Development And Utilization Of Models For The Electrical Conditions In Submerged Arc Furnaces (SAF).

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Abstract

This work addresses the critical challenge of accurately determining the inner states of three-phase electric smelting furnaces, commonly used in ferro-alloy and silicon production. Gaining insights into these internal states is crucial for optimizing furnace performance, energy efficiency, and product quality. However, the harsh operating environment and challenging conditions within the furnaces charge make experimental surveys very difficult.

To bridge this knowledge gap, we developed detailed, parametrized 3D Finite Element Method models of industrial-size SAFs in COMSOL Multiphysics®. Our models use idealized yet realistic geometrical representations of structural elements and materials. The AC/DC Module, specifically utilizing the Magnetic and Electric Fields (mef) interface, was employed to setup the electrical conditions within the furnace. An Electrical Circuit (cir) model was integrated to track the true power for each phase, providing a comprehensive understanding of power flow.
The base model provides essential information on power distribution (both active and reactive power), the electric and magnetic field distributions throughout the furnace as well as derived quantities like resistances and reactances. Building on this, we have developed and utilized several specialized derived models, each designed to address a specific operational or measurement question, examples are:
- Virtual magnetometers: The models can predict the magnetic field at any given point in space. This fundamental capability, in theory, facilitates the identification of optimal strategies for acquiring the most comprehensive and informative data concerning the furnace's internal condition. Consequently, this could lead to the implementation of novel measurements for real-time monitoring and control protocols.
- Assessment of Traditional Multi-Lead Measurement Methods: We rigorously reviewed and analyzed traditional voltage measurement methods that rely on combining signals from multiple leads to reduce errors caused by strong magnetic fields inducing spurious voltages in measurement apparatus. Our models allowed for a detailed examination of the effectiveness and limitations of these compensation techniques under various operating conditions.
- Development of Parametrized Models for Surrogate Model Training: We developed highly parametrized versions of our furnace model. This parametrization allowed for the efficient generation of large and diverse datasets. These serve as the foundation for training advanced surrogate models (also known as metamodels or reduced-order models), enabling rapid and computationally inexpensive predictions of furnace behavior for a wide range of input parameters.

Through the systematic development and application of these COMSOL-based FEM models, this research provides invaluable insights into the complex electrical and electromagnetic phenomena within SAFs, contributing to improved operational control, enhanced measurement accuracy, and the development of more efficient and sustainable ferro-alloy and silicon production processes.

Reference

M. Sparta et al. Metamodeling of the electrical conditions in submerged-arc furnaces, Metallurgical and Materials Transactions B 52, 1267–1278 (2021)
M. Sparta et al. Electrical conditions in a manganese submerged-arc furnace: A web-based simulator, Proceedings of the 17th International Ferro-Alloys Congress (INFACON XVII) Beijing, China, (2024).

Figures used in the abstract

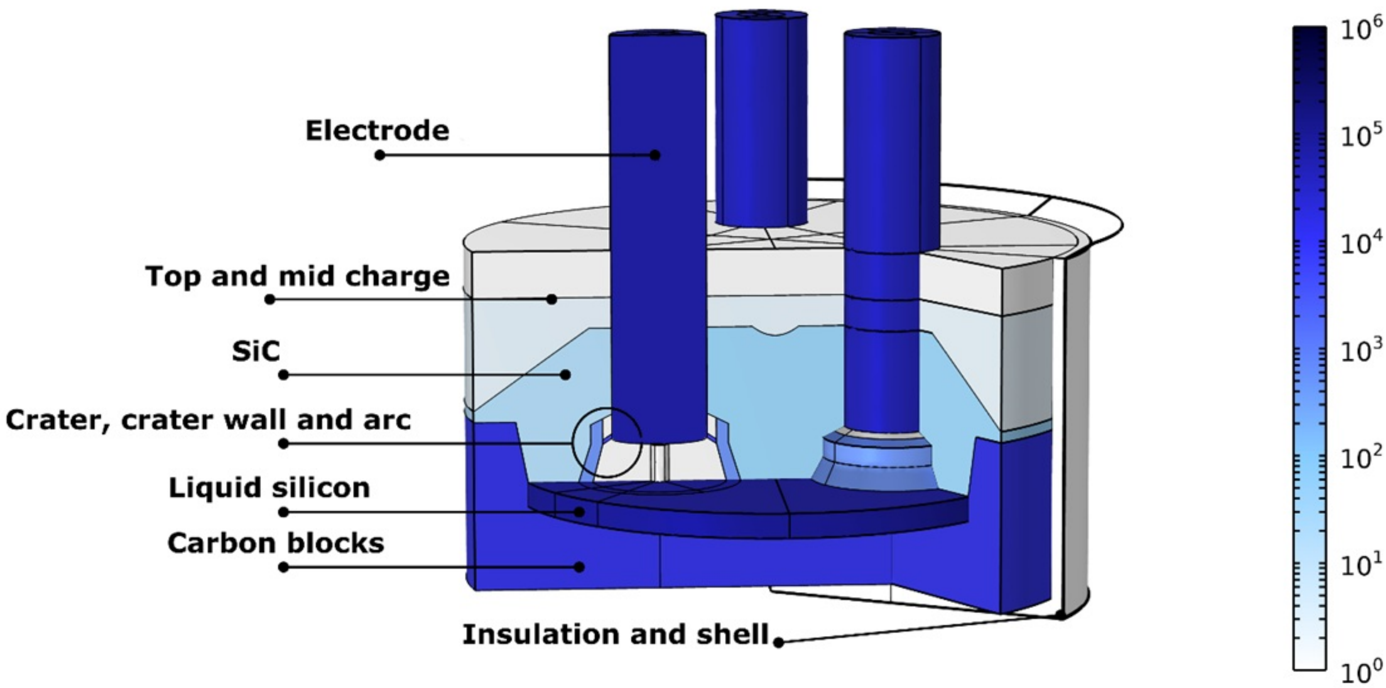

Figure 1 : Cross section of the furnace color-coded with electrical conductivity of the domains (S/m).