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A Global Multiphysics Model of Flow Mechanisms in Industrial Scale DC Electric Arc Furnaces

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Electric arc furnaces (EAFs) play a very important role in modern steel making by offering both an environmental and operational advantages over blast furnaces. An important gain by EAF utilization relies in lower carbon emission, potentially a zero-carbon footprint when relying on renewable energy sources. Moreover, EAF offers greater operational flexibility and higher energy efficiency through precise electric heating and production of high-quality steel with minimal impurities making it essential for sustainable and green steel production.

This study presents a comprehensive 2D axisymmetric model of an industrial-scale direct-current electric arc furnace (DC-EAF), fully integrating the electric arc, slag layer, molten metal bath, and refractory walls. The model simultaneously solves coupled electromagnetic, thermal, and hydrodynamic fields across the entire furnace domain, building upon prior validated sub-models for the arc and liquid metal regions. Simulations were conducted for DC arcs operating at 30 kA and 60 kA. Key findings highlight the furnace's flow dynamics, including arc characteristics, impingement effects, magnetohydrodynamic interactions, and buoyancy-driven convection. Three primary flow mechanisms are identified: (1) arc-induced shear stress driving slag radially outward at the surface; (2) electro-vortex effects generating inward convergence beneath the arc in both slag and metal phases; and (3) pronounced thermal buoyancy near the arc and walls, arising from steep temperature gradients. Additionally, arc impingement depth into the bath exhibits strong dependence on current intensity. The model yields valuable insights into internal EAF conditions that are experimentally challenging to probe under extreme operational environments.

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