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Experimental model of the interfacial instability in aluminium reduction cells

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Abstract – A solution has been found to the long-standing problem of experimental modelling of the interfacial instability in aluminium reduction cells. The idea is to replace the electrolyte overlaying molten aluminium with a mesh of thin rods supplying current down directly into the liquid metal layer. This eliminates electrolysis altogether and all the problems associated with it, such as high temperature, chemical aggressiveness of media, products of electrolysis, the necessity for electrolyte renewal, high power demands, etc. The result is a room temperature, versatile laboratory model which simulates Sele-type, rolling pad interfacial instability. Our new, safe laboratory model enables detailed experimental investigations to test the existing theoretical models for the first time.

Introduction. – Overcoming magnetohydrodynamic (MHD) instabilities in aluminium reduction cells is a problem of enormous industrial importance [1]. This is not surprising as current production facilities consume about 2% of the entire electricity generated worldwide, which translates into about 10 billion US dollars annually [2]. Thus the efficiency of the process of aluminium smelting has considerable economic dimension.

Aluminium is produced in rows of about 100 shallow baths or cells with horizontal dimensions of 4–5 m by 10–16 m each by passing an electric current of between 150 and 500 kA through a mixture of alumina (Al_2O_3) and cryolite (sodium aluminium fluoride) (fig. 1). The electric current flows vertically down from the carbon anodes at the top of the cell to the carbon cathode at the bottom, melting both alumina and cryolite by means of Joule heating. As a result of very complex thermo-, electro-, hydro-, magnetohydro-dynamic, and electrochemical processes involving consumption of carbon from anodes and accompanying CO_2 and perfluorocarbon gas emissions, a two-fluid layer is formed, up to 35 cm deep. The fluid on top, about 4–5 cm thick, is an electrolyte with very poor electrical conductivity of $\sigma_c \approx 200\,(\Omega\mathrm{m})^{-1}$ while the fluid below is a slightly heavier molten aluminium with high conductivity of $\sigma_a \approx 3\times 10^6\,(\Omega\mathrm{m})^{-1}$. Both are kept at about 960 °C.

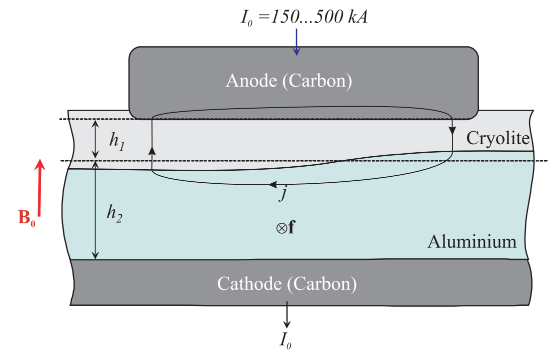

Fig. 1: (Colour on-line) Schematic diagram of the aluminium smelting process.

The interface between the electrolyte and the liquid metal may become unstable to MHD waves if parameters of the process rise above or fall below certain thresholds. The key to the mechanism of instability, suggested first by Sele [3], is the MHD interaction of the horizontal component of the disturbance electric current **j** (see fig. 1), which flows mainly in highly conducting aluminium layer with the vertical component of the background field B_0. The Lorentz force $\mathbf{f} = \mathbf{j}\times\mathbf{B}_0$ (see fig. 2) drives the metal

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