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SCIENTIFIC COMPUTING FOR ALUMINUM PRODUCTION

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Abstract. Numerical simulation in aluminum production envolves many different topics, this paper is dedicated to some aspects of two of them. In the first part, a numerical approach for the computation of the motion of the fluids in an electrolitic cell is presented, with an emphasis on a mesh deformation technique to track the free interface during the time. In a second part, a model for the simulation of alumina dissolution and repartition is exposed.

Key Words. Aluminum production, Electrolysis, Magnetohydrodynamics, Alumina injection and dissolution.

1. Introduction

The industrial production of aluminum is based, since the end of the 19th century, on the electrolysis process. In most countries, aluminum is produced from alumina (Al_2O_3) which itself comes from bauxite. Aluminum electrolysis is performed in big Hall-Heroult cells, of approximate size 10 meters long, 3 meters wide and 1 meter high. Figure (1) gives a schematic representation of a vertical transverse cut of such a cell. Alumina particles are injected periodically in a corrosive electrolytic bath lying over the liquid aluminum. Both fluids are kept at temperature 965°C and are immiscible.

A strong electric current (current density about $10'000\ A/m^2$) runs through the fluids from the carbone anodes to the cathode allowing electrolysis to take place in the electrolyte. The chemical reaction:

$$2Al_2O_3 + \text{ energy} \rightarrow 4Al + 3O_2,$$

produces liquid aluminum and oxygen bubbles which are gradually burning the anodes and creating CO_2. Anodes must therefore be changed regularly. Alumina is added periodically to the electrolytic bath and the aluminum is produced and recolted at the bottom of the cell every day.

All these running operations can produce perturbations of the cell rendering. Moreover, industry wants to optimize the production, this is to say increase current density as much as possible, by acting on the geometrical and electrical configurations of such electrolytic cells. Since physical observations are difficult to perform due to high temperature, current and magnetic induction in the cells, numerical simulations are very useful.

In this paper, some of the physical phenomena involved in aluminum production are presented, with emphasis on numerical simulation.

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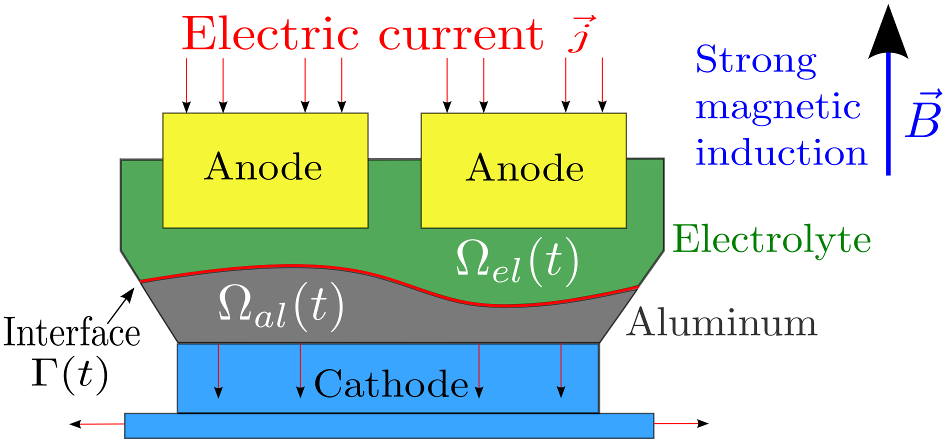

Figure 1. Simplified electrolytic cell : Notations

The most important point, is that both fluids are immiscible and moving, since they are subject to electromagnetic and gravity forces. These electromagnetic forces (Lorentz forces) arise from the combination of the current density running through the fluids and the magnetic induction due to the whole electric configuration of a hall containing many cells. It is of great importance to be able to control the motion of the fluids in a cell because if the aluminum, which is a much better conductor than the electrolyte, touches the anodes then the cell would be strongly damaged.

This leads to the following magnetohydrodynamic (MHD) modelling: multi-fluid incompressible Navier-Stokes equations for the computation of the velocity and pressure, with an unknown interface between liquid aluminum and electrolyte determined by a level-set function, are coupled with the quasi-static Maxwell model for the computation of the magnetic induction in the whole space. The electric current density is given by Ohm's law in moving media, determined only in the cell.

Many other phenomenons may be considered. Let us mention two of them :

(1) *Temperature effects.* Temperature in the electrolytic bath is maintained at a value close to 965°C. This is the result of an equilibrium between heat production mainly in the bath due to Joule's effect and heat transfer through the walls of the cell. Since the fusion temperature of the electrolytic bath is close to the mean production temperature, it can solidify on the internal walls of the cell, creating the so-called ledges. These ledges are very useful to protect the walls of the cell against the extreme chemical agressivity of the bath but they are modifying the electric currents in the cell and, of course, the shape of the fluid domain. In this document we do not deal with thermal effects but refer to [6] for a discussion on this particular question.

(2) *Ferromagnetic effects.* The whole cell is placed in a steel container two centimers thick. Since the container is ferromagnetic, it reduces the intensity of magnetic induction into the fluids by screening and therefore the Lorentz