Lecture #13 Modeling of Hydro-Electrometallurgical Processes

Goal

This lecture introduces the modeling principles of hydro-electrometallurgical processes, which involve metal extraction, purification, and recovery from aqueous media using electrochemical methods. Students will learn how to model electrode reactions, mass transport, overpotential behavior, and deposition rates in industrial systems such as copper recovery and nickel electroextraction.

Hydro-electrometallurgy involves the use of aqueous solutions to extract and recover metals via electrochemical processes. These processes are integral to industries producing high-purity metals and alloys. Modeling such processes provides insights into reaction kinetics, mass transport, and energy efficiency.

This lecture focuses on modeling hydro-electrometallurgical processes, with examples of copper electrochemical recovery and nickel electroextraction. Key modeling considerations include electrolyte composition, electrode surface reactions, and transport phenomena.

Copper Electrochemical Recovery

Copper recovery from industrial waste streams or leach solutions is a critical process for sustainable resource management. The electrochemical reactions occur at the cathode and anode, as shown below:

- Cathode reaction: $Cu^{2+} + 2e^- \rightarrow Cu(s)$
- Anode reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

Key equations for modeling copper recovery include:

1. Nernst Equation: Determines the equilibrium potential as a function of Cu^{2+} concentration.

$$E = E^0 - (RT/2F) \ln(C_{Cu^{2+}})$$

2. Butler-Volmer Equation: Models current density (i) based on overpotential (η):
$i = i_0 [\exp(\alpha F\eta/RT) - \exp(-\beta F\eta/RT)]$

Mass transport is modeled using Fick's law for diffusion and convective contributions in stirred systems:
$\partial C/\partial t = D \nabla^2 C - (v \cdot \nabla C)$

Nickel Electroextraction

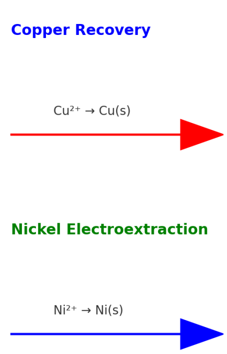
Nickel electroextraction involves recovering nickel from aqueous solutions, typically containing nickel sulfate ($NiSO_4$). The electrochemical reactions are:

- Cathode reaction: $Ni^{2+} + 2e^- \rightarrow Ni(s)$
- Anode reaction: $H_2O \rightarrow ½O_2 + 2H^+ + 2e^-$

Key factors for modeling include:
1. Electrodeposition rate, modeled as:
$m = (M_i / zF) \int i\, dt$
where m is the mass of deposited metal, M_i is the molar mass, z is the number of electrons, and F is Faraday's constant.
2. Mass transport, affected by diffusion and migration in the electrolyte.

An additional consideration is the effect of impurities, which can alter electrode kinetics and deposition morphology.

Illustration: Hydro-Electrometallurgical Processes



The schematic illustrates the electrochemical reactions involved in copper recovery and nickel electroextraction. These processes are characterized by electrode reactions and transport phenomena in the electrolyte.

Summary

Modeling hydro-electrometallurgical processes provides valuable insights into the reaction kinetics, mass transport, and energy efficiency of metal recovery systems. Copper electrochemical recovery focuses on reducing Cu^{2+} to Cu, while nickel electroextraction involves reducing Ni^{2+} to Ni. Understanding these processes is critical for optimizing industrial operations and improving sustainability.

Learning Outcomes

By the end of this lecture, students will be able to:

1. Explain the fundamental electrochemical reactions involved in hydro-electrometallurgical systems (related to LO 4, ID 4.4–4.7).

2. Apply the Nernst equation and Butler–Volmer kinetics to model copper and nickel electrodeposition (related to LO 4, ID 4.4).

3. Formulate mass transport equations (diffusion, convection, migration) for aqueous metal-ion systems (related to LO 4, ID 4.5–4.6).

4. Model electrodeposition rate and metal recovery efficiency using Faraday's law (related to LO 4, ID 4.6).

5. Analyze the influence of impurities, hydrodynamics, and electrolyte composition on electroextraction performance (related to LO 4, ID 4.7).

6. Evaluate hydro-electrometallurgical systems for industrial applications in metal recycling and purification (related to LO 4, ID 4.7).

Questions and Self-Study Assignments

1. Write the cathode and anode reactions for copper and nickel electrodeposition.

2. Use the Nernst equation to calculate equilibrium potential for Cu^{2+} at 0.05 M.

3. Derive the mass transport equation including convection for a stirred tank reactor.
4. Explain how impurities influence nickel electrodeposition kinetics.
5. Using Faraday's law, calculate the mass of nickel deposited at 2 A for 30 minutes.
6. Review a recent article (≤3 years) on electrochemical recovery of Cu or Ni. Summarize:
- modeling approach
- governing equations
- main findings

References

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— Chapters on diffusion, reaction kinetics, and modeling of multiphase processes.
2. Newman, J., & Thomas-Alyea, K. Electrochemical Systems. 3rd ed. Wiley, 2004.
— Fundamental theory of electrochemical processes, porous electrodes, and metal deposition.
3. Pletcher, D., & Walsh, F.C. Industrial Electrochemistry. Springer, 1993.
— Classic reference on electrochemical metal extraction, electrorefining, and electro-winning (Cu, Ni).