Nonlinearities in energy saving material processing with electromagnetic coupling

V. Bojarevics, K. Pericleous, S. Easter and A. Roy

University of Greenwich, Park Row, London SE10 9LS, UK
v.bojarevics@gre.ac.uk

The interface stability problem for aluminium electrolysis cells is of great practical importance due to significant electrical energy losses, disruptions in the technology and increased environmental pollution rate. The electric current with the associated magnetic field are intricately involved in the oscillation process at the interface between liquid aluminium and electrolyte, which results in the observed wave frequencies being shifted from the purely hydrodynamic ones. The theory and numerical model of the electrolysis cell are extended to the cases of variable bottom and top solid surfaces. We present instructive analysis of different physical coupling factors affecting the magnetic field, electric current, velocity and wave development with animated examples for the high amperage cells. The results indicate that the 'rotating wave' instability is dominant in the idealized linear cases, while the inclusion of nonlinear interaction exerts a stabilizing effect with a 'sloshing' parametrically excited MHD wave development in the aluminium production cells.

A number of different methods have been developed, which allow the noncontact electromagnetic levitation of liquid metal droplets to investigate the melting/solidification process and measure the properties of these highly reactive materials. The intense AC magnetic field required to produce levitation in terrestrial conditions, along with the buoyancy and thermo-capillary forces, results in turbulent convective flow within the droplet. The presented numerical results show that the use of a homogenous DC magnetic field allows the large scale flow to be damped. However the turbulence properties are affected at the same time, leading to a lower turbulent damping. The reduction in the AC field driven flow in the main body of the drop leads to a noticeable thermo-capillary convection at the edge of the droplet. An alternative method without internal electric currents, using high gradient D.C. magnetic levitation, is analyzed analytically and numerically. A comparison is made between the analytical perturbation theory and the numerical pseudo spectral approximation solutions for small amplitude oscillations.

Intense AC magnetic field can be used to levitate larger volumes of liquid metal in terrestrial conditions, as it is known from experiments and industrial applications of cold crucible melting systems. The confinement mechanism in this case is considerably different from the case of a small droplet where the surface tension plays a key role to constrain the liquid outflow at the critical bottom point. The dynamic interaction of the turbulent flow with the oscillating interface, confined by the magnetic force needs to be accounted in a unified model for the time dependent liquid metal and magnetic field generating coil system. The MHD modified turbulence model is used to describe the mixing and damping properties at smaller scales not resolved by the macro model. The numerical multiphysics simulations demonstrate the possibility to levitate liquid metal of few kilograms mass in a cold crucible type melting system without the contact to container walls. Possible applications to processing of reactive metals are discussed.