SPECIAL REPORT

Electrochemical engineering – Towards 2000

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1. Introduction

This communication is written on behalf of the Working Party on Electrochemical Engineering which is one of several working parties of the European Federation of Chemical Engineers (EFCE). This Working Party is chiefly concerned with the application of the concepts and methodology of Chemical Engineering to industrial electrochemistry and related technologies. Electrochemical engineering is seen as the science of the design, engineering and operation of batch and continuous electrochemical processes under optimum technological and economic conditions.

Since its inception in the 1940s and 50s the discipline has been concerned with the definition and development of its scientific bases and concepts and their application to industrial problems. For example, some of the areas developed have been:
(i) the theory of mass transfer near electrode surfaces by diffusion, convection and migration,
(ii) the theory of potential and current distribution in both ideal and real cells,
(iii) the analysis of mass, heat, momentum and electrical charge transfer coupled phenomena,
(iv) electrochemical reaction engineering applied to the modelling, simulation and design of reactors,
(v) optimization of cells and processes.

Among the many areas of large scale application of industrial electrochemical engineering are the chloralkali, hydrogen/oxygen and aluminium industries and several important hydrometallurgical processes for the winning and refining of bulk metals. The battery industry represents a further large scale and widespread example of electrochemically based technology.

Particular applications of the ECE approach has led to significant developments in specific areas such as:
(i) the electrolytic treatment of dilute solutions in which mass transport plays an important controlling role,
(ii) the design of new cells characterized by high mass transfer rates and large specific surface areas, such as particulate and porous electrodes, which have found application in effluent treatment,
(iii) electroorganic synthesis by direct or indirect means. The development of electrochemical engineering applied to such technologies was greatly stimulated by the appearance in the 1960s of two industrial processes due to Monsanto (for adiponitrile) and Nalco (for tetra-alkyl lead).

The current existence of several (for example, [1–9]) text books as well as some special series (for example, [10]) reflects both the need and the concern for the establishment of a strong scientific and methodological approach within the discipline.

Although research will continue in the fields mentioned above and particularly in the extension of existing theories to concentrated solutions and molten media, and the acquisition of physico-chemical properties of electrolytes, it may confidently be predicted that the next ten years will offer new opportunities involving stronger collaboration with specialists from other disciplines such as solid state physicists, control and computational engineers, materials scientists and biologists. In a recent technical session of the Electrochemical Engineering Working Party held in Aachen in April 1989 various aspects of electrochemical engineering were reviewed specifically with a view to future trends in the next 10 years. Contributions to the technical session were made by Professors G. Kreysa (Frankfurt), H. Wendt (Darmstadt), P. Spinelli (Turin), D. Drazic (Belgrade) and A. Storck (Nancy).

2. Key areas for strategic development

From the presentations made the following have been highlighted as representing areas in which significant new work might profitably take place in the short term future:

2.1. *Modelling and simulation of complex processes*

Coupling between electrochemical and chemical reactions – optimization of yield and selectivity
Periodic process operation – pulsed current or potential
Automation and control of plant and processes
New model-assisted control strategies
Dynamic modelling – start-up and non-steady state operation
Cell design and optimization for complex processes
Process intensification

2.2. *New techniques in electro-technology*

Photoassisted organic electrochemistry
Electropolymerization
Bioelectrosynthesis and electroenzymatic processes
Laser-induced metal deposition

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Electroseparation techniques – electrodialysis, electro-chromatography, electrosorption, electro-filtration
High resolution electrochemical sensors – biomolecules, ion and gas sensitive electrodes
Electrolysis with continuous product extraction
Electrolysis in multi-phase systems

2.3. *Identification of interesting novel reactions and processes*

Synthesis based on non-petroleum raw materials – for example coal and biomass
Electroenzymatic reactions
Indirect electrosynthesis with homogeneous organic or inorganic mediators
Indirect electrosynthesis with immobilized redox mediators

2.4. *New and improved materials for electrochemistry*

Electrocatalytic materials – stable anodes, mixed oxide coatings, alloys
Superconducting mixed oxides
Immobilized redox mediators
Solid ionic conductors
New stable ion exchange membranes and bi-polar membranes
Conducting polymers and chemically modified electrodes
Improved corrosion prognosis, monitoring and prevention
New techniques for material and surface characterization
New electrochemically based machining techniques
New materials for molten salt processes

2.5. *Electrochemical energy conversion and storage*

Improvement of present standard primary cells
Major improvement in Li cells
Commercialization of larger scale metal-air primary batteries
Improvement in the energy density of lead-acid batteries
Development of the Na/S and other high temperature systems for electric traction
Large scale fuel cell systems for load levelling and special applications
Development of solar cells
Development of solar driven photoelectrochemical treatment process

The first two categories mentioned above represent classical areas of electrochemical engineering. The third and fourth constitute new and challenging opportunities for the discipline. Success in such areas will depend crucially on collaboration with workers in other varied scientific fields. The fifth category represents an ever present challenge as the search for greater energy efficiency and alternative environmentally friendly power sources intensifies.

3. Technical and educational targets

The Working Party recognises the following important targets:
(i) to evaluate and promote the role of electrochemical engineering in contributing to the exciting new fields outlined above,
(ii) to encourage stronger and more effective collaboration between electrochemists and electrochemical engineers and scientists from other fields,
(iii) to encourage a higher profile for education and training in electrochemical engineering at undergraduate, graduate and post-experience levels,
(iv) to encourage more interaction between academic institutions and industry, particularly with a view to the translation of fundamental ideas and laboratory results into commercially viable process and products,
(v) to encourage cooperation with other EFCE Working Parties such as chemical reaction engineering, environmental protection and membranes,
(vi) to promote and support good quality colloquia, conferences and workshops on both classical and new electrochemical subjects in collaboration with other societies and organizations.

Readers may be interested to know that a directory of European academic research institutions was recently published by the Working Party [11].

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