Numerical simulation of a thermo-electromagneto-fluid dynamic problem arising from the metallurgical refining of molten metals

A. Bermúdez[†], D. Gómez[†] and D. González-Peñas[†]*

[*] Departamento de Matemática Aplicada &
Instituto Tecnológico de Matemática Industrial (ITMATI).
Universidade de Santiago de Compostela
15782 Santiago de Compostela, Spain.
alfredo.bermudez@usc.es, mdolores.gomez@usc.es, david.gonzalez.penas@usc.es,
http://www.usc.es/dmafm/ – http://www.itmati.com

ABSTRACT

In this work a mathematical model is developed to investigate a metal refining process related to the removal of volatile impurities under controlled atmosphere. All the physical phenomena take place inside an industrial scale furnace.

The furnace essentially consists of a refrigerated stainless steel chamber containing a hemispherical crucible. The crucible and the molten mixture inside are heated by an electrical resistance, which is located below the crucible and connected to three-phase alternating current. Heat generated by Joule effect, and transmitted mainly by radiation, keeps the metal contained into the crucible in liquid state. Eddy currents are induced into the melt leading to an electromagnetic force and thereby to a motion. Stirring and heating ensure the homogenization of the mixture and produce the vaporization of impurities that are condensed on the walls of a top chamber. Operating conditions in the chamber affect the kinetics of the process and the movement of the gases.

The overall process in the furnace is very complex due to the coupling of the different physical phenomena that take place: electromagnetics, heat transfer with S2S radiation models, motion in the molten metal and in the gaseous region, and chemical kinetics and thermodynamics of evaporation and condensation processes. On the one hand, the thermal mathematical model is coupled with the electromagnetic one because the Joule effect is a source terms in the heat transfer equation and the physical parameters depend on temperature. On the other hand, the dependence of the liquid buoyancy forces on the temperature, the velocity in the convective term of the heat transfer equation and the electromagnetic force in the Navier-Stokes equation couple the hydrodynamic model with the others. Stirring and temperature distribution in the molten region determine the evaporation mass flow of the base metal and its impurities. Furthermore, this flow determines the movement and distribution of gases in the condensation chamber. Finally, heats of reaction in the chamber walls and the convection generated by the gaseous movement should be incorporated into the global heat balance.

We state the mathematical models of the overall 3D process, propose a global procedure for numerical solution and show some numerical results. These results allow us to improve the furnace design and to optimize its performance.

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