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Thermal Analysis of Induction Furnace

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Abstract

Induction heating furnaces are employed for vacuum distillation process to recover and consolidate heavy metals after electrorefining operation. Induction heating furnaces of suitable heating rates are required to be developed for this purpose. Hence it is planned to set up a mock-up induction furnace which will simulate the conditions to be realized in actual induction heated vacuum distillation furnace. The mock-up induction furnace will be used to demonstrate the melting of copper. Preliminary results of the mock-up furnace are aimed at understanding the induction heating process and control which will be useful for the design and operation of actual vacuum distillation furnace. The mock-up induction furnace has been modeled in COMSOL Multiphysics. Prior to that the Induction Heating Interface algorithm under the Heat Transfer Module of COMSOL Multiphysics was validated with the experimental data reported in the literature. This paper describes the thermal and electromagnetic modeling of induction furnace and discusses the numerical results obtained. These results will be compared with the experimental results which will be obtained during the operation of mock-up facility.

Introduction

The mock-up induction furnace consists of furnace liner (susceptor), crucible, induction coil, copper-liner, graphite felt insulation and alumina refractory. These furnace components are enclosed in stainless steel vacuum vessel. Figure 1 shows the schematic layout of the equipment. Induction heating is achieved by supplying AC power at 2-8 kHz to the coil..The furnace liner essentially gets coupled with the magnetic field generated by the induction coil, heats up and indirectly heats the crucible by radiation heat transfer. The melting of copper takes place in crucible. The copper liner prevents the coupling of stainless steel vessel with magnetic flux lines. The carbon felt insulation is used to prevent the heat loss to the coil and other parts. The melting is carried out under vacuum and the contents in the crucible need to be heated to 1500 ºC in 2-5 hours. These conditions are sufficient for melting process. After melting, the crucible is cooled to form the metal ingot which is then removed. The induction coil is not water cooled due to safety considerations. The coil is only cooled by radiation to the walls of vacuum vessel which can be cooled by water. The 2D axisymmetric COMSOL model of the furnace is used to study the induction heating in the mock-up furnace.

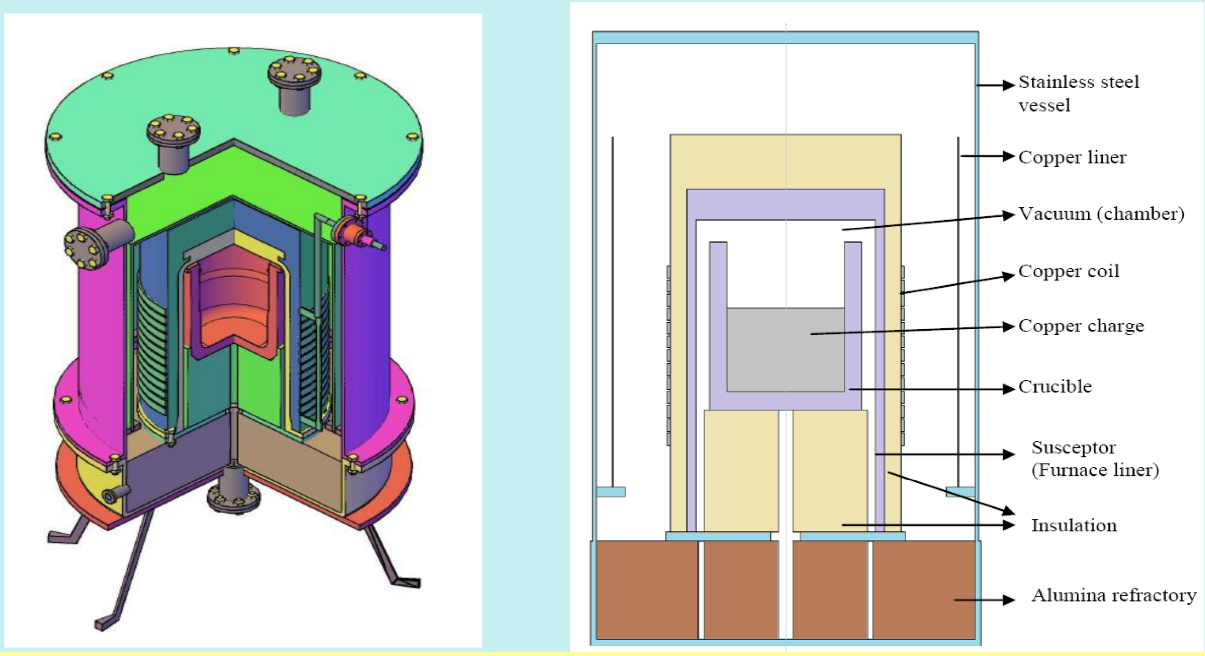

Fig.1: 3D and 2D schematic models of mock-up induction furnace

Modeling in COMSOL

Salient Features in Modeling

The induction heating process in mock-up furnace is a complex process where different physical fields i.e., electromagnetic and heat transfer phenomena are strongly coupled due to inter-related nature of physical properties (Figure 2). A simplified 2D axisymmetric model shown in Figure 3 was built in COMSOL. The model has the same dimensions as that of the mock- up induction furnace. The crucible has the diameter of 265 mm and that the coil inner diameter is about 400mm. The important parameters used in the model are given in Table 1. Figure 4 gives the he geometry and mesh networks of the validation model created using COMSOL.

Mathematical Modelling

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

$$B = \nabla\times A$$

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

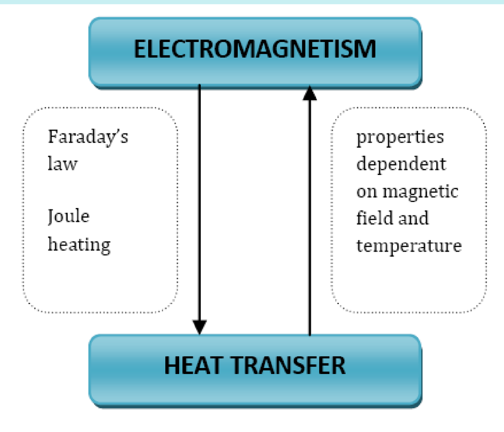

Fig. 2: Coupling of different fields in induction heating.

S. No	Parameter	Value
1	Frequency	8 kHz
2	Current	400 A
3	Height of copper in the crucible	30 mm (for 3.5 kg)
4	Time of heating	7200 s (2 hours)
5	Time step for computation	60 s

Table 1: Important parameters used in simulation.

Boundary Conditions

The Maxwell's equations are solved in entire computational domain. In the outer boundaries of domain the magnetic insulation boundary condition is used, which imposes that the normal component of magnetic field has to be zero. The heat conduction equation is solved in solid computational domains of the model. All the initial temperatures are set to 30ºC. 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 heat transfer coefficients for top bottom and vertical surfaces.

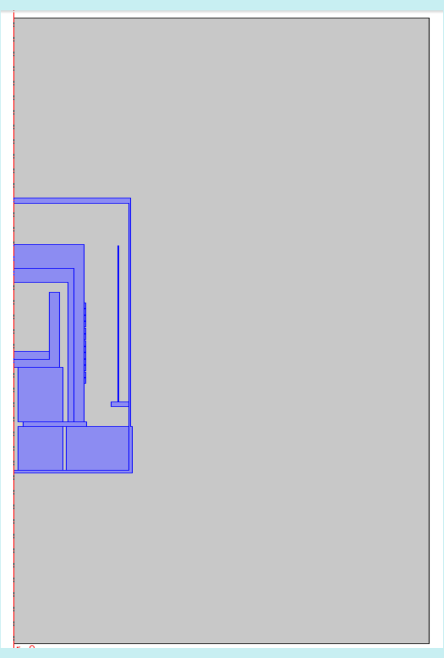

Fig.3: 2D axisymmetric model of mock-up induction furnace.

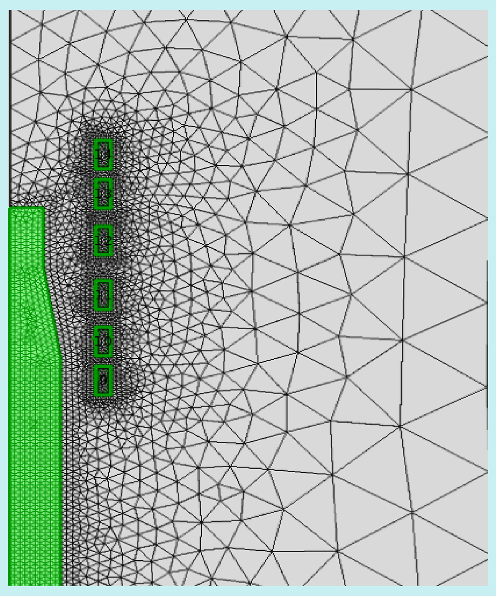

Fig. 4:The 2D axisymmetric model (with mesh) of validation model .

Results

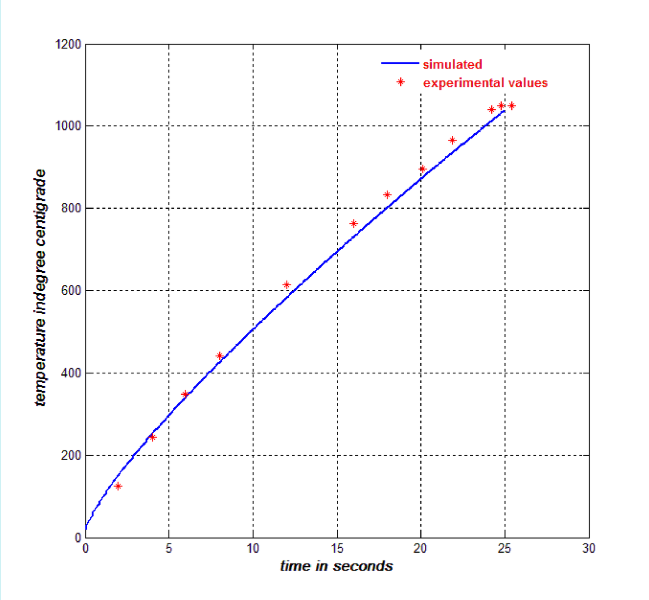

Fig.5: Experimental and simulated temperatures at 5mm from the top of work-piece in validation model.

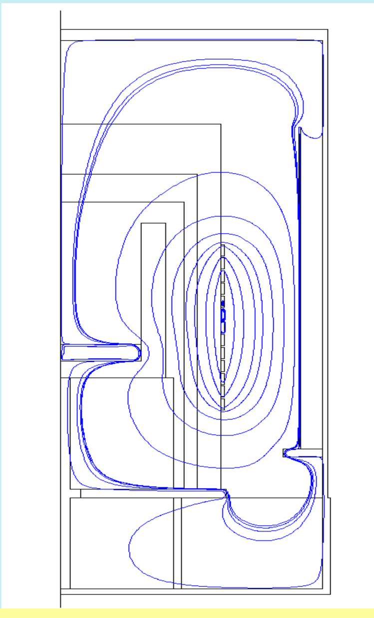

Fig. 6: Magnetic flux density inside the furnace.

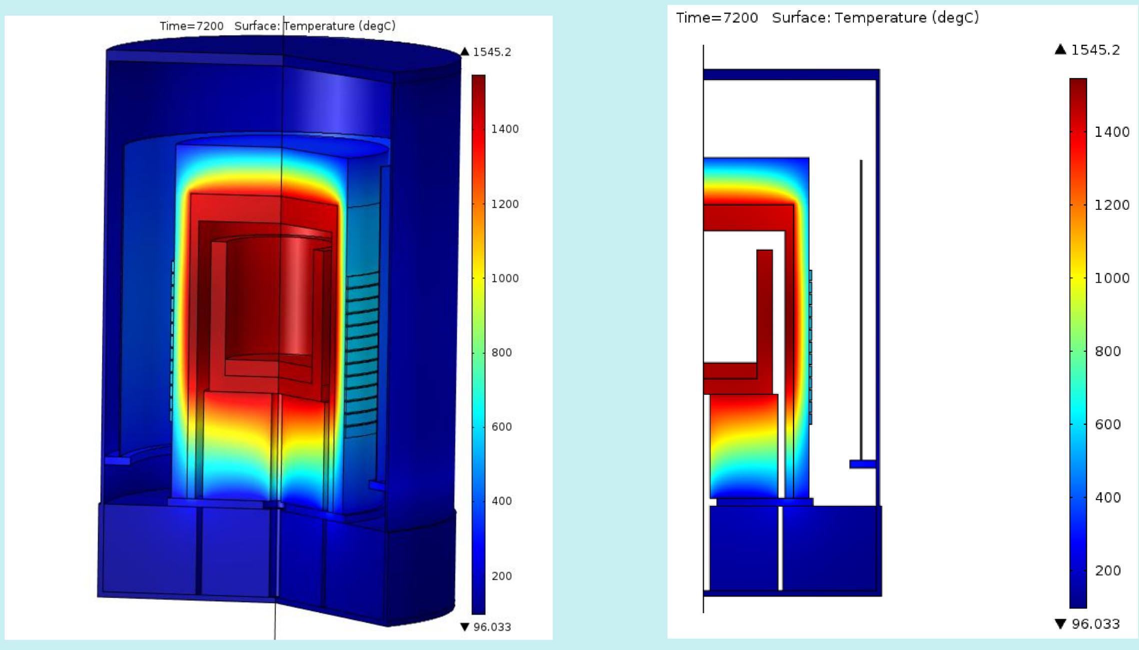

Fig. 7: 2D and 3D temperature distribution in mock-up induction furnace after 2 hours.

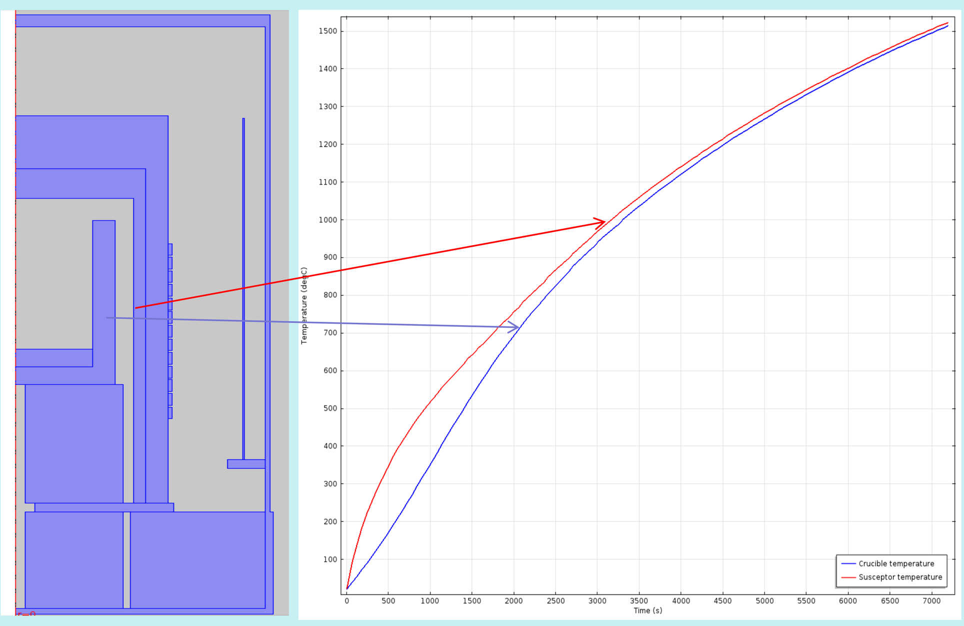

Fig. 8: Temperature rise with time at the indicated points on the susceptor and crucible respectively.

Conclusions

Transient thermal analysis of mock-up induction furnace is done using COMSOL. The results of this study have shown that the temperature of the crucible rises to 1500 ºC in 2 hours of heating time at frequency of 8 kHz and current of 400 A. Hence these conditions are favorable for melting of copper (melting point = 1085 °C) in the crucible. The studies reveal that copper-liner is effective in reducing the electromagnetic coupling between the coil and the vessel and thus prevents vessel from getting heated up by this effect.

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