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Electromagnetic and Thermal Modeling of Vacuum Distillation Furnace

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OVERVIEW

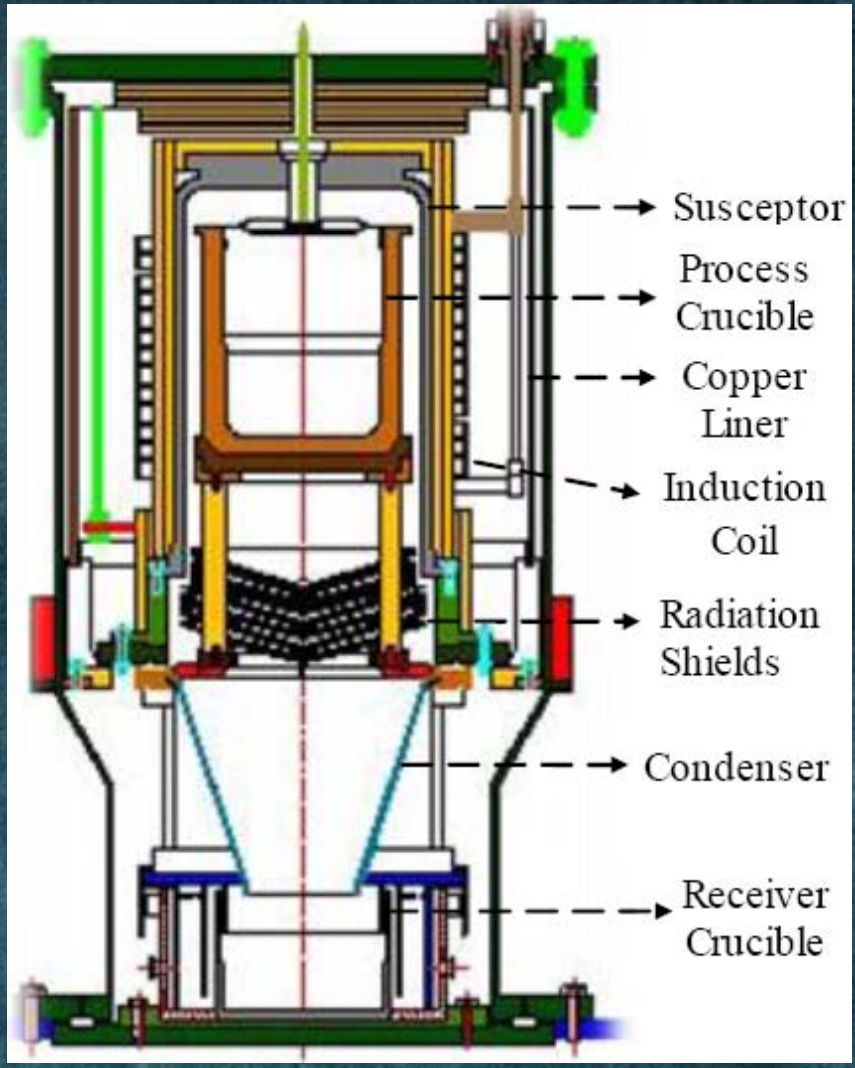
- Introduction
- Numerical model
  - Main features of the model
  - Geometry & Meshing
  - Governing equations
  - Boundary Conditions
- Numerical results
- Conclusions

❑ INDUCTION FURNACE

It is a high temperature vacuum distillation furnace used for recovery of heavy metals

Functions :

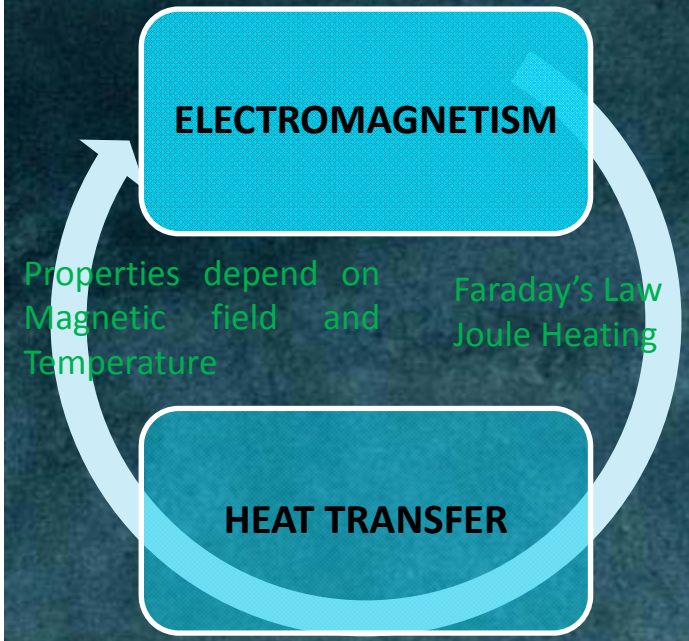
- melt and consolidate of heavy metals
- distill the volatile metals and salts
- operate in inert containment box
- heat reasonably fast while being capable of holding temperature

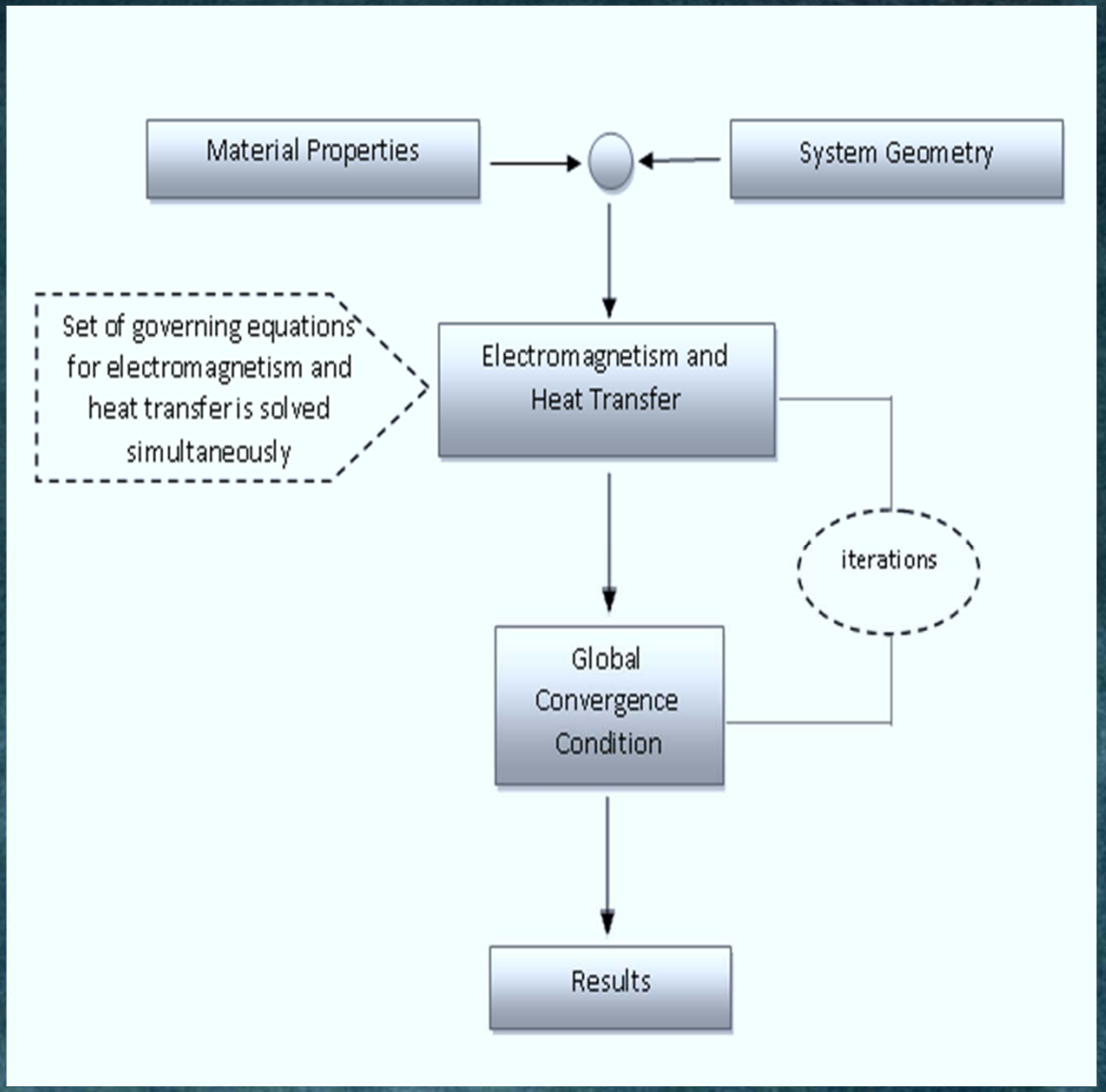


Induction heating

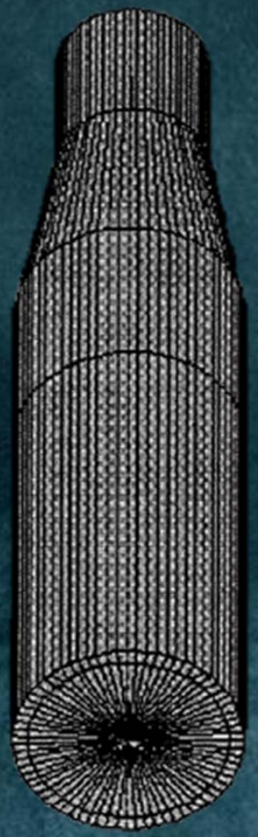
- Tightly coupled phenomena
- Non linear

$\mu(T, \omega)$, $\sigma(T)$, $C(T)$, $k(T)$

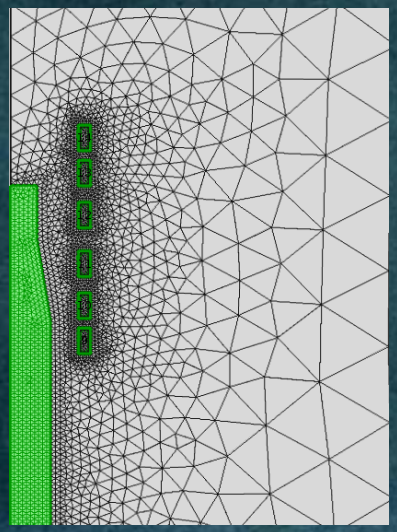


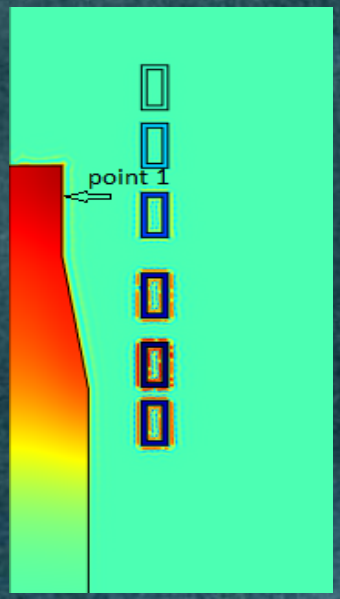


Work piece

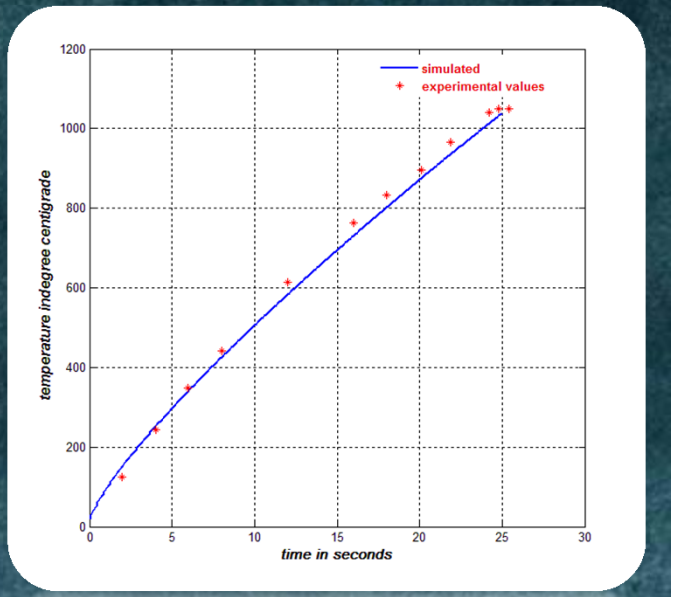


COMSOL model of induction heating setup with meshing .





Comparison of experimental and simulated temperatures at thermocouple location..



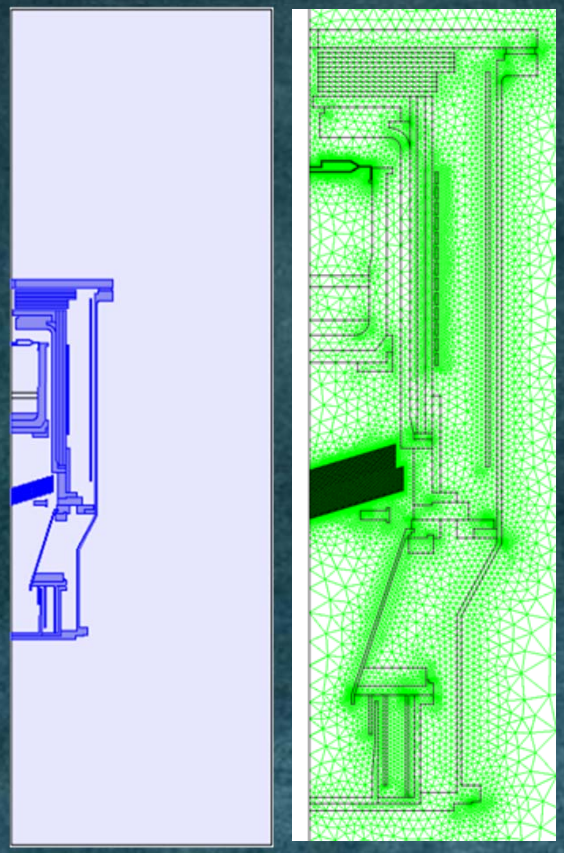
Voltage	77V
Power	13-15kW
Frequency	10kHz

Numerical modeling of induction heating of long work pieces, C.Chaboudez, S Chain et al

❑ Geometry and MESHING

Magnetic field in invariant in ϕ direction

- Physics –controlled and user defined meshes
- Triangular /boundary layer elements
- Extremely fine
- 34580 elemets



2D-axisymmetric COMSOL Multiphysics model of VDF.

S. No	Parameter	Value
1	Frequency	2.5 kHz
2	Coil Voltage	100-300 V
3	Time of heating	8 hours
4	Time step for computation	60-100 s
5	Number of radiation shields	10 & 20

Important parameters used in simulation

GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Electromagnetic field - Maxwell's equations

$$(j\omega\sigma - \omega^2\epsilon_0\epsilon_r)A + \nabla \times (\mu_0^{-1}\mu_r^{-1}B) = J_e$$

$$B = \nabla \times A$$

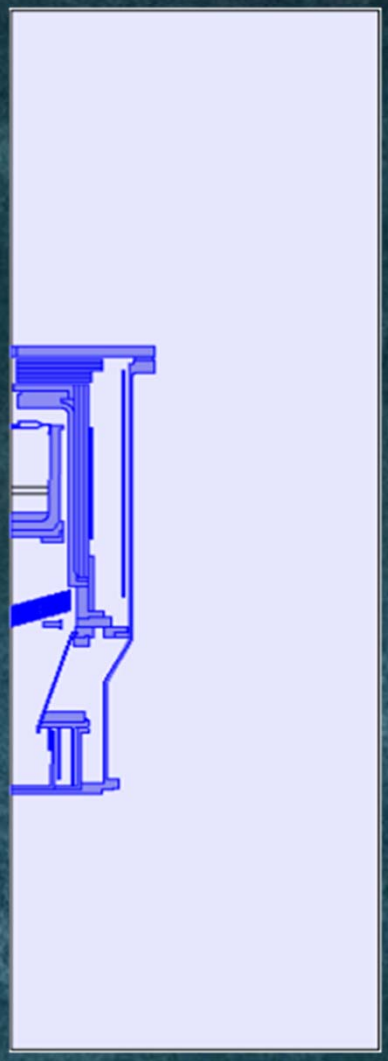
- These equations are solved in entire computational domain (including copper charge, coil, crucible, susceptor, insulation).
- The input data for the coil is 250 V with a working frequency of 2.5 kHz.
- In the outer boundaries of computational domain the magnetic insulation boundary condition is used, which imposes that the normal component of magnetic field has to be zero

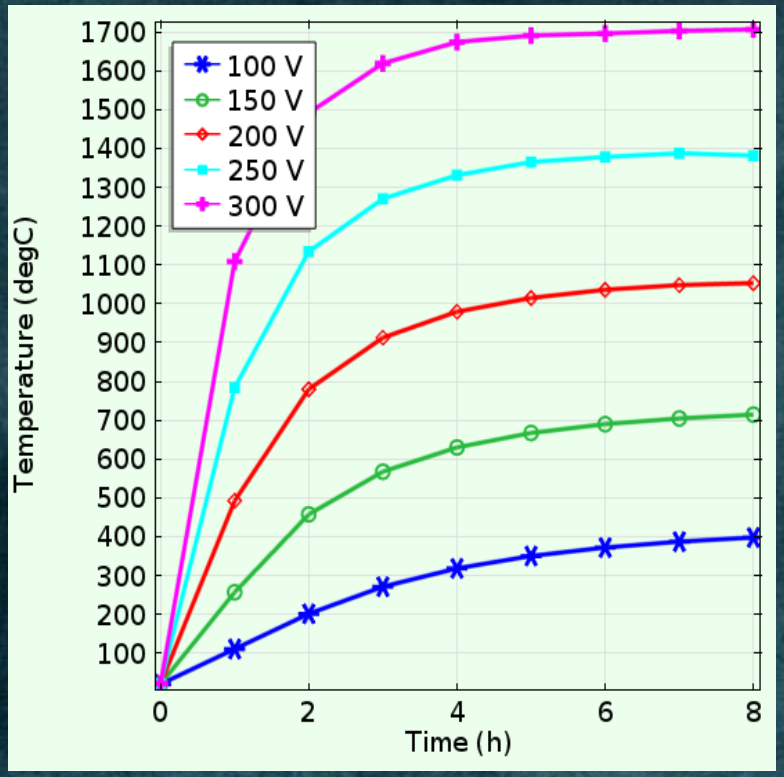
❑ GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Thermal field – Fourier equation

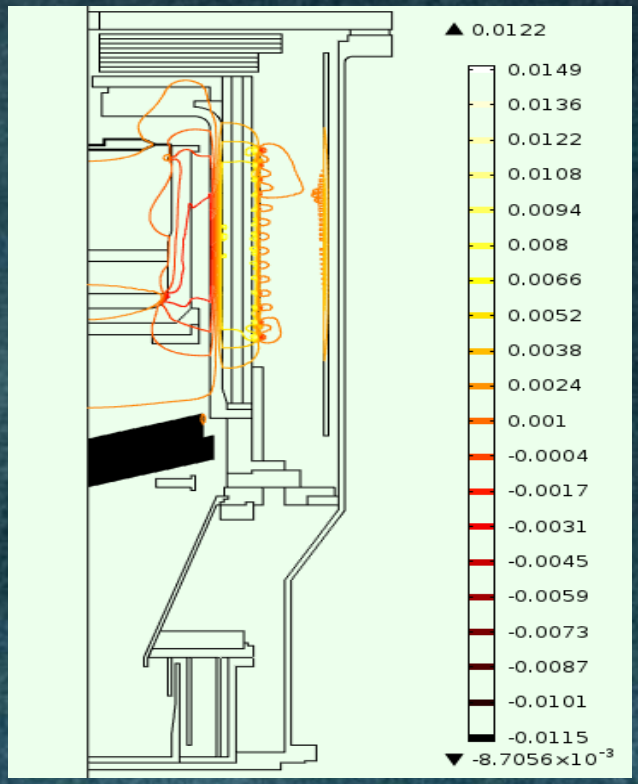
$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q$$

- Solid computational domains of the model,
- All the initial temperatures are set to 30°c.
- All the inside free surfaces in the model are allowed to participate in surface to surface radiation.
- The outer vessel wall surfaces are allowed to participate in surface to ambient radiation and convective cooling using suitable values of *h*.

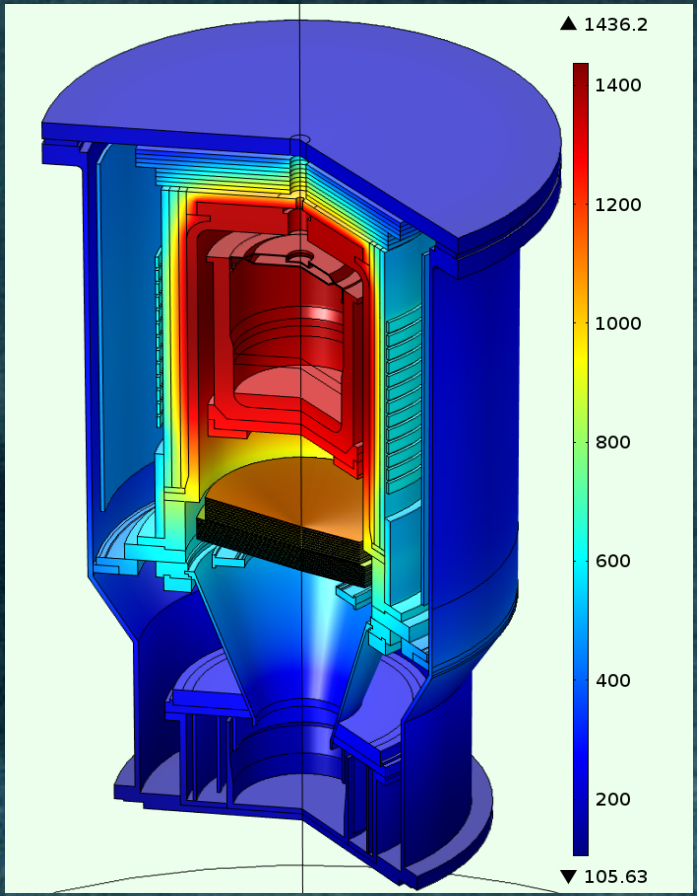




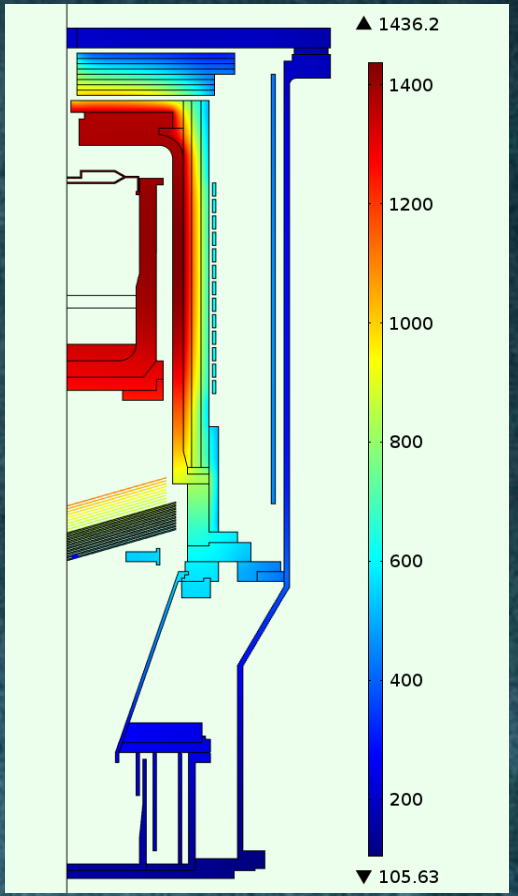
Average temperature rise of crucible with time at different coil voltages.



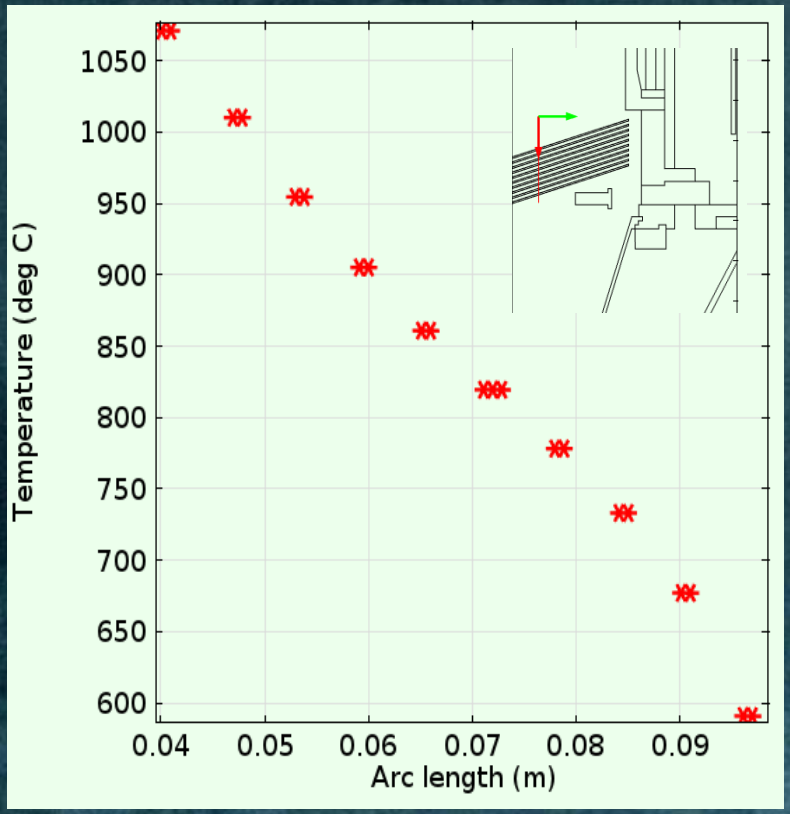
Magnetic flux density inside the furnace at 2.5 kHz and coil voltage of 250. (z component)



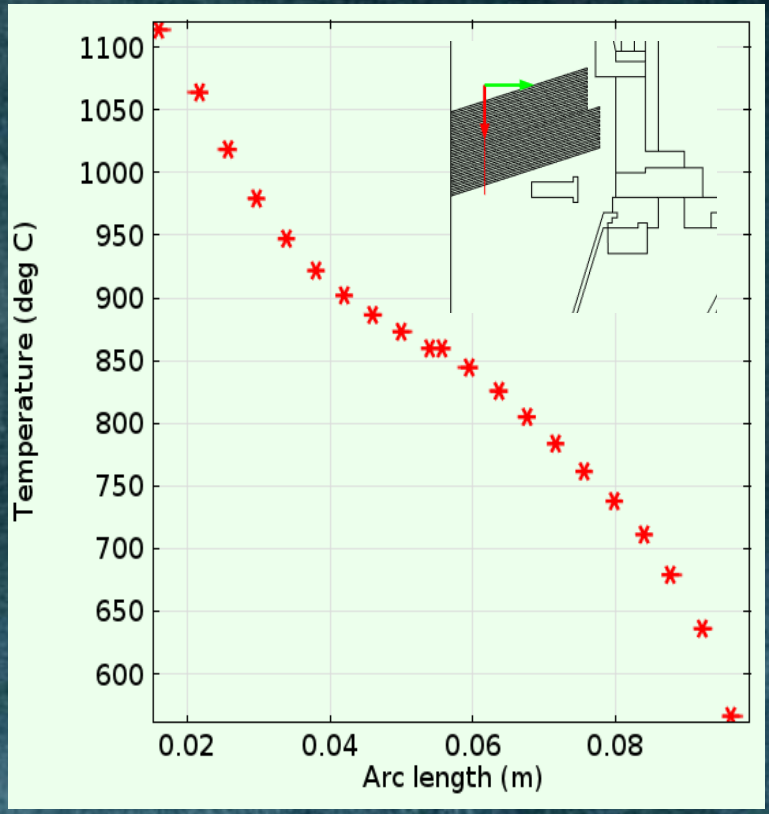
3D Temperature distribution in VDF furnace after 5 hours.



2D Temperature distribution in VDF after 5 hours.



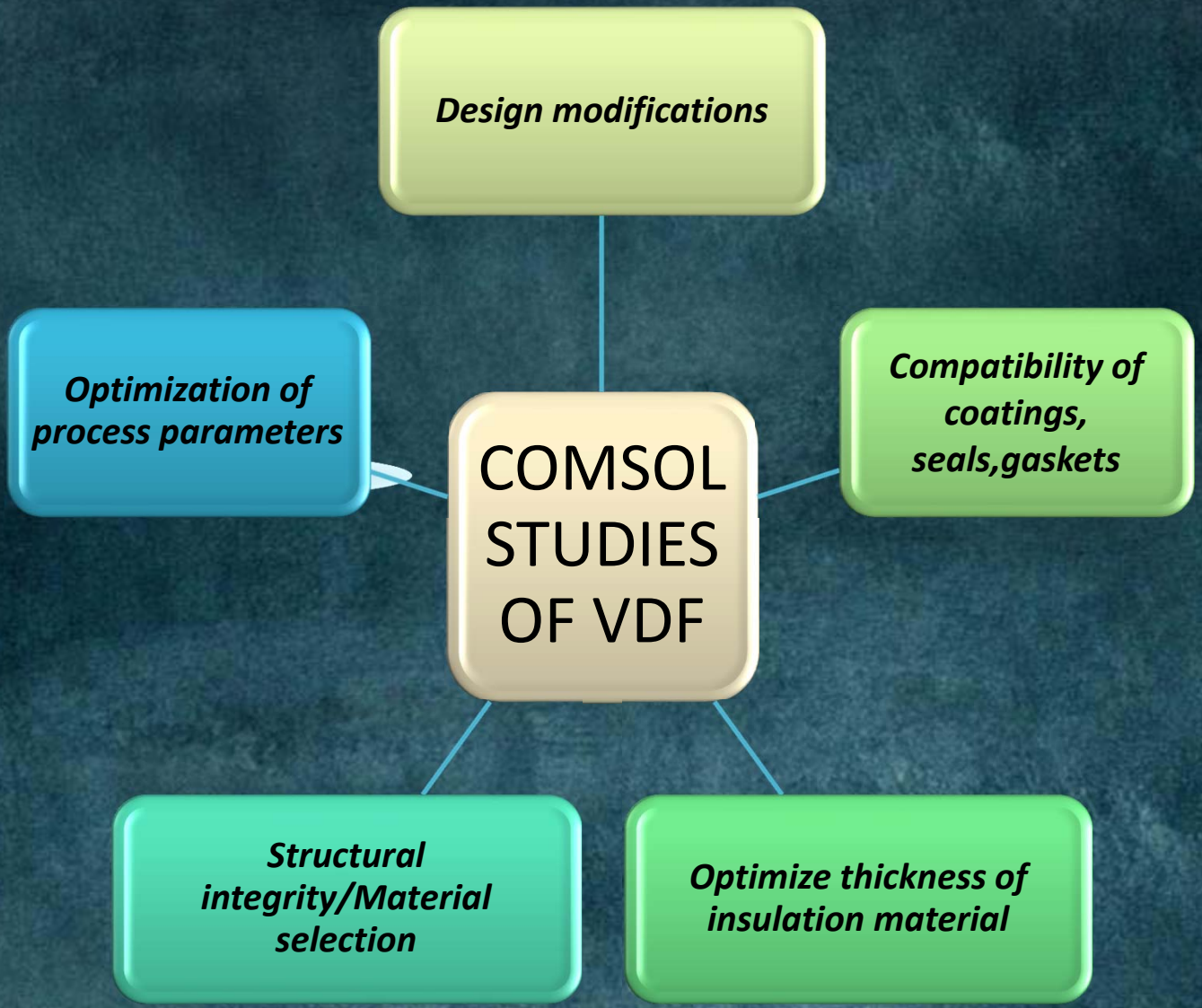
Temperature profile in the radiation shields with 20 numbers (gap = 2 mm between the plates) and added vapour heat flux.



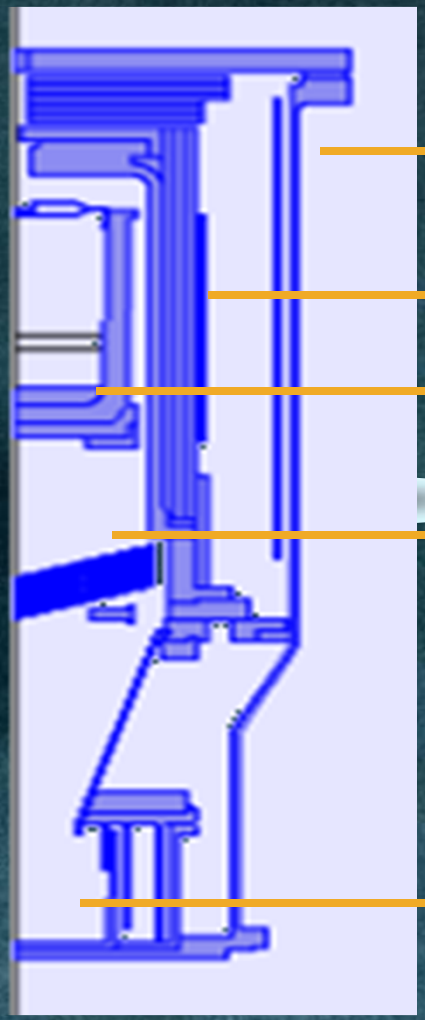
Temperature profile in the radiation shields with 20 numbers (gap = 2 mm between the plates) and added vapour heat flux.

- ✓ 2D axisymmetric model of VDF
- ✓ Solution of induction heating problem in the VDF.
- ✓ Evaluation of parameters like voltage , Frequency and number of required radiation shields.
- ✓ At the operating frequency of 2.5 kHz, the requisite maximum temperature in the crucible is attained at coil voltage 250 V.
- ✓ The studies reveal that in place of 20 number of radiation shields 10 number is also sufficient to maintain the suitable temperature gradient between the vaporization region and condensation region based on the process requirement.

Importance


Design modifications
Optimization of process parameters
COMSOL STUDIES OF VDF
Compatibility of coatings, seals,gaskets
Structural integrity/Material selection
Optimize thickness of insulation material

Future Work



Forced convection

Forced convection cooling

Melting and Magneto-hydrodynamics

Vapour Transport

Melting and solidification

References

1. B. R. Westphal et al., On the development of a distillation process for electrometallurgical treatment of irradiated spent fuel, Nuclear Engineering and Technology, Vol 40 No.3, April 2008.

2. D. Sujish, et.al "Thermal Analysis of Vacuum Distillation Chamber in Pyroprocessing Facility" 'COMSOL Conference India 2010'.

3. S. Zinn and S.L. Semiatin, *Elements of Induction Heating: Design, Control, and Applications*, ASM International, Metals Park, Ohio, 1988

4. Rudnev, V., Loveless, D., Cook, R., and Black, M.,.*Handbook of Induction Heating*.Inductoheat,Inc. 2003

5. COMSOL Multiphysics, *User Manual* and *Model Library.*

6. Yunusa .Cengel, *Heat and Mass Transfer, A Practical Approach,* .tmh' 3rd, 2007.

Thanks for your attention.....