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# Simulation and Experimental Validation of Induction Heating of MS Tube for Elevated Temperature NDT Application.

Bhupendra Patidar
Scientific Officer
Bhabha Atomic Research Centre
Mumbai

# Outline

1. Introduction
2. Schematic of induction heating process
3. Mathematical modeling
4. Simulation
5. Result comparison and analysis
6. Conclusion
7. References

# Introduction

- Induction heating(IH) is widely utilize in industries in different applications because of,

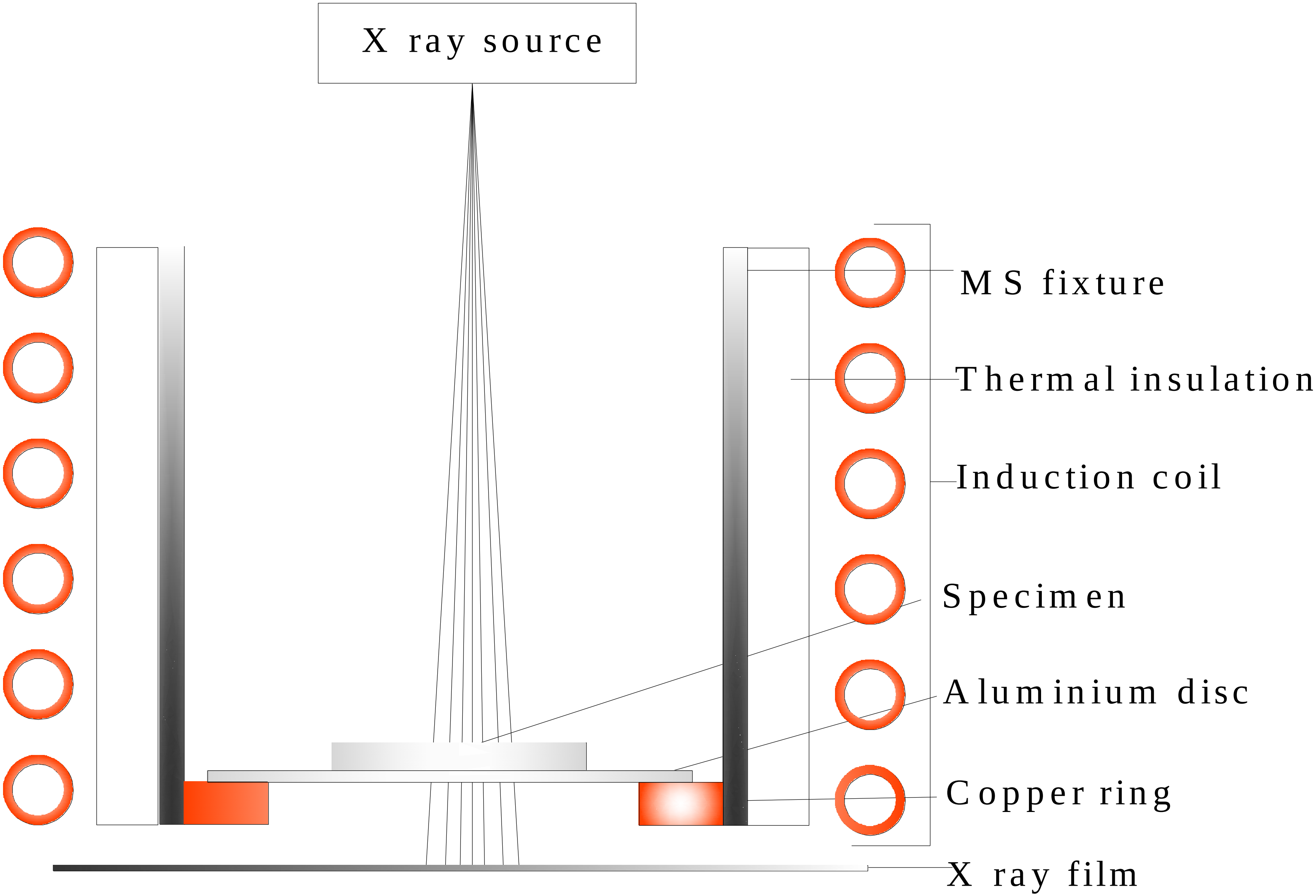
➢ High efficiency

➢ Cleanliness

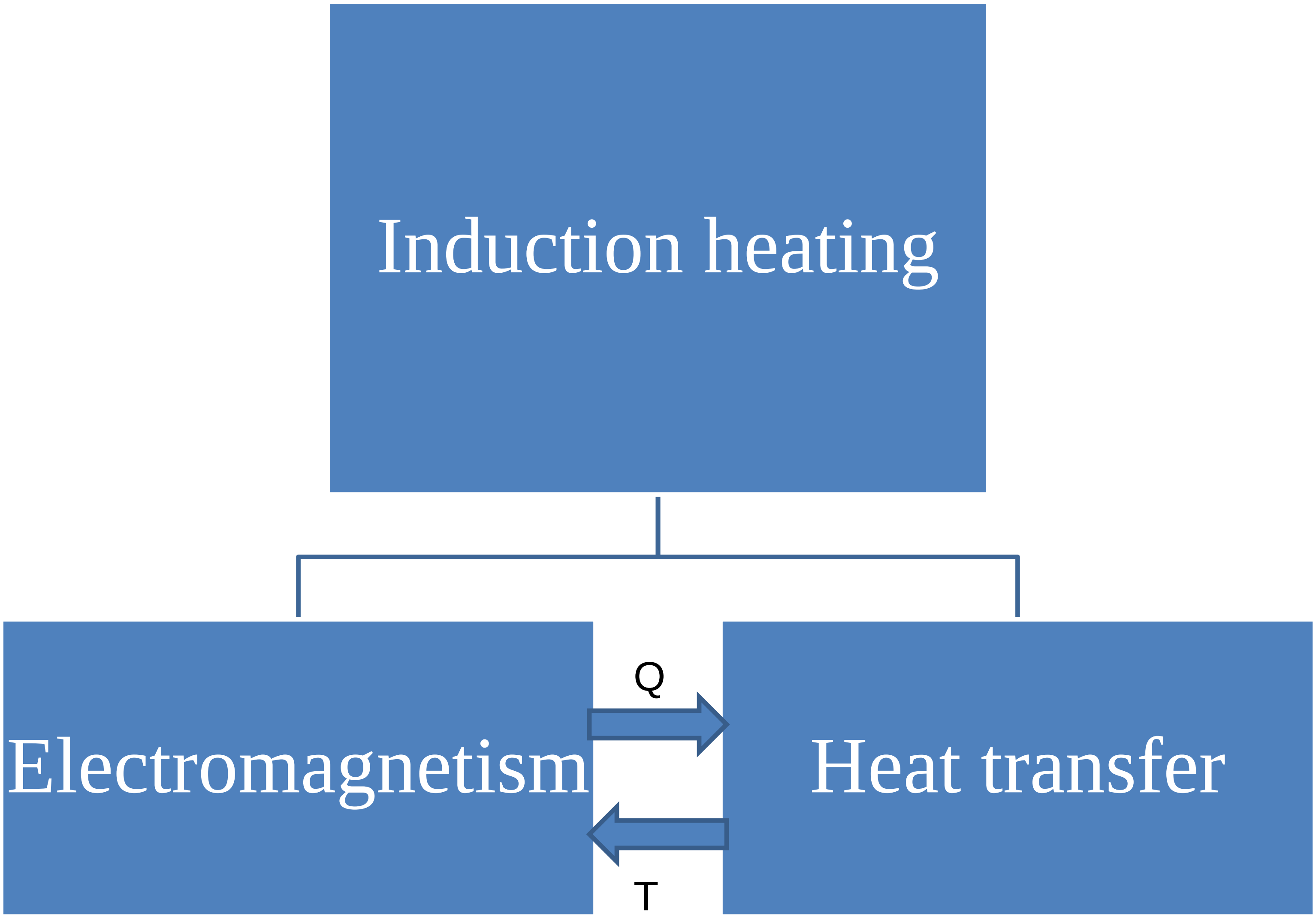
➢ Non contact heating method

- Therefore, IH is choose for this application.

# Schematic diagram of induction heating process



# Mathematical Modeling



# Electromagnetism

- Magnetic vector potential formulation is used.
- It is derived from the maxwell equations.
- It requires less computation compared to magnetic field formulation.

$$\frac{1}{\mu_0 \mu_r(T)} \nabla^2 A + J_s - j\omega\sigma(T) A = 0 \qquad (1)$$

# Electromagnetism

- **Assumptions**
  - The system is rotationally symmetric about Z-Axis.
  - All the materials are isotropic.
  - Displacement current is neglected.
  - Electromagnetic field quantities contents only single frequency component.

# Electromagnetism

$$\frac{1}{\mu_0 \mu_{r(T)}} \nabla^2 A - j\omega\sigma(T)A = 0 \qquad (2)$$

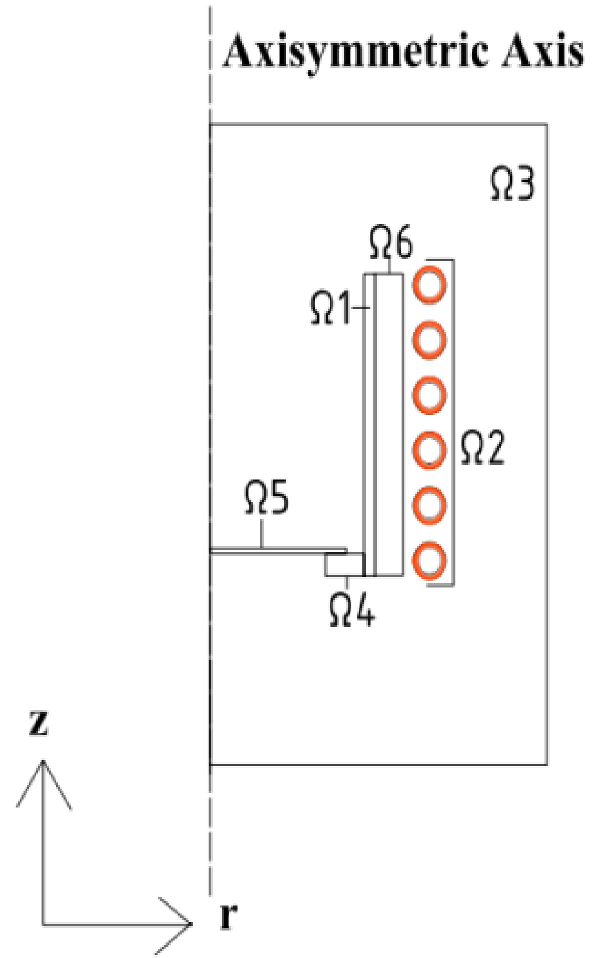
in Ω1, Ω4, Ω5, Ω6

$$\frac{1}{\mu_0 \mu_{r(T)}} \nabla^2 A + J_s - j\omega\sigma(T)A = 0 \qquad (3)$$

in Ω2

$$\frac{1}{\mu_0 \mu_{r(T)}} \nabla^2 A = 0 \qquad (4)$$

in Ω3



# Electromagnetic power

- Electromagnetic power induced in MS tube, copper ring & Al disc.

$$Q = \frac{{J_e}^2}{\sigma(T)} = \sigma(T)(j\omega A)^2 \qquad (5)$$

- Eq (5) is used as source term in heat transfer equation.

# Heat Transfer

- Heat transfer represented using fourier equations,

$$K(T).(\nabla^2 T) + Q = \rho c_p(T)\frac{\partial T}{\partial t} \quad (6)$$

- **Boundary conditions,**

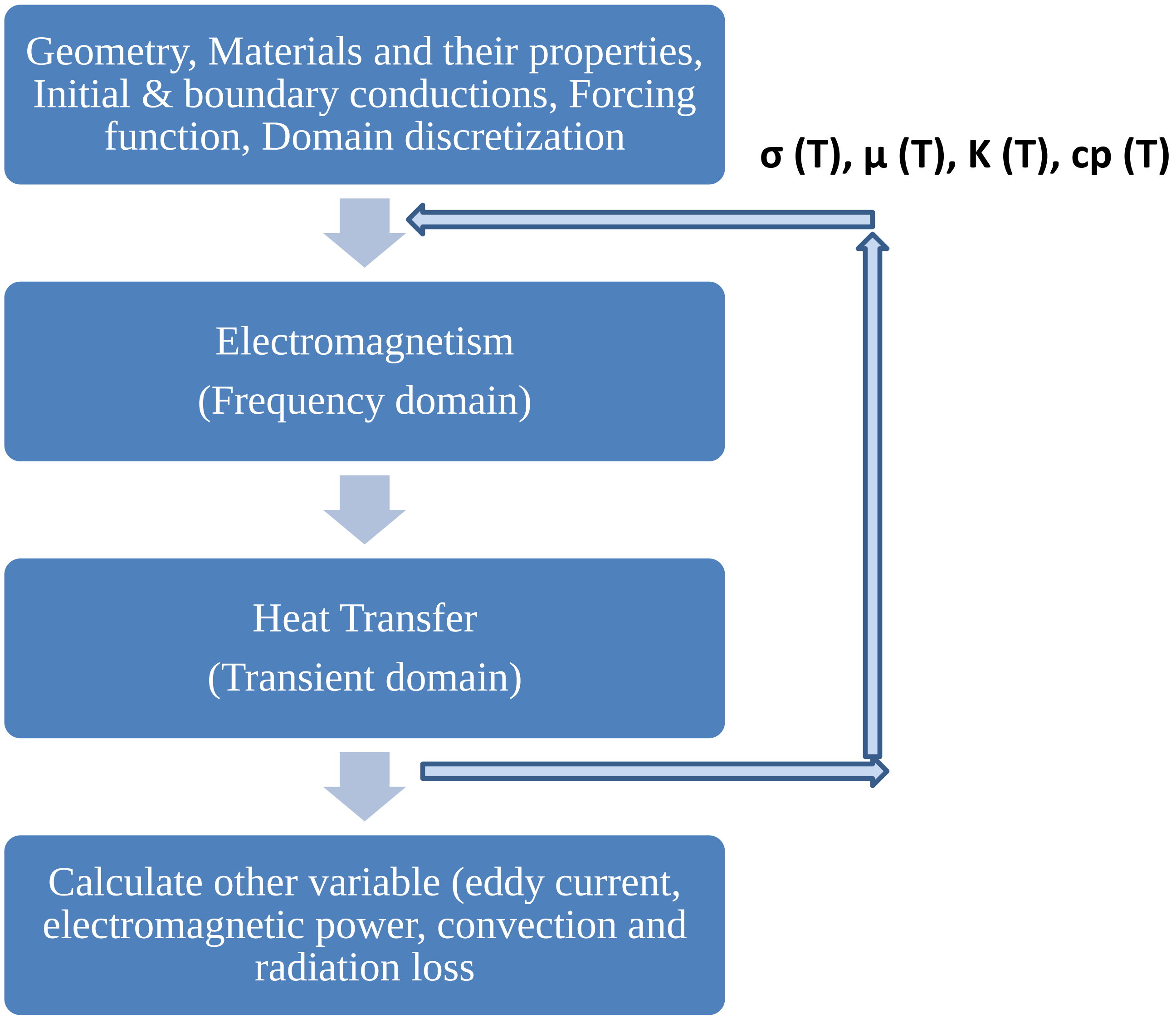
➢Convection

$$Q_{conv} = h.(T - T_{amb})\ \mathrm{W/m^2} \qquad (7)$$

➢Radiation

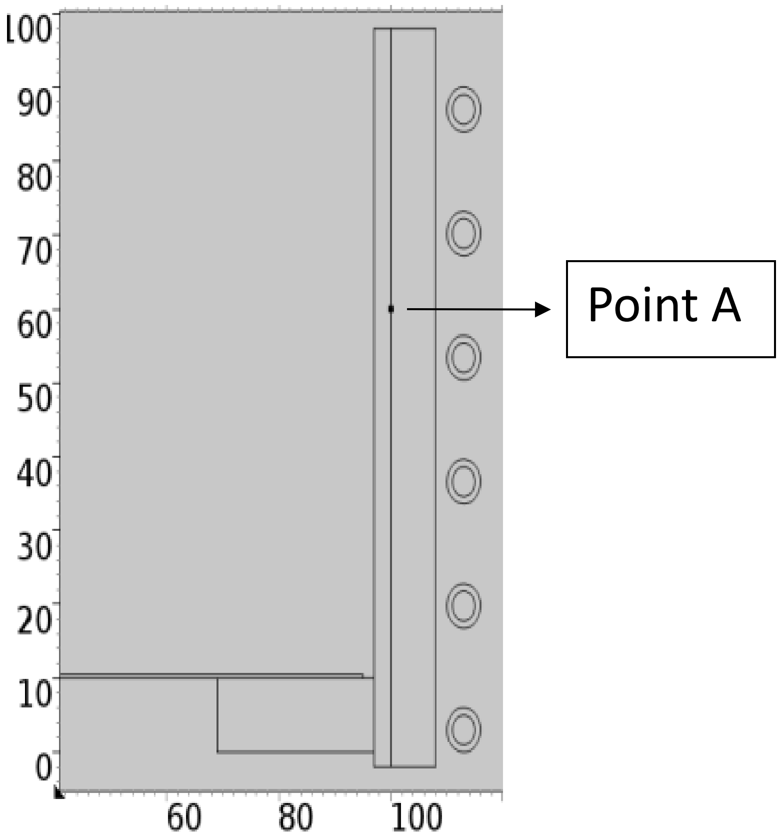
$$Q_{rad} = \epsilon\sigma_b.(T^4 - T_{amb}{}^4)\ \mathrm{W/m^2} \qquad (8)$$

# Simulation Procedure



# Simulation

- Geometry



# Simulation

### Table -I

| **Induction coil** | **Description** |
|---|---|
| Material | Copper |
| Inside diameter | 220mm |
| Outside diameter | 232mm |
| Height | 90mm |
| Coil tube diameter | 6mm |
| Coil tube thickness | 1mm |
| No. of turn | 6 |

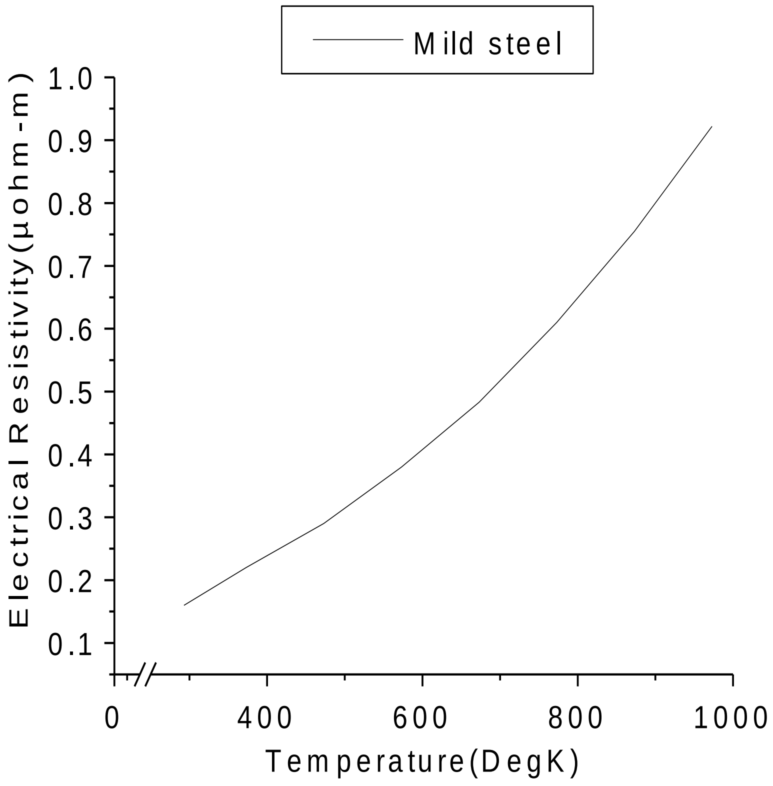
### Table -II

| **Workpiece** | **Description** |
|---|---|
| Material | Mild steel |
| Outside diameter | 200mm |
| Height | 100mm |
| Thickness | 3 mm |

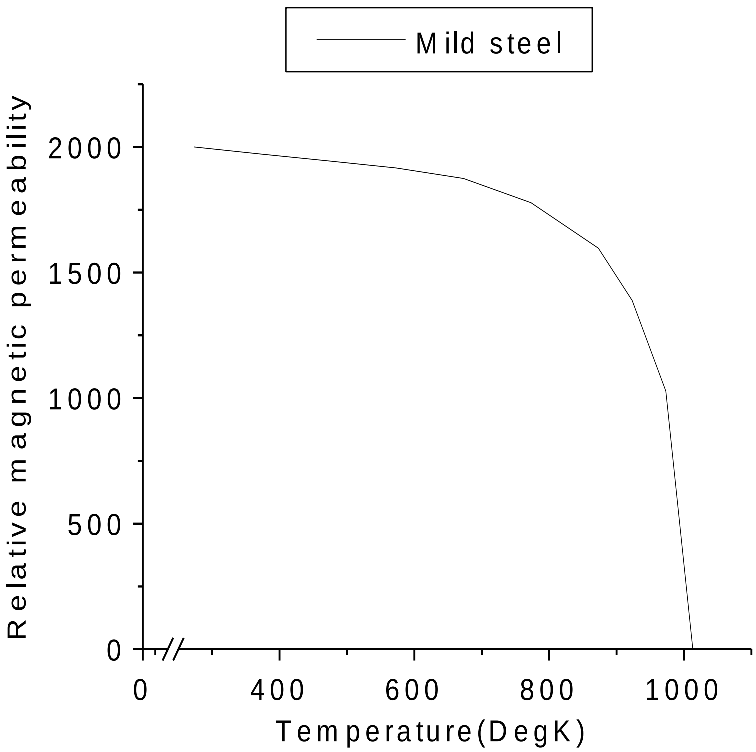
### Table -III

| **Material Properties** | **Copper ring** | **Al disc** |
|---|---|---|
| Dimension | 194mm(OD)<br>138mm(ID)<br>10mm(th) | 190(D)<br>5mm(th) |
| Electrical Conductivity (S/m) | 5.8X10$^7$ | 3.703X10$^7$ |
| Relative electric permittivity | 1 | 1 |
| Relative magnetic permeability | 1 | 1 |
| Density(kg/m3) | 8760 | 2700 |
| Thermal conductivity (W/(m.K)) | 395 | 211 |
| Specific heat(J/(Kg.K)) | 378.34 | 933.33 |

# Simulation

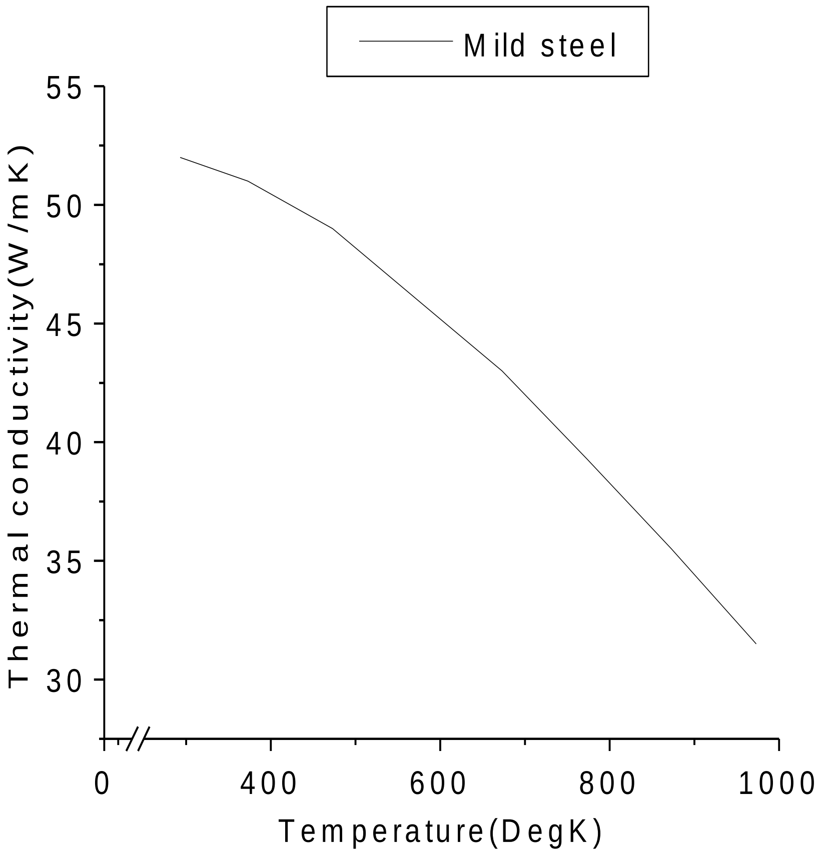


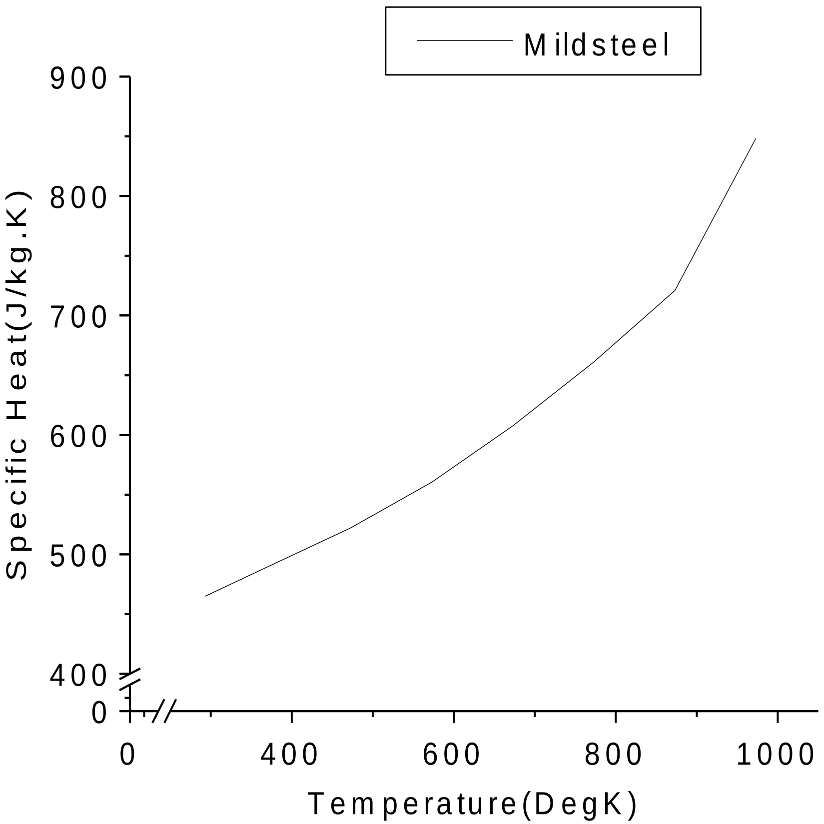
Mild steel
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Electrical Resistivity(μohm-m)
0
400
600
800
1000
Temperature(DegK)

Mild steel
2000
1500
1000
500
0
Relative magnetic permeability
0
400
600
800
1000
Temperature(DegK)

# Simulation


Mild steel
55
50
45
40
35
30
Thermal conductivity(W/mK)
0
400
600
800
1000
Temperature(DegK)


Mildsteel
900
800
700
600
500
400
0
Specific Heat(J/kg.K)
0
400
600
800
1000
Temperature(DegK)

# Simulation

**Electromagnetism**

| Boundary condition | Description |
|---|---|
| Outer boundary | A=0 |
| Asymmetry axis | $\frac{\partial A}{\partial n} = 0$ |

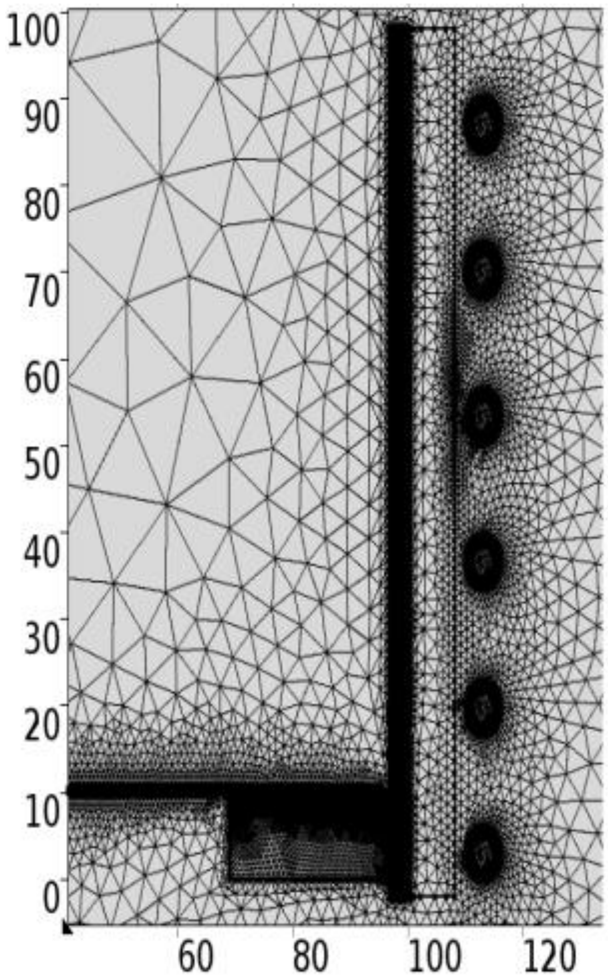
| Forcing function | Description |
|---|---|
| Induction coil current<br>0 to 270 sec<br>270 to 1110 Sec<br>(Frequency- 8.2 kHz) | <br>49.93 A<br>94.31 A |

**Heat Transfer**

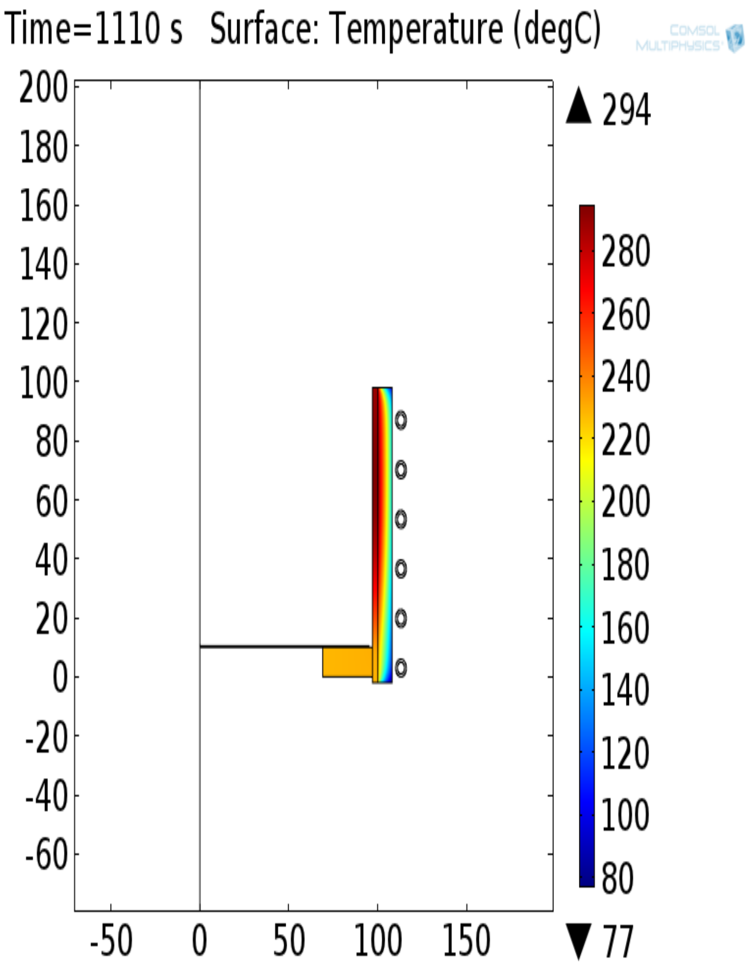
| Boundary condition | Description |
|---|---|
| Initial temperature | 312 DegK |
| Convection coefficient(h) | 10 (W/m$^2$K) |
| Emissivity( MS surface) | 0.32 |
| Emissivity(copper and Al) | 0.04 |

# Simulation

- Meshing



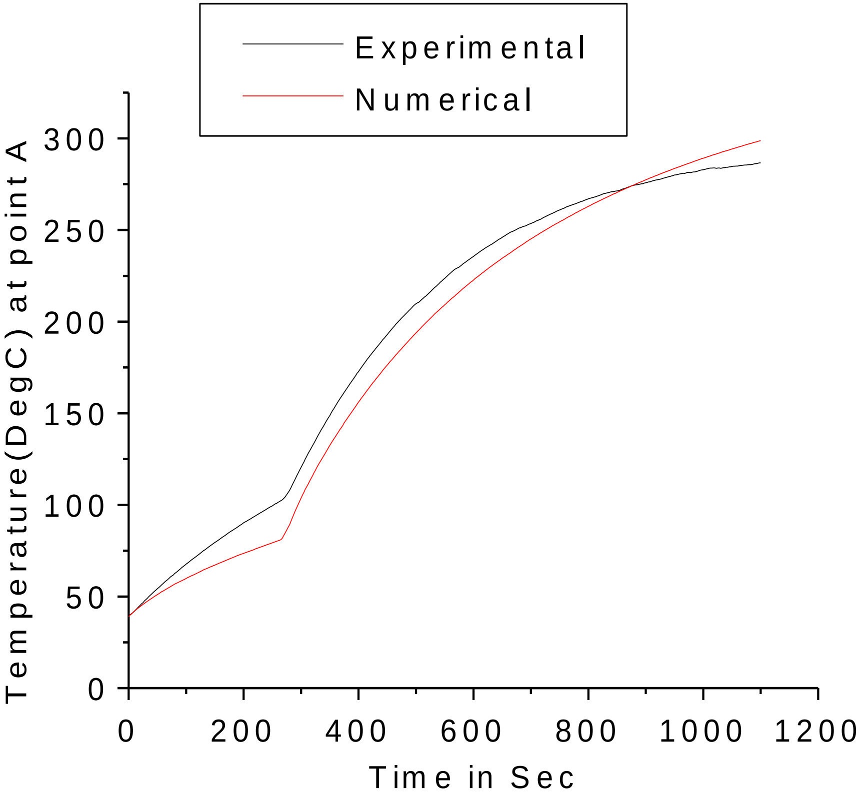

Temperature Profile



# Experimental set up

**Power source capacity:-15 kW,9kHz**

# Experimental and numerical validation



# Error minimization in Numerical method

- Discretization elements size should be less than penetration depth.
- External domain size shall be more than 10 times of induction coil.
- Current is used as forcing function to accurately calculate the mmf generated by the induction coil.

# Conclusion

- There are good agreement between numerical and experimental results.
- Use of temperature dependent material properties makes numerical result close to experiment results.
- This study can be applied for design and optimization of induction coil for induction heating process.

# Reference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# Thank you