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Towards Better Furnace Design: Minimizing Energy Consumption Through Controlled Freeze Lining Formation

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The formation of freeze lining (FL) –a solidified slag layer that protects the furnace inner walls and refractory linings from chemical corrosion and physical degradation –is essential for the safe, energy-efficient, and long-term operation of high-temperature metallurgical reactors. Building upon a successful prior research program, a new consortium has been established, bringing together Montanuniversität Leoben (MUL) and KU Leuven (KUL) with the industrial partners RHI-Magnesita, Aurubis, and Primetals Technologies. This new partnership addresses fundamental and industrial challenges associated with FL formation to accelerate the transition toward the next generation of sustainable pyrometallurgical processes.

The previous work successfully established a physics-based Computational Fluid Dynamics (CFD) model framework and validated it against laboratory measurements and industrial data from an electric smelting furnace and a slag fuming reactor. The simulation results demonstrated good agreement with experimental data for FL thickness, heat fluxes, and global energy balance, thus providing a solid foundation for further refinement.

The newly-established research project introduces significant new experimental capabilities at both scales. Laboratory experiments use transparent analog systems and custom crucibles with direct visual access for in-situ observation of FL evolution, complemented by industrial-relevant cooling probes and high-resolution diagnostics for accurate measurements. These methods provide unprecedented insights into solidification kinetics, microstructure development, mobile-crystal transport, and the coupling between flow and phase change. These are phenomena critical to FL formation but remain insufficiently understood. At the industrial scale, new industrial-scale test campaigns in the slag fuming furnace (process used to recover valuable metals from slags) and in the emerging hydrogen-based electric smelting furnace (a key technology for the new carbon-neutral steel production) will supply critical real-word data for comprehensive model validation.

The integration of advanced laboratory measurements and multi-process industrial-scale validation will deepen the understanding of the physics governing FL formation and enable a substantial refinement of the CFD model framework. This collaborative effort between academia and industry directly addresses the existing knowledge gaps in slag solidification and FL dynamics. The resulting refined model will be a powerful tool to optimize furnace design, minimize energy consumption through controlled FL formation, and ultimately lead to tangible benefits in the respective industrial process and accelerate the transition toward low-carbon and circular metallurgical processes.

Speaker Country

Austria

Speaker Company/University

Montanuniversity of Leoben

Primary author: RODRIGUES, Christian (Montanuniversitaet Leoben, Department of Metallurgy)

Co-authors: Prof. WU, Menghuai (Montanuniversitaet Leoben, Department of Metallurgy); Prof. KHARICHA, Abdellah (Montanuniversitaet Leoben, Department of Metallurgy)

Presenter: RODRIGUES, Christian (Montanuniversitaet Leoben, Department of Metallurgy)

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