ChE 4520/5520: Introduction

Gerardine G. Botte

Outline

- Definitions:
  - Electrochemistry
  - Electrochemical Engineering
- Challenges
- Course Content
- Major Applications
- History

Electrochemistry

- Electrochemistry is the branch of chemistry concerned with the interrelation of electrical and chemical effects
- Deals with:
  - The study of chemical changes caused by the passage of a current
  - The production of electrical energy by chemical reactions
Electrochemical Engineering

- It is the branch of engineering dealing with the technological application of electrochemical phenomena
- Application of chemical engineering principals to the fundamental understanding, design, and optimization of electrochemical systems
- Electrochemical Engineering is to Electrochemistry as Chemical Engineering is to Chemistry

What is an electrochemical system?

- System characterized by:
  - Strong interactions among solute and with the solvent (ionic species)
  - Passage of a current
  - Potential
  - Electrical energy transformed into chemical energy or vice versa
  - e.g., batteries, fuel cells, etc

Challenges

- No much cover on other courses
  - Chemistry
  - Thermodynamics
  - Physical chemistry
- Electrochemical systems are different
- Break any myths about electrochemical systems
**Course Content**

- Basic concepts
- Thermodynamics
- Electrode kinetics
- Transport mechanisms
- Electrochemical reactor design (introduction)
- Applications

**Applications**

- Production of Al and Cl
- Corrosion
- Batteries and Fuel Cells
- Electroplating
- Cathodic protection
- Super capacitors
- Remediation
- Sensors

**Major Products based on electrochemical technology**

<table>
<thead>
<tr>
<th>Process or Product (data from National Research Council)</th>
<th>Annual Market ($ billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>4</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>3</td>
</tr>
<tr>
<td>Chlorine</td>
<td>2</td>
</tr>
<tr>
<td>Copper</td>
<td>2</td>
</tr>
<tr>
<td>Other metals and chemicals</td>
<td>2</td>
</tr>
<tr>
<td>Electroplating</td>
<td>10</td>
</tr>
<tr>
<td>Batteries</td>
<td>4</td>
</tr>
<tr>
<td>Semiconductor Processing</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
</tr>
<tr>
<td>History</td>
<td></td>
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<tr>
<td>- Discoveries started around 1800</td>
<td></td>
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<tr>
<td>- Alessandro Volta (first battery)</td>
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<tr>
<td>- Michael Faraday (Faraday's law)</td>
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<tr>
<td>- William Grove (1839) discovered the fuel cell</td>
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<td>- Georges Leclanche (1868) constructed the carbon zinc battery</td>
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<table>
<thead>
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<tr>
<td>- Hall-Heroult aluminum process (1886) reduced the price from $100/lb to $2/lb</td>
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<tr>
<td>- Walter Nernst</td>
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<tr>
<td>- Julius Tafel</td>
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<tr>
<td>- Great advances in electroplating (1920-1940s)</td>
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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>- The formal synthesis of electrochemistry and engineering began in 1950s</td>
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<tr>
<td>- Norbert Ibl in Switzerland</td>
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<tr>
<td>- Charles Tobias in US</td>
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Center for Electrochemical Engineering Research (CEER)

**Mission**
- Develop solutions to global problems (sustainable energy, water, air) through an electrochemical approach
- Educate future generations of experts in electrochemistry and electrochemical technologies
- Be a resource to industry and government on policy issues where electrochemical technologies can provide solutions
- Disseminate scientific knowledge on electrochemistry and electrochemical technologies
- Contribute to economic growth (local, regional, and national)

**Organization**
- Advisory board: 12 experts and leaders from industry, academia and national laboratories
- CEER team: 38 (faculty, research professors, scientists, project managers, engineers, technicians, students)
CEER and ChE-4520/5520

** faculty members

**Kevin Beverage**
- 14 years of industry experience in PEM fuel cells and H2 systems
- 6 Patent applications for cell designs, seals, and system operation
- Experience in active area scale-up and performance optimization

**Dr. Dongmyung Suh**
- Industry, National Lab, and University experience
- 30 Fuel Cell / Hydrogen System Patents
- Thermal, transport, and process modeling experience

**Dr. Samgopiraj Velraj**
- Ph.D. in Material Science
- 4 years of experience with catalyst synthesis and electrode fabrication for metal-air batteries in alkaline media
- Experience in electrode processing and application-focused test techniques

**Dr. Yuxuan Wang**
- Ph.D. in Material Science and Engineering
- Experience in structure/property relationships of nanomaterials
- Advanced analytical techniques and microscopy such as in-situ electrochemical TEM

**Dr. Dan Wang**
- Ph.D. in Chemistry
- Experience in advanced material synthesis including nanostructured transition metal oxides/hydroxides, carbon nanotube and graphene-metal nanocomposites

**Dr. Madhivanan Muthuvel**
- Ph.D. in Chemistry
- Experience in electrochemical deposition, catalyst development, and electroanalytical techniques

**Dr. Zhefei Li**
- Ph.D. in Materials Science
- Experience in synthesis of advanced functional nanomaterials for energy storage and conversion
- Extensive experience with interpreting analytical data and materials characterization

**Vision of Growth**

**Industrial Park**

**Center for Electrochemical Engineering Research**

**Educational emphasis**
- Combines academic excellence with business-oriented training
- Leadership
- Team work and interdisciplinary approach
- Safety
- Business/financial skills
- Communication skills
- Professionalism and ethics
- Intellectual property
- Entrepreneurial skills
Center for Electrochemical Engineering Research

Approach
- Rapid Evaluation and Prototyping
- Design, Synthesis, Characterization of Materials
- Water sustainability
- Fast Transfer of Technology/Manufacturing
- Electrodess, electrolytes, membranes, separators
- Process and Systems Modeling
- First principles, multiscale modeling, economic models, life-cycle

Examples of Research Integration and Development

CEER in action
- Multi-scale Modeling
- In-situ Electrochemistry
- X-ray Spectra in the presence of 5M KOH and 1M Urea

Electrochemical Engineering Worldwide

Research Centers
Our market research has concluded that there are only nine electrochemistry or electrochemical engineering institutes/centers worldwide (including the Center for Electrochemical Engineering Research at Ohio University).

Only 5 in the US

4 in the rest of the world
Electrochemical Engineering Worldwide

- 4 Centers outside of the US
  - Materials not engineering
  - Non is not academic (non-profit)
- 5 Centers in the US
  - 1 is focused on basic science
  - 3 are housed in chemistry
- 2 are housed in engineering
  - CEER
  - Center for Electrochemical Engineering Research (CEER, Ohio University)

Centers outside of the US:
- 1 focused on corrosion
- 1 focused on fuel cells and batteries
- 1 holistic approach with emphasis on economic growth

Centers in the US:
- 1 on basic science
- 3 are housed in chemistry and/or materials
- 1 is non-academic (non-profit)
- 1 outside of the US

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State-of-the-Art Research Facilities

$7M + in research and instrumentation and over 20,000 ft^2

- In situ electrochemical dynamics characterization
- Prototype fabrication
- Multiscale modeling

Technology IP

- Ammonia and Urea Electrolysis
- Water Remediation
- Hydrogen Production
- Advanced Electrochemical Sensors
- Carbon-Titanate Nanomaterials
- Efficient Recovery of Metals
- Efficient Planting
- Nanotubes
- Nanosheets
- Graphene
- Carbon Nanostructures

Technology under development – available for licensing: 20 issued patents, 30 pending
Summary

- Electrochemistry
- Electrochemical Engineering
- What is an electrochemical system?
- Major applications of electrochemistry