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TECHNICAL NOTE

Magnetoelectrolysis in non-uniform solenoidal fields

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Symbols

B	magnetic flux density
F	magnetohydrodynamic body force density; $F = JB$
J	cathode current density; J_0 same, in the absence of a magnetic field
v	velocity
x, y, z	spatial coordinates; z in the axial direction
ρ	electrolyte density
ω	vorticity ($\boldsymbol{\omega}$ = curl v)
D/Dt	substantial derivative ($\partial/\partial t$ + v. grad)

In previous work on magnetoelectrolytic cells in uniform magnetic fields [1–3] preliminary findings have suggested that in non-uniform gradient fields the mass transport enhancement effect can further be increased. The effect was studied in more detail in a specially designed apparatus, shown in Fig. 1, where the non-uniform magnetic field was established via a 960 turn AWG 14 copper wire coil consisting of twelve layers of winding (total winding length: about 853 m, room temperature resistance about 7 Ω). The major purpose of this study was to facilitate scale-up to larger size cells and the rational design of magnetoelectrolytic processes. The generated field, whose axial component variation is shown in Fig. 2, had a negligible strength distribution along the x, y-coordinates and the flux density, averaged over the entire axis, as well as its z-distribution was proportional to the exciting electric current flow. The electrolyte solutions were 0·05–0·58 mol dm^{-3} technical grade $CuSO_4$ in a 1·60–1·62 mol dm^{-3} H_2SO_4 supporting electrolyte; electrolysis was carried out at an average temperature of 39–40° C via a standard regulated d.c. power supply, using an active electrode area of 700–800 cm^2 per electrode face.

A typical set of experimental results is shown in Fig. 3, where the shaded area represents the domain of the mass transport enhancement factors observed in non-uniform solenoidal fields whose flux density varied between 0·0 and 90 mT, whereas Curves A and B correspond to uniform magnetic fields of 4·0–785 mT. These results indicate that comparable relative mass transport

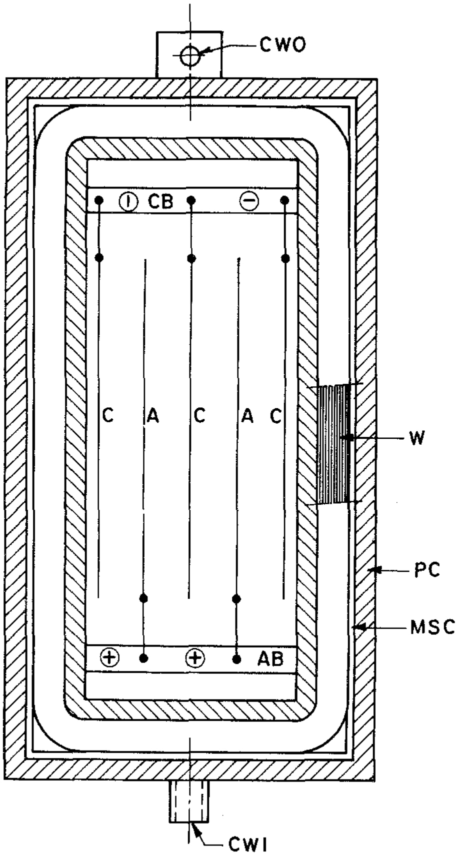

Fig. 1. Top view of the experimental set-up. A: anodes, C: cathodes, AB: anode bus bar, CB: cathode bus bar, CWI: cooling water inlet, CWO: cooling water outlet (overflow), MSC: mild steel casing, W: windings of the solenoid, PC: plastic container.

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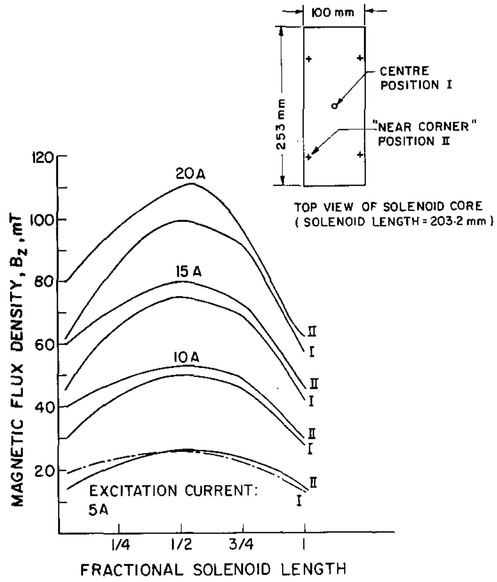

Fig. 2. The variation of the axial component of the magnetic flux density in the solenoid core.

rates can be achieved in non-uniform fields whose average strength is about one tenth of the uniform field strength otherwise required, under similar experimental conditions.

While a rigorous theoretical explanation of the observed phenomena cannot yet be offered, a tentative and semi-quantitative analysis based on the vorticity equation in an MHD continuum [4, 5]

$$\frac{D}{Dt}\left(\frac{\boldsymbol{\omega}}{\rho}\right) - \frac{\boldsymbol{\omega}}{\rho} \cdot \operatorname{grad} \mathbf{v} = \frac{1}{\rho} \operatorname{curl}\left(\frac{\mathbf{J} \times \mathbf{B}}{\rho}\right) \qquad (1)$$

allows one plausible interpretation. Since the magnetic Reynolds number is very low, induced electric currents are negligible and it follows that the velocity field in the convective diffusion layer obeys the simplified vorticity equation

$$\begin{aligned} \boldsymbol{\omega} &= \mathbf{e}_x \omega_x + \mathbf{e}_z \omega_z \\ &= \mathbf{e}_x\left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z}\right) + \mathbf{e}_z\left(\frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y}\right). \qquad (2) \end{aligned}$$

The existence of closed loop vortex motion around the electrodes in multiple-electrode cells [1, 6] indicates that the ω_z component is strong in a thin subsection of the convective–diffusion layer adjacent to the electrodes, and it appears that this component becomes predominant in non-uniform magnetic fields. The more pronounced the field non-uniformity, the larger the order of magnitude of ω_z, as ascertained via preliminary approximate computations; a detailed numerical analysis will be the subject matter of a future study.

Practical applications of the non-uniform magnetic field effect might be possible in electroplating, electrowinning and electrorefining of aqueous metal-ion solutions via bus bars sectioned in a 'rectangular coil' consisting of a few turns around the electrolytic cell; the solenoidal magnetic field would be excited by the d.c. current required for electrolysis. A thorough analysis of economic factors will be needed to optimize gains resulting from smaller tank construction costs at a fixed current level, or higher production rates at a fixed tank size.

Acknowledgment

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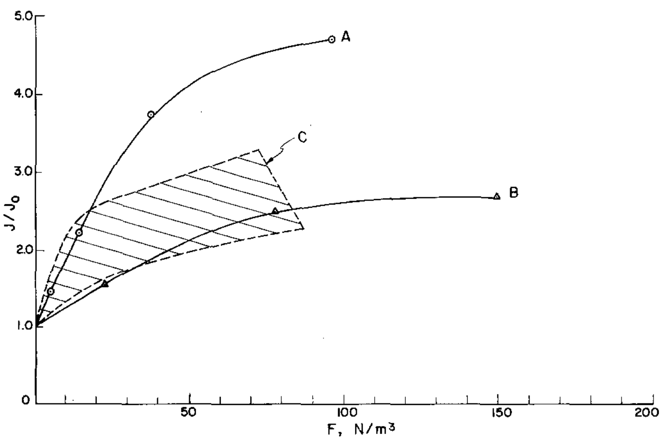

Fig. 3. Enhancement factors in uniform and non-uniform magnetic fields. The shaded area represents experimental data obtained in *non-uniform* fields of average flux density 0–90 mT; A: 0·048 mol dm^{-3} $CuSO_4$/1·56 mol dm^{-3} H_2SO_4; B: 0·409 mol dm^{-3} $CuSO_4$/1·56 mol dm^{-3} H_2SO_4. *Uniform* magnetic flux density in A and B: 4–785 mT.

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