PERSPECTIVES ON THE EVOLUTION OF ELECTROCHEMICAL ENGINEERING

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The evolution of electrochemical engineering and the underlying mathematical modeling tools that emerged during the past half century will be traced. Several driving forces that shaped these events will be summarized, including (1) the complexity and overall characteristics of electrochemical processes that need to be engineered, (2) advances in chemical engineering that provided mathematical methods for describing transport processes in electrochemical systems, and (3) the development of experimental methods for characterizing electrochemical systems with high spatial and temporal resolution.

The engineering landscape has grown in large part from the recognition that most large industrial electrolytic processes are driven at a rate that is determined by limitations on transport processes. One consequence of this economic reality is that the local rate of reaction along the surface of an electrode can vary from place to place and influence product quality. For this reason, the literature has focused strongly on understanding of ohmic and mass transport processes including the effect of hydrodynamic flow.

The use of dimensionless numbers based on the (algebraic) ratio of surface-to-volume effects is important, as was recognized independently by Wagner and Hoar. The development of mathematical models for limiting cases of behavior based on differential equations provided additional level of sophistication, particularly the seminal works of Wagner and Levich. Building on these foundations, the development of increasingly sophisticated mathematical methods for cleaving complex problems into manageable components using a combination of analytical and numerical approaches, coupled with experimental data, has been accomplished by many workers including Tobias and Ibl along with the pioneering efforts of Newman. Such tools include perturbation methods, coordinate transformations, and numerical algorithms implemented at the continuum level with dilute solution theory. The most difficult situations today remain those where coupled phenomena at several length/time scales are important simultaneously.

The remarkable development of experimental methods for probing the electrochemical interface has served to shift the recent focus of electrochemical science to small spatial scales ranging from the molecular level to the wavelength of light. These events are leading to discovery of new applications where control of events at the small scale is critical to product quality. The shape of the engineering landscape is therefore shifting toward multi-scale simulation tools that bridge both continuum and non-continuum phenomena.