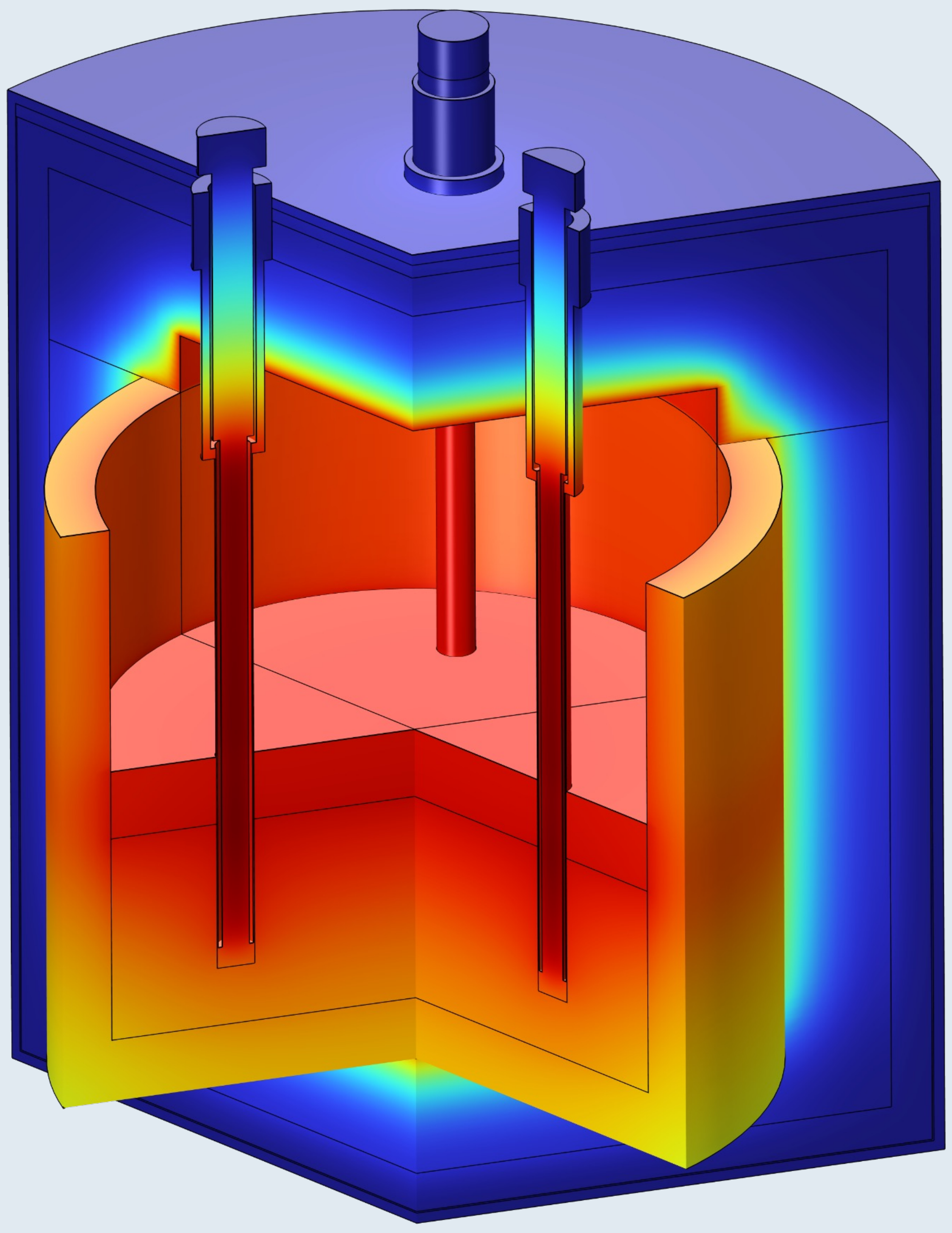

Ladle Furnace Preheating and Charge Heating with Graphite Heating Rods

Optimizing the silicon production in Europe by using a carbon-emission friendly technology. Numerical testing of new thermal and electrical designs of a ladle furnace for aluminothermic reduction.

S. Semenov[1], P. Namy[1], A. Kale[2], S. Tsebe[2]
1. SIMTEC, Grenoble, France.
2. MINTEK, Randburg, South Africa.

Introduction & Goals

Present work is done in the framework of the SisAl Pilot EU project, which aims at optimizing the silicon production in Europe by recycling materials and using a carbon-emission friendly technology. Silicon is produced in different types of furnaces, including ladle furnaces used as chemical reactors for molten slag-metal mixtures. Besides experimental work, the process optimization relies on the numerical modeling. With help of COMSOL Multiphysics®, new thermal and electrical designs of the ladle furnace are tested by simulating its preheating and charge heating in it with three graphite heating rods powered by a three-phase alternating current transformer. The model predicts that available electrical equipment is sufficient for preheating the empty ladle furnace up to 1600°C in less than 4 hours. The heating rods geometry was optimized to keep their temperature below 2500°C. Heating furnace charge with heating rods submerged into it is analyzed.

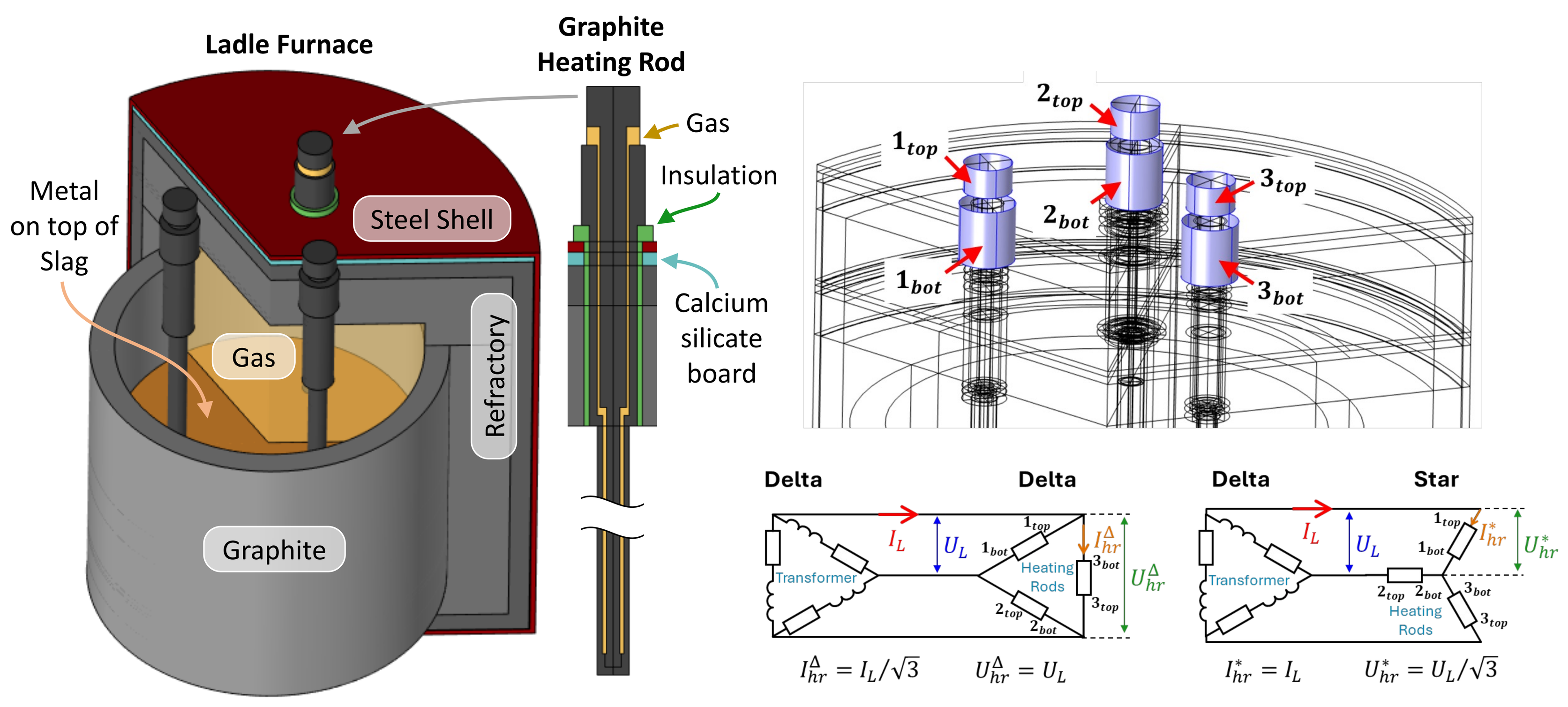

FIGURE 1. Left: 3D computational domain and materials [1-4]. Right: Heating rod terminals and connection types.

Methodology

The thermal part of the problem with surface-to-surface radiation benefits from the 120° sector symmetry. The frequency domain formulation of AC electrical equations with the Joule effect is resolved in a complete 3D geometry in all electrically conducting parts of the furnace. Liquid-solid phase change in slag is modeled with the Apparent Heat Capacity method. Fluid flow is not directly modeled but is considered with help of convectively enhanced conductivity. The electrical boundary conditions on the heating rod terminals are defined by the transformer that powers up the furnace and by the type of 3-phase electrical connection: either delta or star. Spatial discretization with a quadrilateral mesh results in approximately 1.1x10^6 finite elements, resulting in 2.5x10^6 degrees of freedom.

Results

Model predicts that available electrical equipment ($U_L = 105$ V) is sufficient for preheating empty ladle furnace up to 1600°C in less than 4 hours. The geometry of heating rod was optimized to keep its temperature below 2500°C. It is found, however, that the electrical functioning of the furnace is strongly affected by the presence of the furnace charge, as both slag and metal conduct electricity. The reduction of line voltage down to 40 V is found to be sufficient to avoid electrical and thermal damage of the furnace in the configuration with heating rods submerged into the melt. A numerical study with no electrical power input shows that the aluminothermic reduction power alone is sufficient to maintain the melt in a liquid state during at least 30 minutes of the process.

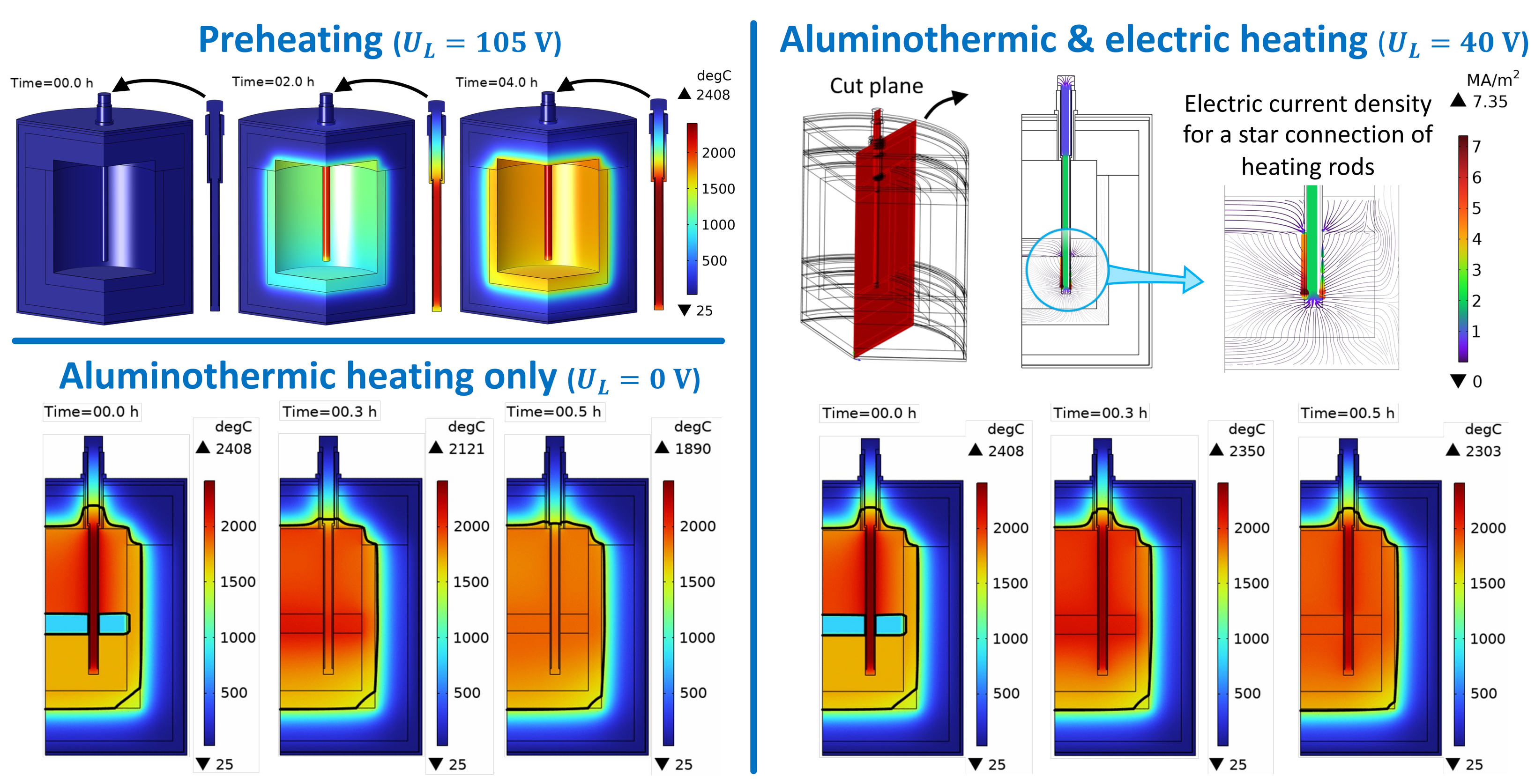

FIGURE 2. Temperature and electric current fields. Thick black line represents 1540°C, the slag melting temperature isoline.

REFERENCES

1. Entegris, Inc., "Properties and Characteristics of graphite, for the semiconductor industry," 2013.
2. D. S. Smith, A. Alzina, J. Bourret, B. Nait-Ali, F. Pennec, N. Tessier-Doyen, K. Otsu, H. Matsubara, P. Elser and U. T. Gonzenbach, "Thermal conductivity of porous materials," Journal of Materials Research, vol. 28, no. 17, pp. 2260-2272, 2013.
3. K. C. Mills, L. Yuan and R. T. Jones, "Estimating the physical properties of slags.," J. S. Afr. Inst. Min. Metall., vol. 111, no. 10, pp. 649-658, 2011.
4. K. Tang, C. van der Eijk, S. Gouttebroze, Q. Du, J. Safarian and G. Tranell, "Rheological properties of Al2O3-CaO-SiO2 slags," Calphad, vol. 77, p. 102421, 2022.

The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N°869268.