LETTER TO THE EDITOR

To the Editor:

The numerical work of Wang and Andrews (May, 1995, p. 1071) is a very worthwhile addition to the literature on a most difficult fluid-mechanical problem. Several comments, however, may be appropriate and may stimulate a response from the authors that will be helpful to the readers.

- The article failed to reference the comprehensive review by Nandakumar and Masliyah (1986) and thereby overlooked a number of other experimental and computational papers on square helical ducts.

- They credit the derivation of their Eq. 12 to Ward-Smith although it was previously derived by many others as far back as St. Venant (1855).

- λ is defined differently on p. 1076 and in the Notation section.
- The legends of the figures are somewhat difficult to decipher. The captions of Figures 7, 8 and 12 are in part in very small print and in computerese. RCS, RhR, and VPO in Figures 9, 10 and 11 are not defined. The abscissa of Figure 11 is presumably $d\phi/d\theta$ rather than dP/dO. C_s is undefined (except in context) although numerical values are given in the text. One must search through the text to find that 'NUM.DAT' refers to the simulation of the current article, that 'EXP.DAT' refers to the experimental results of Huang and Gu, and that $De = Re\sqrt{\lambda}$, since the latter is not included in Notation. Even then, the definition of λ remains uncertain.

Literature cited

Nandakumar K., and J. H. Masliyah, "Swirling Flow and Heat Transfer in Coiled and Twisted Pipes," *Advances in Thermal Processes*, Vol. IV, A. S. Mujumdar and R. A. Mashelkar, eds., Wiley Eastern, New Delhi, p. 49 (1986).

de Saint-Venant, B., "Mémoire sur la Torsion des Prismes, avec des Considérations sur leur Flexion, ainsi que sur l'Equilibre Intérieur des Solides Élastiques en Genéral, et des Formules Practiques pour le Calcul de leur Résistance a Divers Efforts s'Exercant Simultanement," *Mémoires des Savants Étrangers*, Vol. 14, p. 233, Paris (1855).

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BOOK REVIEWS

Electrochemical Process Engineering

By F. Goodridge and K. Scott, Plenum Press, New York, 1995, 312 pp., $59.50.

A First Course in Electrochemical Engineering

By Frank Walsh, Electrochemical Consultancy, Hants, England, 1993, 381 pp., $45.00.

These two books are both primers in electrochemical engineering, developing from basic principles the tools necessary to design processes that include electrochemical reactors. Both are aimed at technical people who are familiar with typical chemical processing, but totally unskilled in electrochemistry. Both limit the discussion to electrochemical synthesis, deliberately excluding such electrochemical processes as fuel cells, batteries, electrowinning and electromachining. There the similarity ends for the most part.

Electrochemical Process Engineering begins with the caveat that, not being a textbook, it will have little descriptive matter about industrial practice. Yet it is a textbook in that it explores the principles of the subject in its development. The authors point out that electrochemistry is still the "Cinderella" of reaction techniques, not appreciated by the mainstream process engineers. It is well constructed and sticks to its main objective of a systematic procedure for design of processes including an electrochemical step. They stress that mathematical models can be used with a minimum of bench-scale experimentation and comment that: "Many supposedly engineering papers have reported results of synthetic processes using electrolytic cells a few square centimeters in surface area. Such results cannot be safely applied to process design." They propose use of simple glass cells or rotating-disk experiments to find the fundamental kinetic constants and then use reactor models and mass-transfer correlations in the design of pilot-scale equipment. Their plan is outlined in their Figure 1.1. They contrast this plan with one that uses a bench-scale cell with a factorial-type approach of changing process variables.

Chapter 1 contains some basic electrochemistry, the relationship between stoichiometry and current, the components of cell voltage, and the voltage distribution in a simple cell, a useful diagram missing from many other similar texts. The "exchange current density" is introduced here, but without develop-

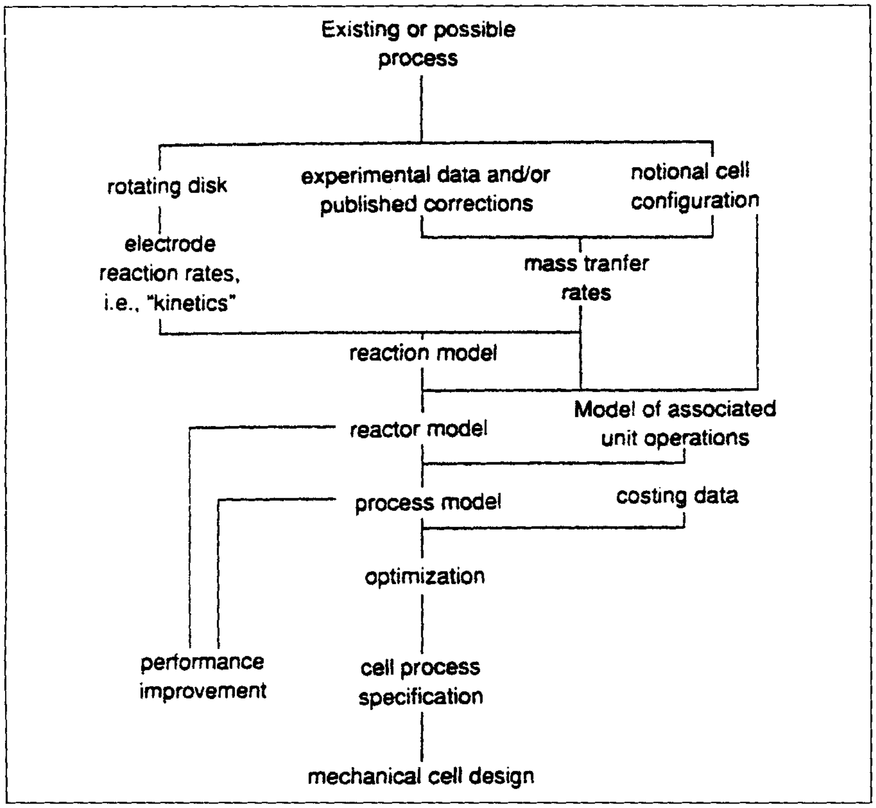

Figure 1.1. Scheme for the design of electrolytic reactors.

ment or connection to the activation overpotential; these are delayed for some 100 pages.

Chapter 2 deals with basic chemical engineering mass-transfer correlations including those for the rotating disk and rotating cylinder. However, nothing has been presented to this point about activation polarization, so the naive reader may be led to believe that the mass-transfer-limiting currents arrived at from these simple experiments are all that are needed in the way of data. The thermodynamics necessary to finding the equilibrium cell voltage is also developed here, leading to some examples of energy demand estimates. These are easily understood, but are devoid of overpotential estimates. One of the few references to cell separators is made here. There is an important weakness in the book; many, if not most, industrially important synthesis reactors require diaphragms or membranes. The possibility of parallel reactions is not adequately discussed, nor is the need for product analysis in this regard.

Chapter 3 on rate processes and the basics of reaction models is a very nicely done development of activation overpotential, concentration overpotential, and their combined effects. There are also two illuminating examples using real systems. Unfortunately, early in the chapter, one of the few chemical reaction equations in the entire book is not balanced:

$$4H^{+}+2I^{-}+2NO_2 \rightarrow I_2+2NO+2H_2O \tag{3.3}$$

so that it is not clear whether it was meant to be an example of a half-cell reaction with 2e missing from the left side or a complete reaction that needed 4 iodides on the left and 2-iodine molecules on the right. This chapter does not explore sufficiently the experiments used to get data for the models.

From reactor models in Chapter 4 the chemical engineer familiar with chemical reactor design will be able to assimilate easily the extension to electrochemical reactors. The authors have done a good job of showing that they are just another type of heterogeneous reactor, whose kinetics are much more sensitive to applied potential than chemical catalysts are to temperature; very modest voltages are commensurate with several hundreds of degrees. There is also an illustrative comparison of conversion and current efficiency as a function of time in a batch reactor in potentiostatic vs. galvanostatic control.

Chapter 5 on reactor design offers some reference to commercial processes, but these are not described. Typical cell designs are shown, however, in fine detail. Mono- vs. bipolar current collection is explained, as is external vs. internal manifolding and series vs. parallel flow. The first mention of porous electrodes and packed beds is made, but with only cursory connection to actual processes. They do, however, develop in detail the causes and effects of nonuniform current distribution in real reactor designs.

Chapter 6 is the culmination of the effort: an exquisitely detailed cost analysis and optimization from an engineering point of view. The generalist will appreciate this chapter; it includes all factors necessary for economic process evaluation and comparison.

A First Course in Electrochemical Engineering begins with much the same premise as the Goodridge and Scott book (G-S) in that electrochemical engineering has been isolated from chemical engineering practice, limited to relatively few practitioners despite some large-scale commercial successes. The mathematical approach, in stark contrast to G-S, is admittedly "dilute," but the examples used are all from commercial reactors. The fundamental difference in design philosophy is seen in Figure 1.3, which should be compared to G-S Figure 1.1. Here the interaction among lab-scale, pilot cells, and commercial installation is stressed, rather than the direct design straight from glassware with the use of mathematical models. While the latter is certainly more pleasing aesthetically, it probably mirrors less actual practice. The importance of bench-scale cells is noted, those a few square centimeters in area.

In Chapter 2, the fundamentals of electrochemistry are developed with the immediate help of common examples, such as the lead-acid battery and the electrolytic plating of copper. The practical need for porous electrodes and membrane separators are introduced early on. Here the series of steps involved in an electrochemical cell is introduced, demonstrating the necessity for resolution of the rate-determining step. The utility of the reference electrode is easily grasped in the discussion of the equilibrium cell potential from thermodynamics; the development is generously sprinkled with readily-understood illustrations.

Chapter 3 is devoted to cell components: electrodes, electrolytes, and separators. There is a useful, if simplified, presentation of electrolyte thermodynamics with the definition of mean ac-

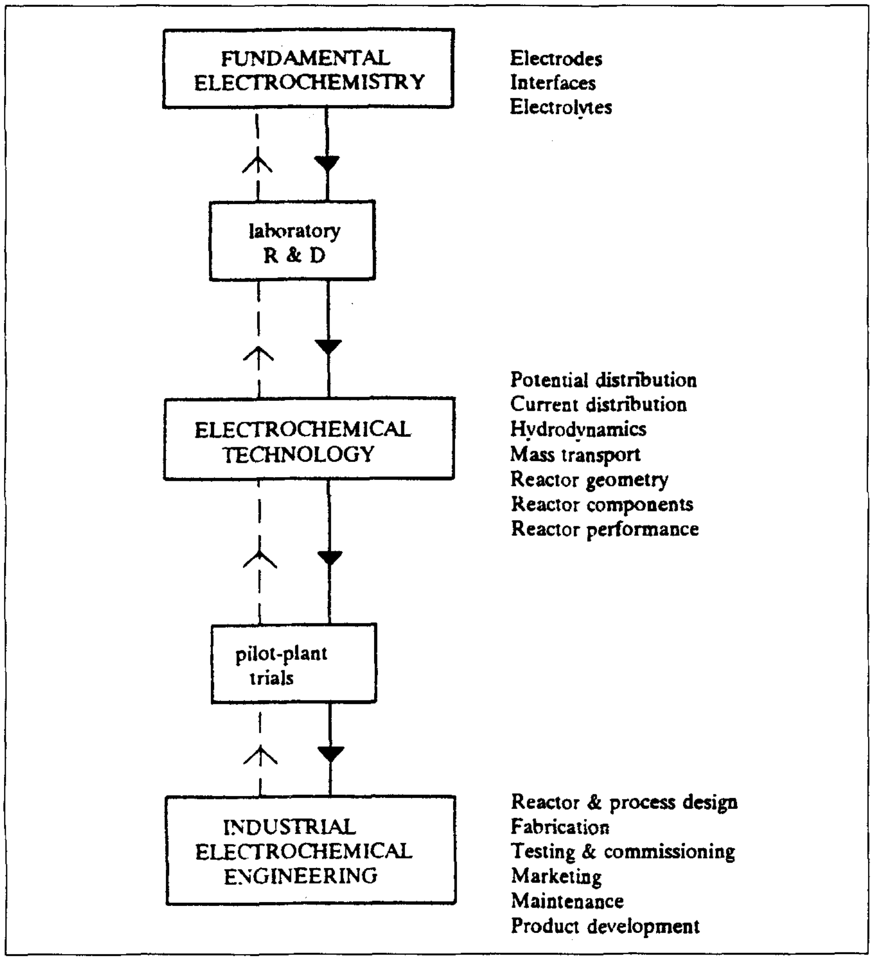

Figure 1.3. Scope of electrochemical engineering showing the bidirectional nature of scaleup and major subject areas.

tivity coefficients and transport numbers. The requisite properties of each component are described, as are their availability. Examples are used to show choice as based on individual process need. In Chapter 4, reaction stochiometry and rates of reaction are explored. First, Faraday's law is introduced, followed by a brief discussion of side reactions and current efficiency. Following an empirical display of the basic electrochemical kinetic expressions, the Butler-Volmer equation is derived from a molecular viewpoint. This order of presentation might annoy the purist, but it certainly mirrors the actual chronology; the empirical Tafel equation preceded by decades the microscopic explanation. Finally, the effect of mass transfer is introduced, with a development of the limiting current and mixed activation and concentration overpotential.

Chapter 5 is limited to transport phenomena; chemists not familiar with chemical engineering techniques for calculating mass-transfer rates will find this useful. Correlations for the Sherwood number for various cell geometries, including those with porous, 3-D electrodes, are presented. Chapter 6 will also be readily grasped by chemical engineers; basic reactor design factors are reviewed, as is calculation of yield, selectivity, and current efficiency. The important group, $k_m A/V$, for porous electrodes is illustrated.

Practical design criteria form the meat of Chapter 7. While the costing bases and optimization are not nearly as detailed as those in G-S, they will be sufficient for most readers. The three factors determining current distribution are clearly set out, followed by an excellent presentation of the design and operation of a 3-D porous electrode. These somewhat simplified equations show the ideal limitations of a finite potential window within which the desired reaction can occur, as manifested in the allowable electrode width. The criteria for separator use and the utility of the fluidized bed are set out here as well.

Chapter 8 comprises a short qualitative description and illustrations of various types of electrochemical reactors, with examples in practice. This is followed by a chapter detailing the development of several commercial processes, quantified as to reactor size, voltage, current, production rate, etc. The chronologies detail the progression of the processes from lab-size cells of a few square centimeters, through the bench-top, 100-cm^2 cell, and then to the multicell stack. The design and analysis include quantitative consideration of such practical matters as cell life, pressure drop, and cost performance prediction. The examples include interesting and important topics: recovery of metals from waste streams, synthesis of a protein, and salt splitting across ion-exchange membranes (the production of an acid and base from the neutral salt). Unfortunately, the equations used here in the design bases are not linked to those developed in the earlier chapters. Chapter 10 completes the book with completely worked practical examples.

Even considering the somewhat low production values, a step above photo-ready copy, this book makes a good text for a senior or graduate-level class. It is also extremely useful for the practicing engineer or chemist looking for a basic self-teaching manual of electrochemical engineering, one that could be readily consumed in about two weeks of concentrated effort. It is recommended over G-S for either purpose as one which is more complete, more easily assimiliated and more closely connected with actual practice.

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Multiphase Flow and Fluidization: Continuum and Kinetic Theory Descriptions

By Dimitri Gidaspow, Academic Press, New York, 1994, 467 pp., $69.50.

Multiphase flows are involved in numerous industrial processes such as pneumatic conveying and solid fuel combustion and occur in various natural phenomena such as sandstorms and aerodynamic ablation. Typical multiphase flow encompasses gas-solid, liquid-solid, gas-liquid and gas-liquid-solid flows. Modeling based on the continuum assumption for multiphase systems