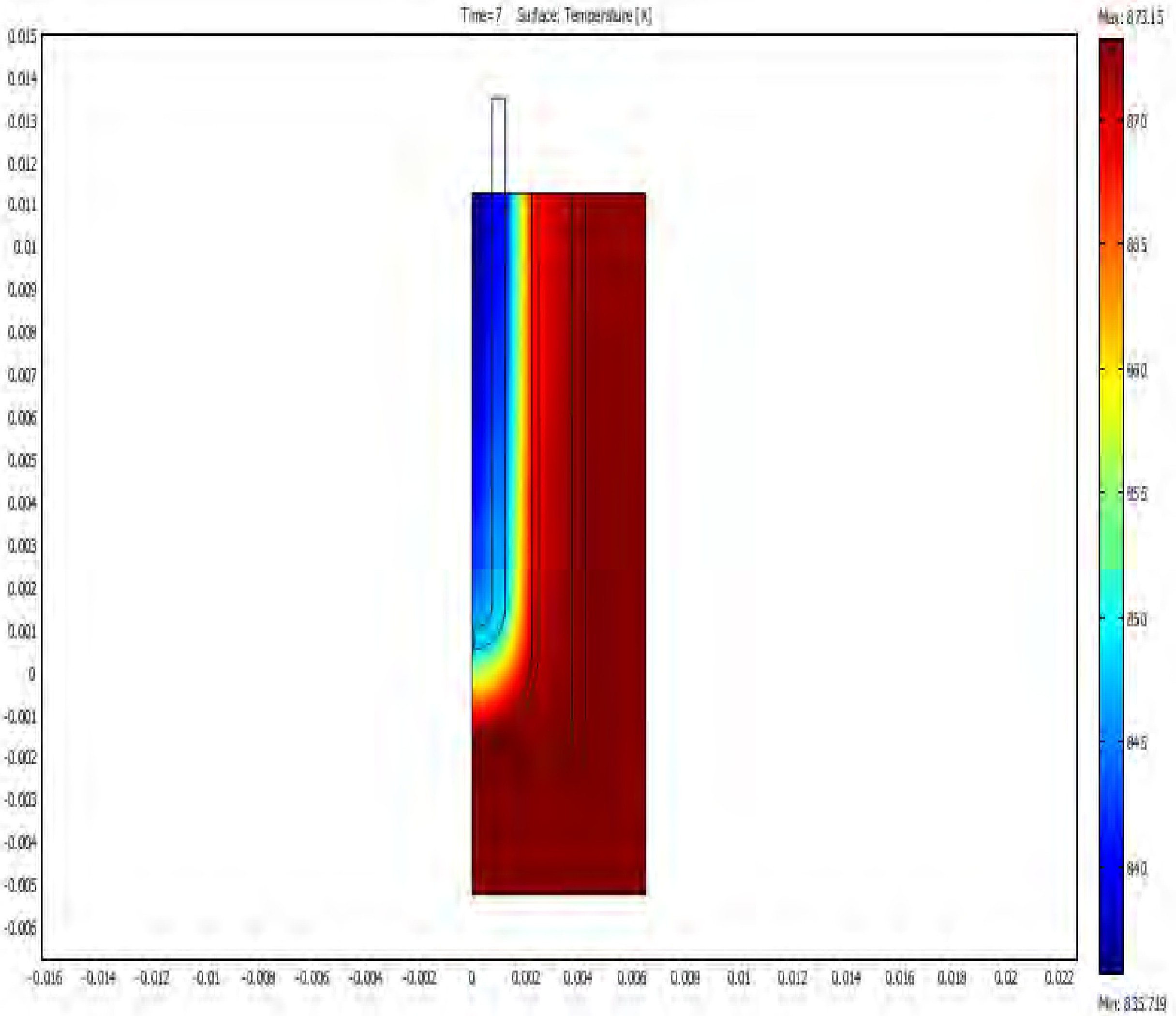
Time Response at hot junction of the grounded and ungrounded 1mm thermocouples



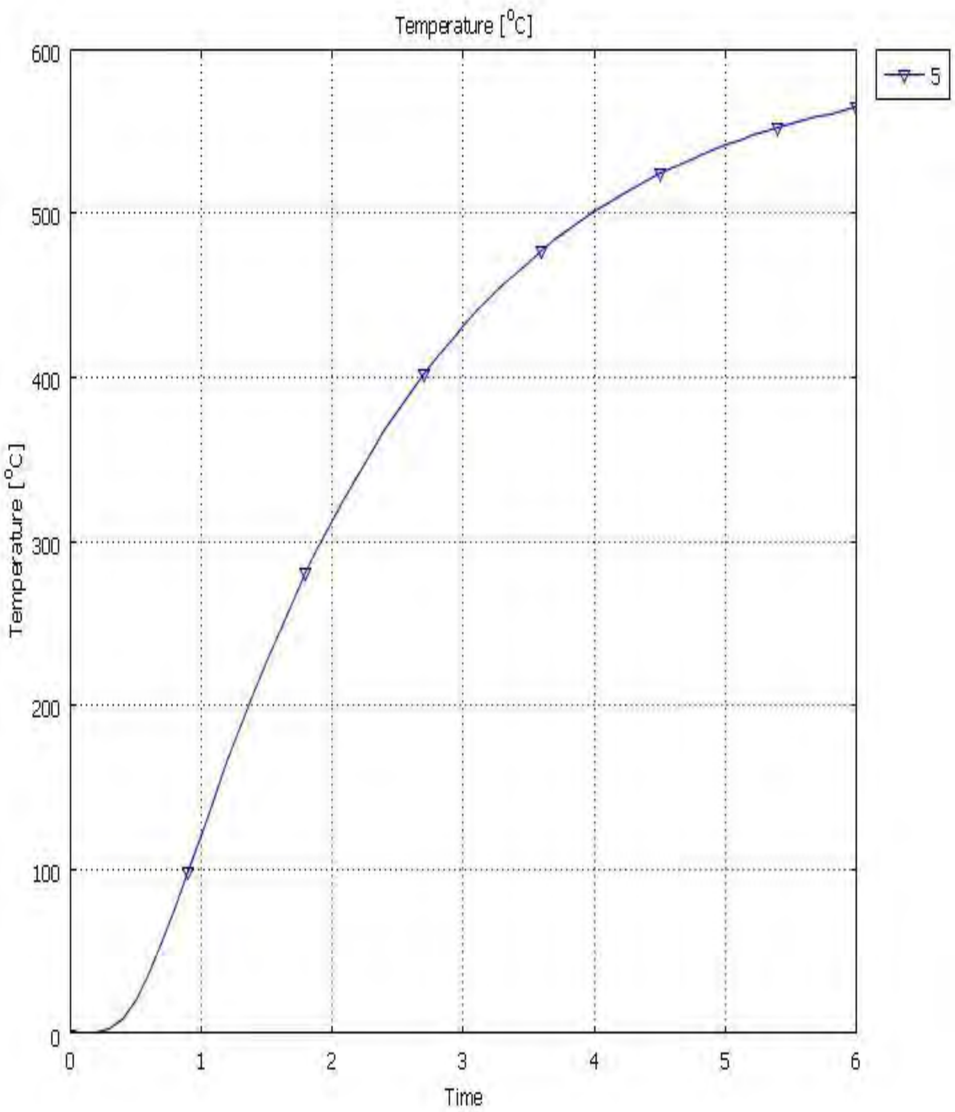


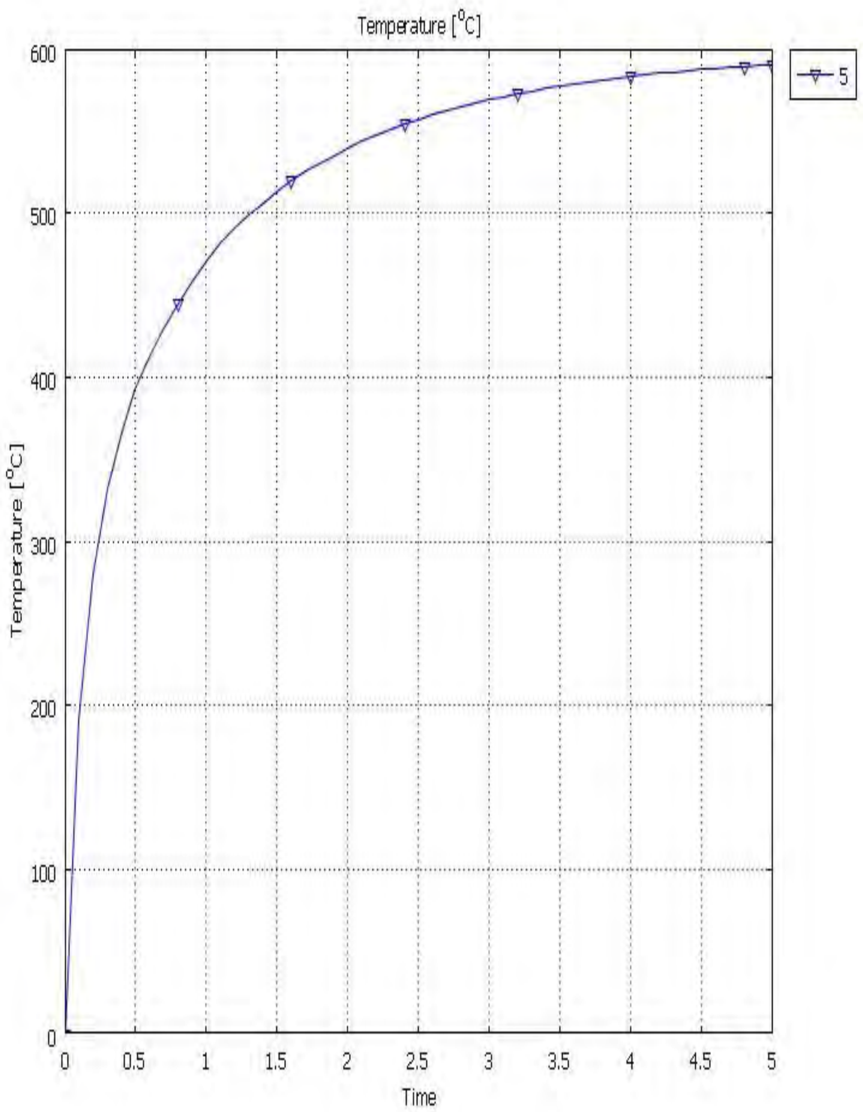
Thermo well





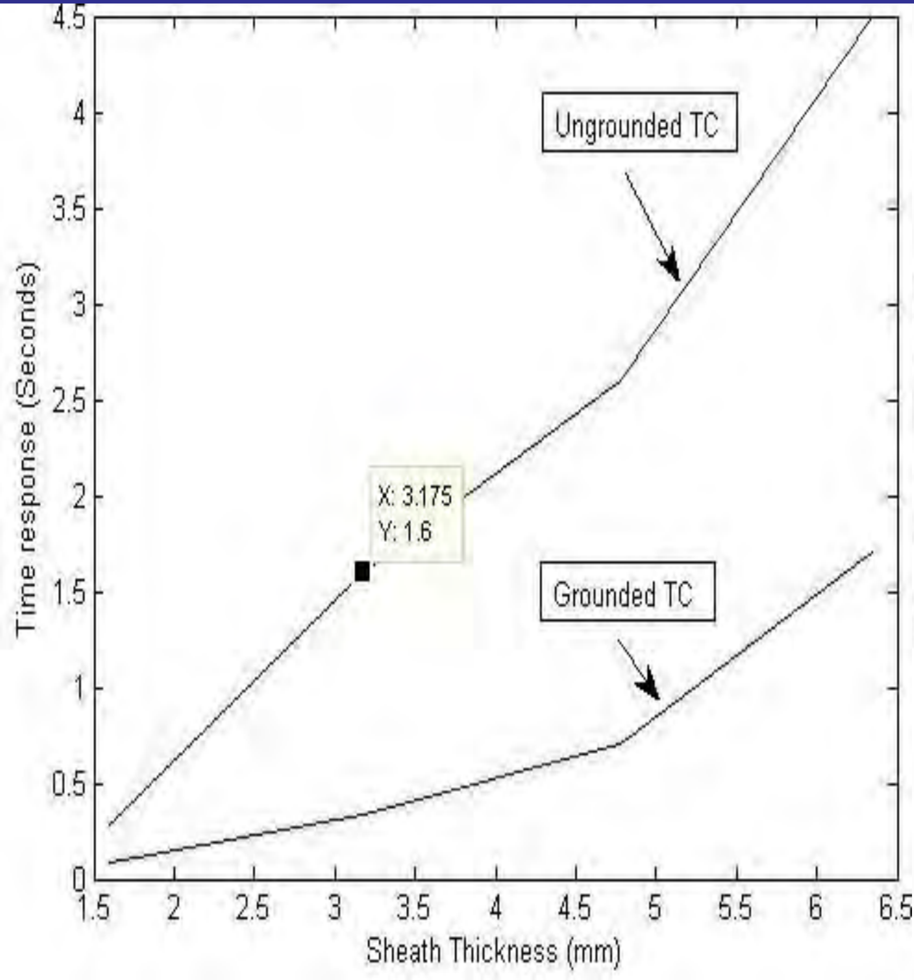
Time Responses at hot junction of 5mm ungrounded and grounded Thermo well

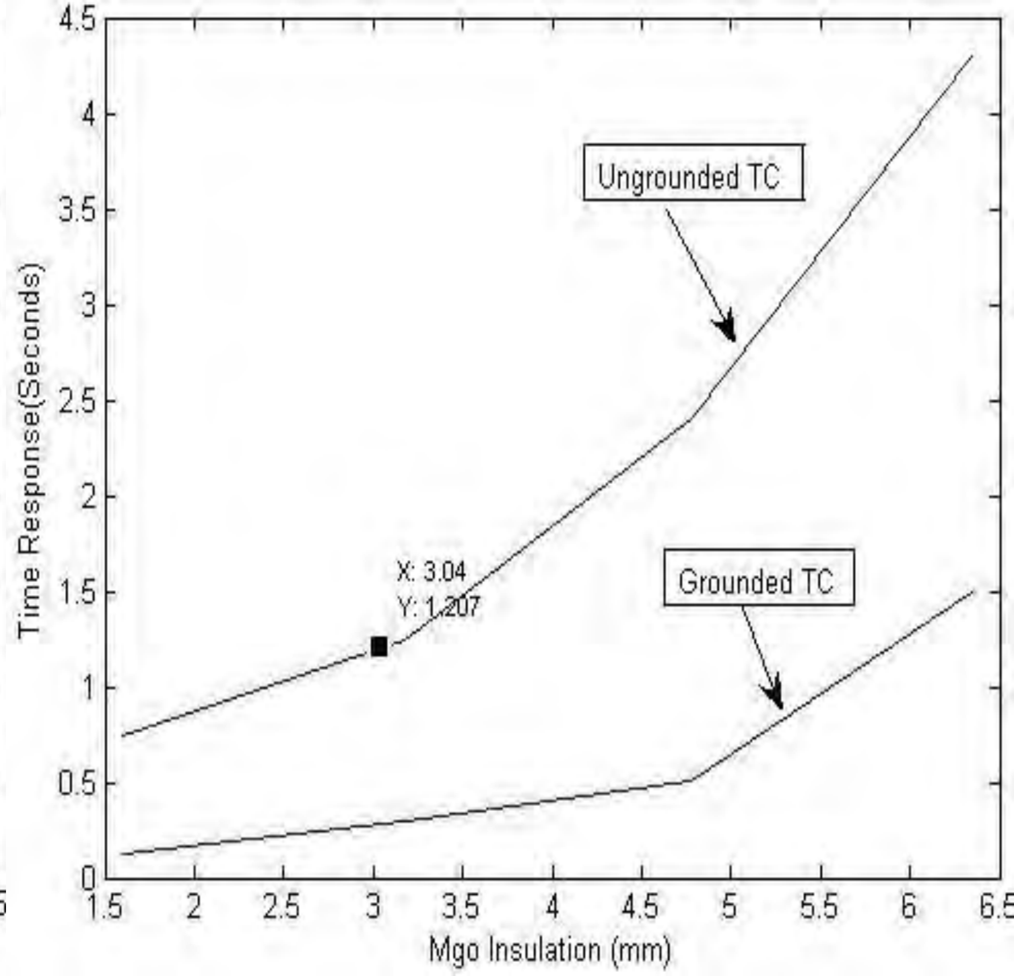




Reference Data for Analysis

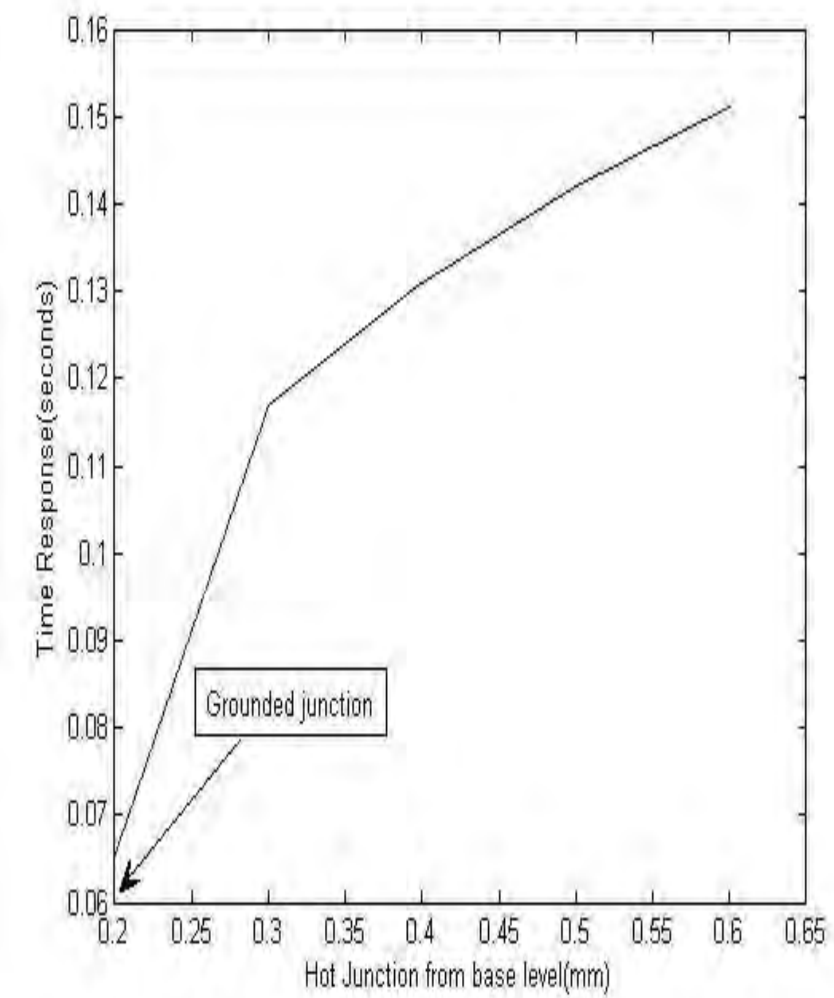
Commercial Thermocouple response time with respect to sheath and insulation





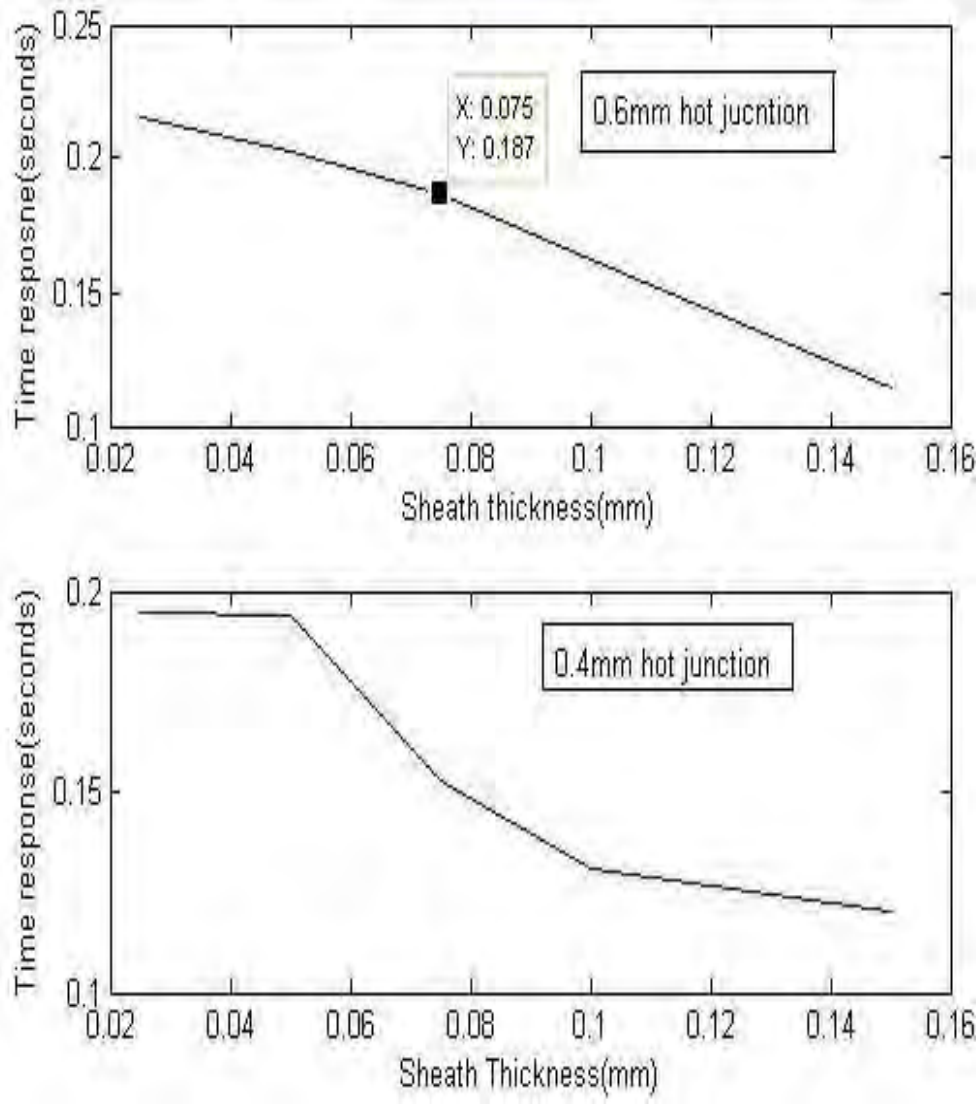
Effect of variation of position of hot junction on response time for 1mm thermocouple

Hot Junction position (in mm)	Response time (seconds)
0.6	0.151
0.5	0.142
0.4	0.131
0.3	0.117
Grounded Junction	
0.2	0.065



Time response variation with thermocouple sheath for 1mm Thermocouple

Sheath thickness(mm)	Hot junction position(mm)	Time response(seconds)
0.15	0.6	0.114
0.1	"	0.162
0.075	"	0.187
0.05	"	0.203
0.025	"	0.215
0.15	0.4	0.12
0.1	"	0.131
0.075	"	0.153
0.05	"	0.194
0.025	"	0.195

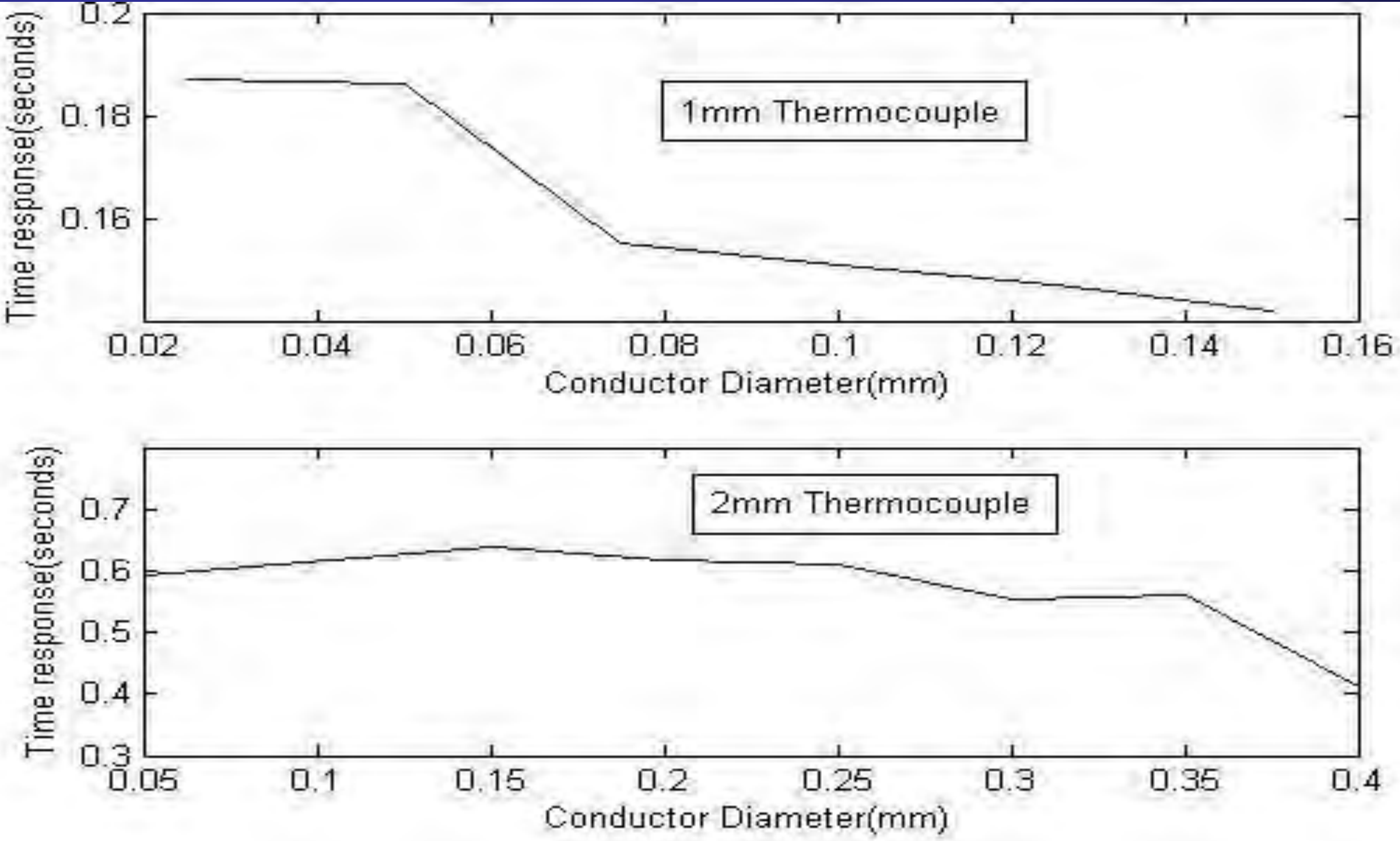


Time responses of 1mm and 2mm thermocouple with variation of bead and wire diameter

Conductor diameter(mm)	Bead diameter(mm)	Time response(Seconds)
0.15	0.15	0.142
0.15	0.1	0.140
0.125	0.125	0.147
0.125	0.5	0.141
0.1	0.1	0.151
0.1	0.2	0.144
0.075	0.075	0.155
0.075	0.15	0.149
0.05	0.05	0.186
0.05	0.1	0.179
0.025	0.025	0.187

Conductor diameter(mm)	Bead diameter(mm)	Time response(Seconds)
0.05	0.05	0.592
0.05	0.1	0.586
0.15	0.15	0.637
0.15	0.3	0.622
0.20	0.2	0.616
0.20	0.4	0.589
0.25	0.25	0.609
0.25	0.5	0.576
0.3	0.3	0.552
0.35	0.35	0.56
0.4	0.4	0.412

Time response of 1mm and 2mm thermocouples variation with wire diameter

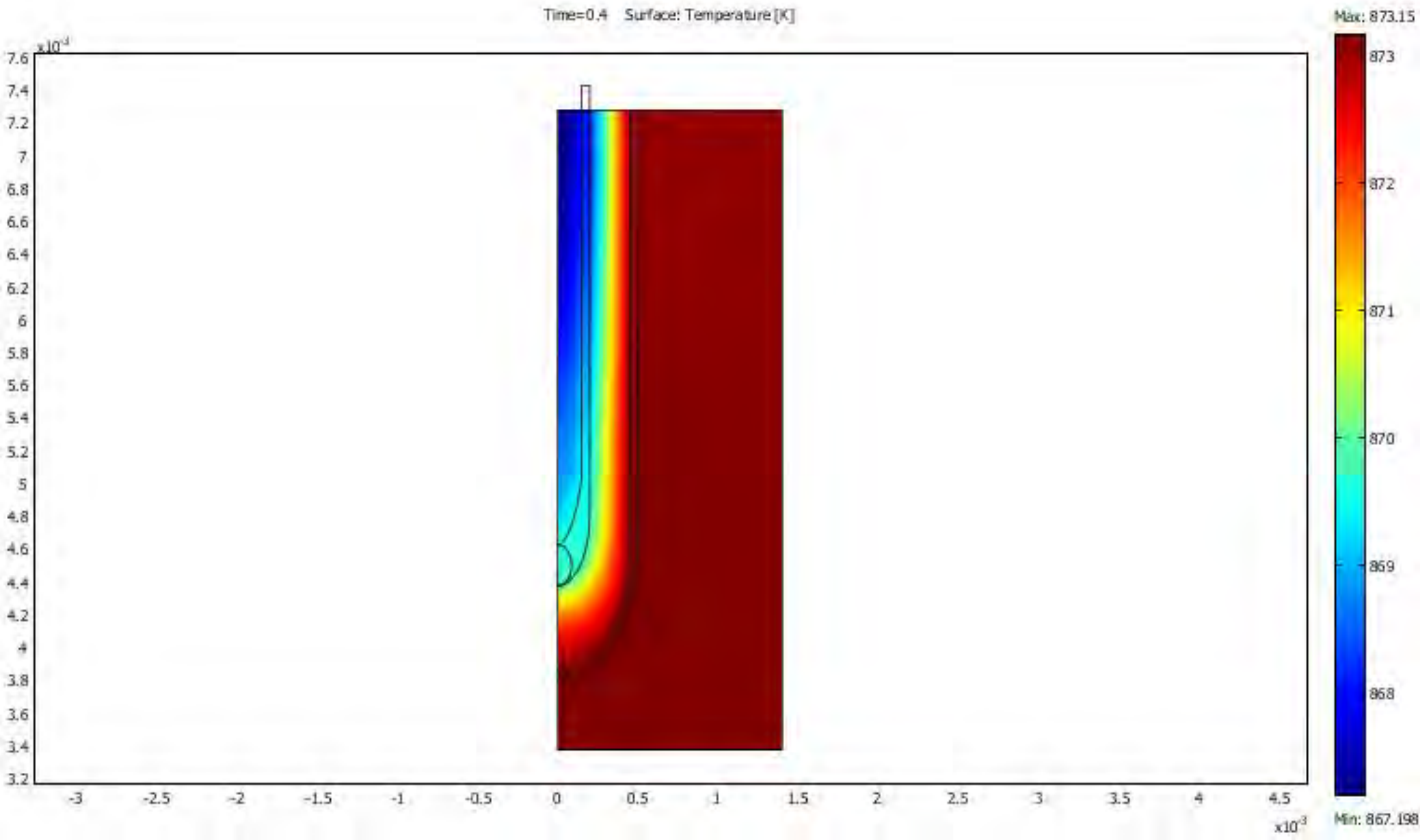


SELECTED CONFIGURATION

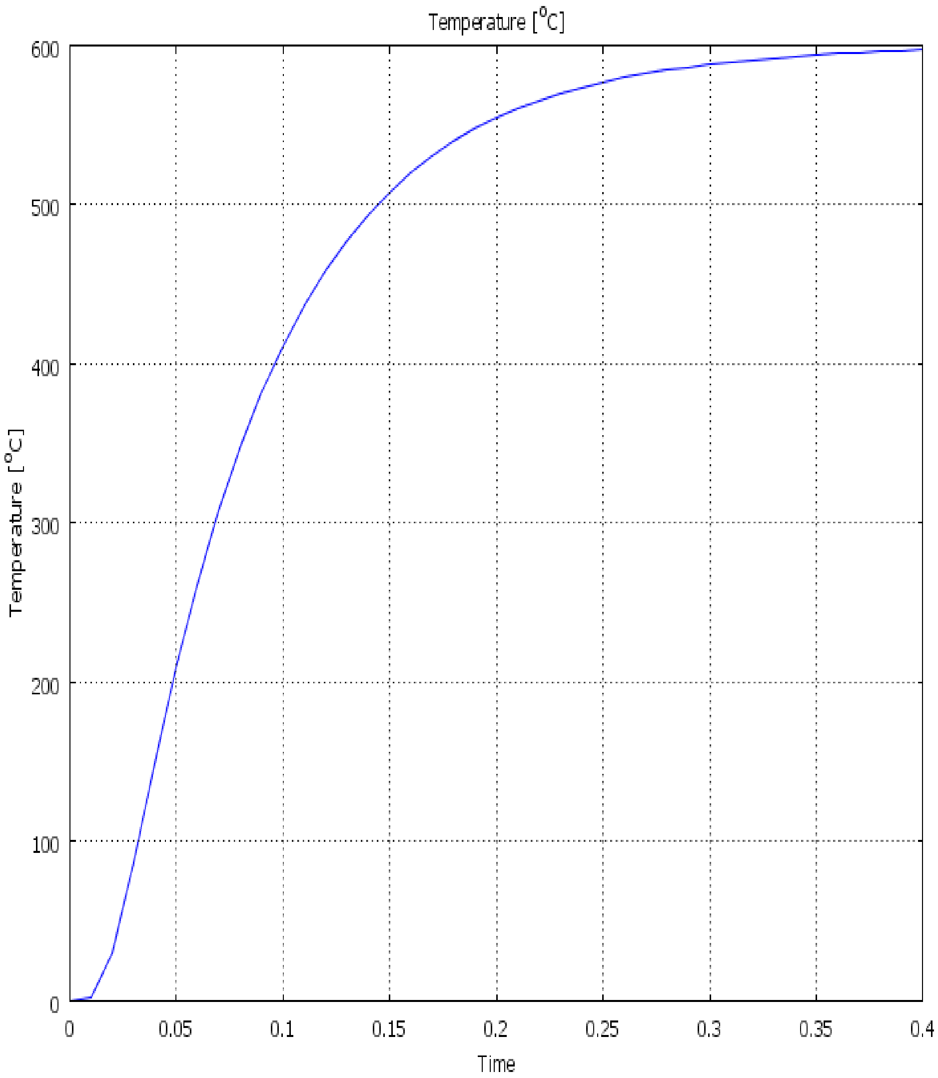
Based on the simulation done for analyzing the effect of various parameters on the response time of the thermocouple, a final configuration which yields a response time meeting the reactor requirement has been selected.

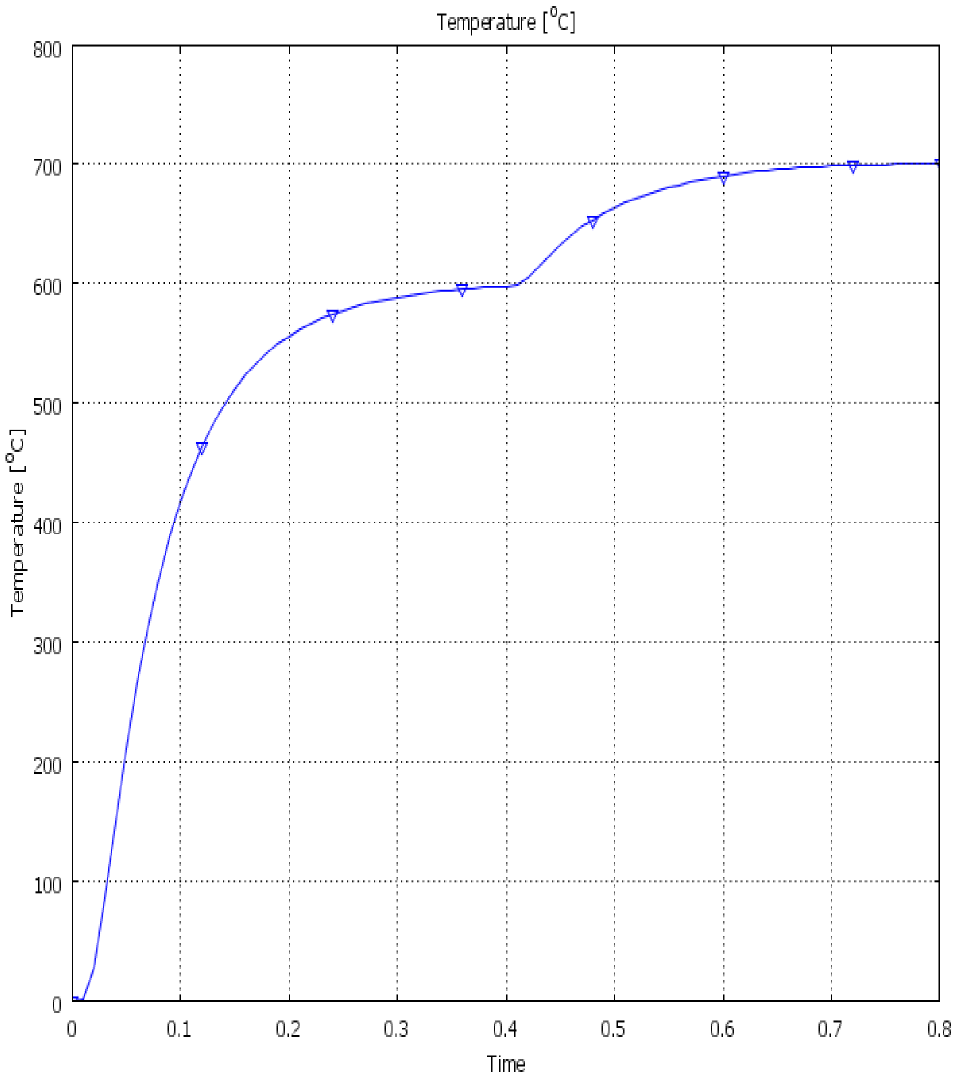
		Response time
For 1mm thermocouple	0.14-0.05-0.6-1 mm	210ms
For 2mm thermocouple	0.25-0.325-0.6-2 mm	270ms
For thermo well	0.5-0.25-4.5-5 mm	5.5seconds

STEADY STATE HEAT TRANSFER FOR SELECTED 1MM CONFIGURATION

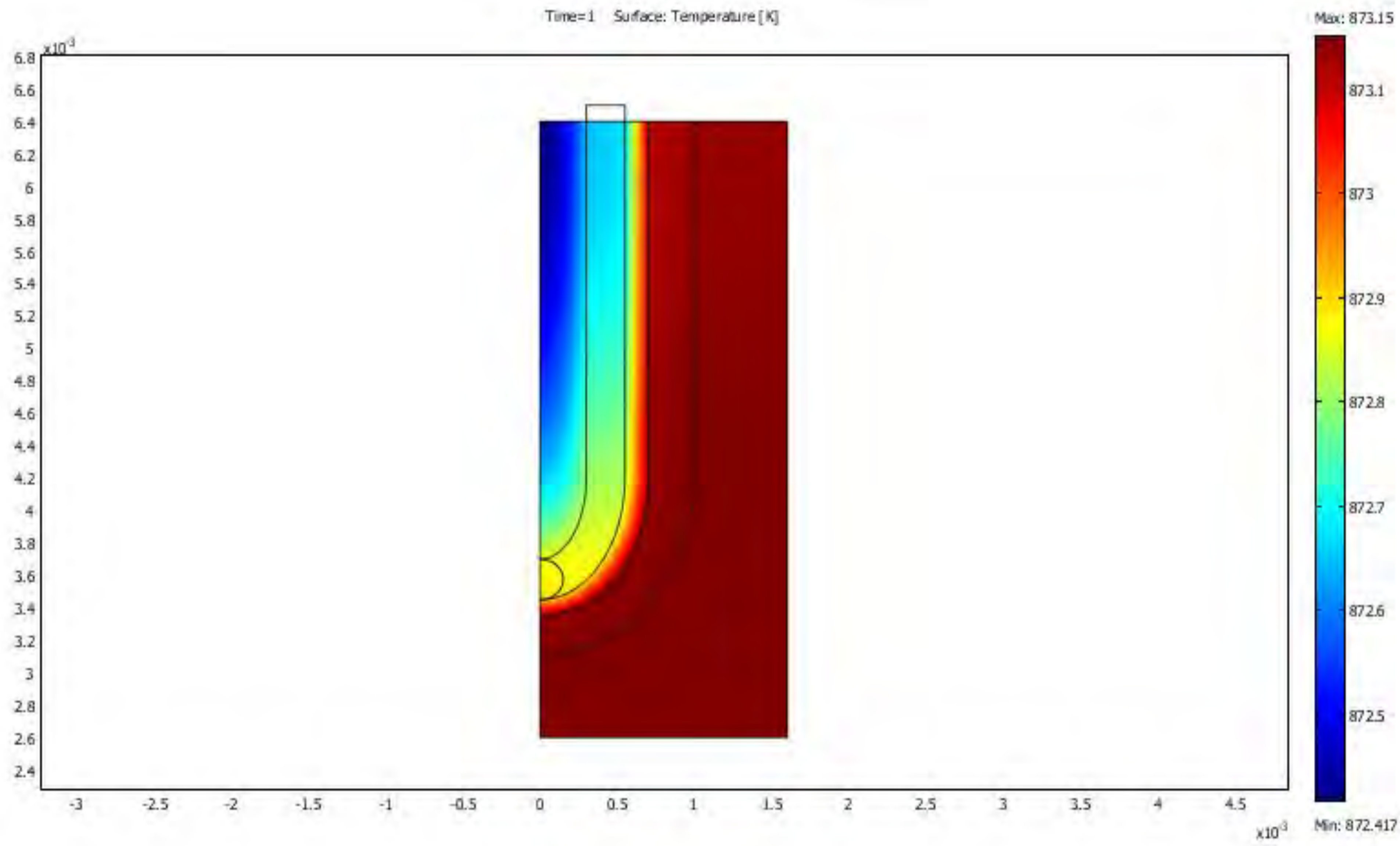


TIME RESPONSE AND STEP RESPONSE OF SELECTED 1MM CONFIGURATION

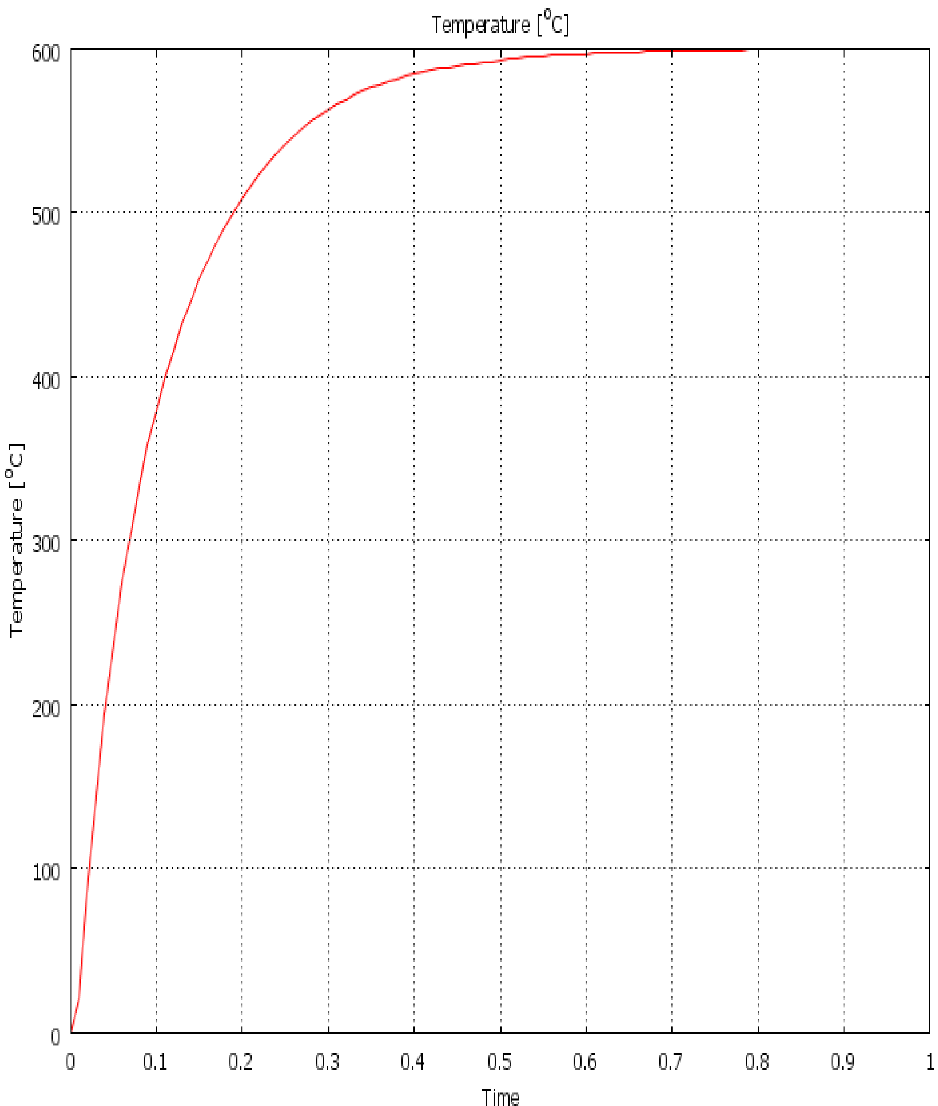


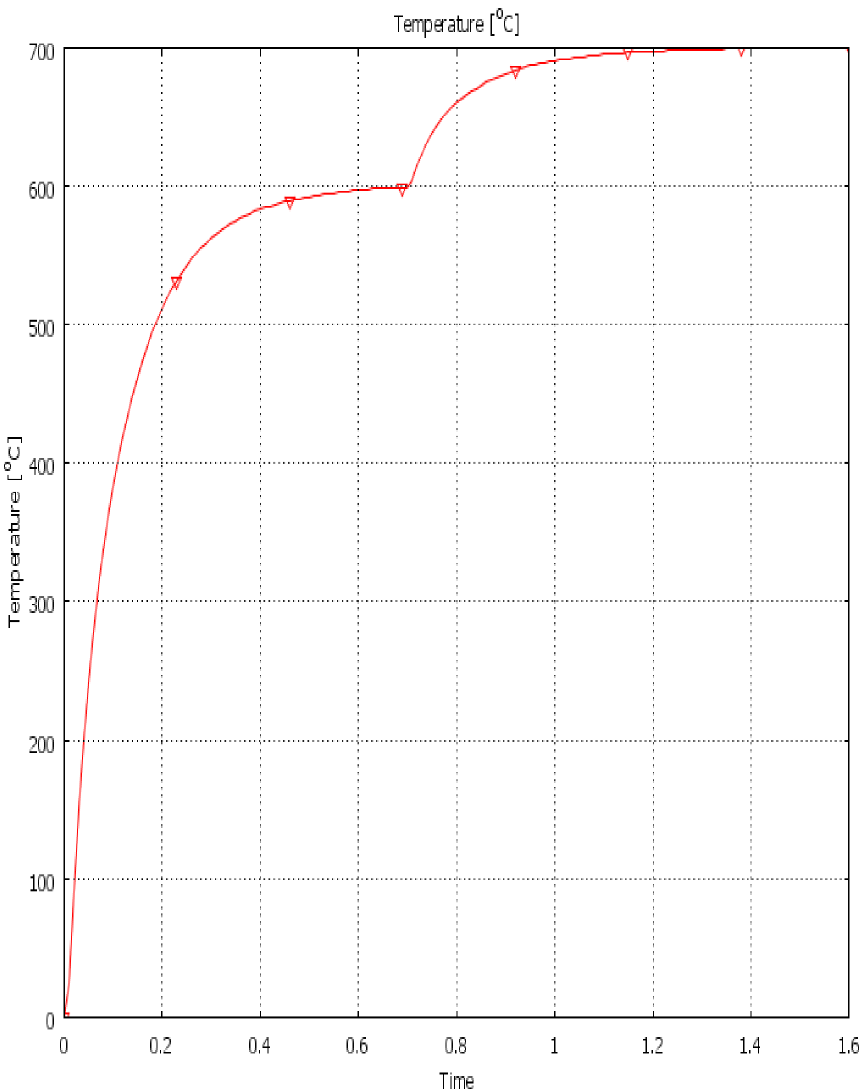


STEADY STATE HEAT TRANSFER FOR SELECTED 2MM CONFIGURATION



TIME RESPONSE AND STEP RESPONSE OF SELECTED 2MM CONFIGURATION





e^{-5}

Approximating the Thermocouple constants

Cold junction temp (Tcold)	Thermocouple constants(4th order)				
	a	b	c	d	e
Zero	-0.03	0.042	-1.1 e-5	3e-8	-2.2e-11
1	0.011	0.042	-1.1e-5	3e-8	-2.2e-11
2	0.064	0.042	-8.4e-6	2.4e-8	-1.8e-11
3	0.089	0.042	-1.1e-5	3e-8	-2.1e-11

$$V = a + b(T_{hot} - T_{cold}) + c(T_{hot} - T_{cold})^2 + d(T_{hot} - T_{cold})^2 + e(T_{hot} - T_{cold})^3 + f(T_{hot} - T_{cold})^4 + \dots$$

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Thank You