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IMPACT OF GRAVITY ON THIN-LAYER CELL ELECTROCHEMICAL DEPOSITION*

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Abstract. Electrochemical deposition (ECD) in thin cells with different orientations relative to gravity leads to complex stable and unstable physicochemical hydrodynamic flows. Here we study the impact of gravity on these flows through a theoretical macroscopic 3D model and its numerical simulation. The model describes the diffusive, migratory, and convective motion of ions in a fluid subject to an electric field through the Nernst-Planck, Poisson, and Navier-Stokes equations, respectively. The equations are written in terms of dimensionless quantities, in particular, the gravity Grashof number, revealing the importance of gravitoconvection. The nonlinear system of partial differential equations is solved on a uniform grid using finite differences and a strongly implicit iterative scheme. In ECD in a cell in a horizontal position, our model predicts the evolution of two gravity-driven convective rolls and concentration shells attached to each electrode. We predict their birth, growth, expansion towards one another, collision, and merger into a single roll that invades the whole cell. In ECD in a cell in a vertical position, cathode above anode, our model predicts that gravity-induced rolls and concentration shells remain locally attached to fingers that grow downwards; thus, global invasion of the cell by gravity-induced rolls is suppressed, leading to a stable stratified flow. In ECD in a cell in a vertical position, cathode below anode, our model predicts the detachment of rolls and concentration shells from each electrode in the form of plumes that expand towards one another, mix, invade the whole cell, and lead to an unstable stratified flow. For ECD, whether in horizontal or vertical position, in the presence of growth, our model predicts the existence of an electrically driven vortex ring at the dendrite tip that interacts with concentration shells and rolls, leading to complex helicoidal flows. Such structures are experimentally observed, suggesting that ion transport underlying dendrite growth is remarkably well captured by our model.

Key words. electrochemical deposition, computational modeling, finite differences, stable physicochemical hydrodynamic flows, unstable physicochemical hydrodynamic flows

AMS subject classifications. 76W05, 76U05, 65Z05, 65C20, 68U20, 65M06, 76D05

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