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Electrochemical Engineering of Cells for Conversion of Renewable Energy

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Abstract

Electrochemical engineering may be regarded as comprised of two fields:
1) Electrochemical engineering science
2) Electrochemical engineering art/technology

Electrochemical engineering science is based on fundamental laws of electrochemistry. It deals with electrochemical systems and processes according to scientific principles, and deals with systems related to industrial electrochemical technologies. Its aim is analysis and mathematical description (modeling), which will allow us to design electrochemical devices and processes, and to operate them under full control at optimal conditions in a profitable manner.

Electrochemical engineering art/technology is based on good intuition and intelligent trial-and-error, which both need broad empirical knowledge and theoretical insight into a number of scientific disciplines. Besides electrochemistry, disciplines such as electro-physics, solid state physics, physical chemistry, chemistry, catalysis, interface science, materials science, quantum mechanics, density functional theory, and mechanical physics are important. None of the above mentioned disciplines can stand alone.

The main difference is that the engineering science needs a coherent and exact mathematical description, while the engineering art “just” needs to show resulting hardware that functions with good performance. However, there is no sharp border between the two fields of electrochemical engineering.

This presentation deals with electrochemical engineering of cells for conversion of renewable electric energy (from solar photovoltaics, wind, and hydropower) into chemical energy and reverse using devices such as electrolysis cells – fuel cells and batteries. Examples are taken from the area of reversible solid oxide cells (RSOCs), which are cells that work well in both solid oxide fuel cell (SOFC) mode and solid oxide electrolysis cell (SOEC) mode, and from the area of proton exchange membrane electrolysis cells (PEMECs).

Electrochemical engineering science would obviously seem to be the tool to use for development of a perfect RSOC, whether the application is for electrolysis or fuel cell. However, when the latest international era of SOFC research and development (R&D) took off about 1990, the fundamental knowledge about all the possible materials for cell and stack components was not available, nor were the mechanisms and kinetics of the electrode reactions, as well as the degradation mechanisms and degradation rate well known. As an example, impurities at interfaces in the cell and on grain boundaries in the materials play a huge role in context of degradation. This means that it has been necessary to deal with a big number of the elements in the periodic table. Even after 30 year we still do not have enough knowledge to do proper electrochemical engineering science on SOCs, and the good progress in R&D has been carried out by electrochemical engineering art.

Materials science and engineering art have become main disciplines as part of the electrochemical engineering in the continued R&D of RSOCs. However, the very broad area have resulted in some research groups that understand only part of the science behind SOC technology.
In spite of the very comprehensive and complex nature of electrochemical engineering science of RSOC it is still helpful to try to do a full mathematical description using the little knowledge available. All the unknowns are then assumed. When such modeling attempt is combined with detailed operando characterization of electrodes, single cells and stacks this may provide a basis for an empirical model that can simulate a cell or a stack of cells of a given type with fair approximation. Comparison between modeling and measurements will give information about which detailed knowledge is still missing. This will give inspiration to new experiments with cell and stack components and lead to new cell and stack designs with new or improved components for further studies. Such iterative R&D strategy is very resource and time consuming, but the international SOC R&D results from the latest 30 - 40 years strongly indicate that this is the most successful strategy. This statement will be illustrated with selected examples of SOC strategies carried out by various R&D groups over decades of work.

Also, examples of slow progress of PEMEC and alkaline electrolysis cells due to a strategy with far too much emphasis on only few aspects forgetting other important aspects will be presented. These examples indicate that the use of the holistic nature of electrochemical engineering is the best cure against an unbalanced R&D strategy.