Modeling Galvanic Corrosion

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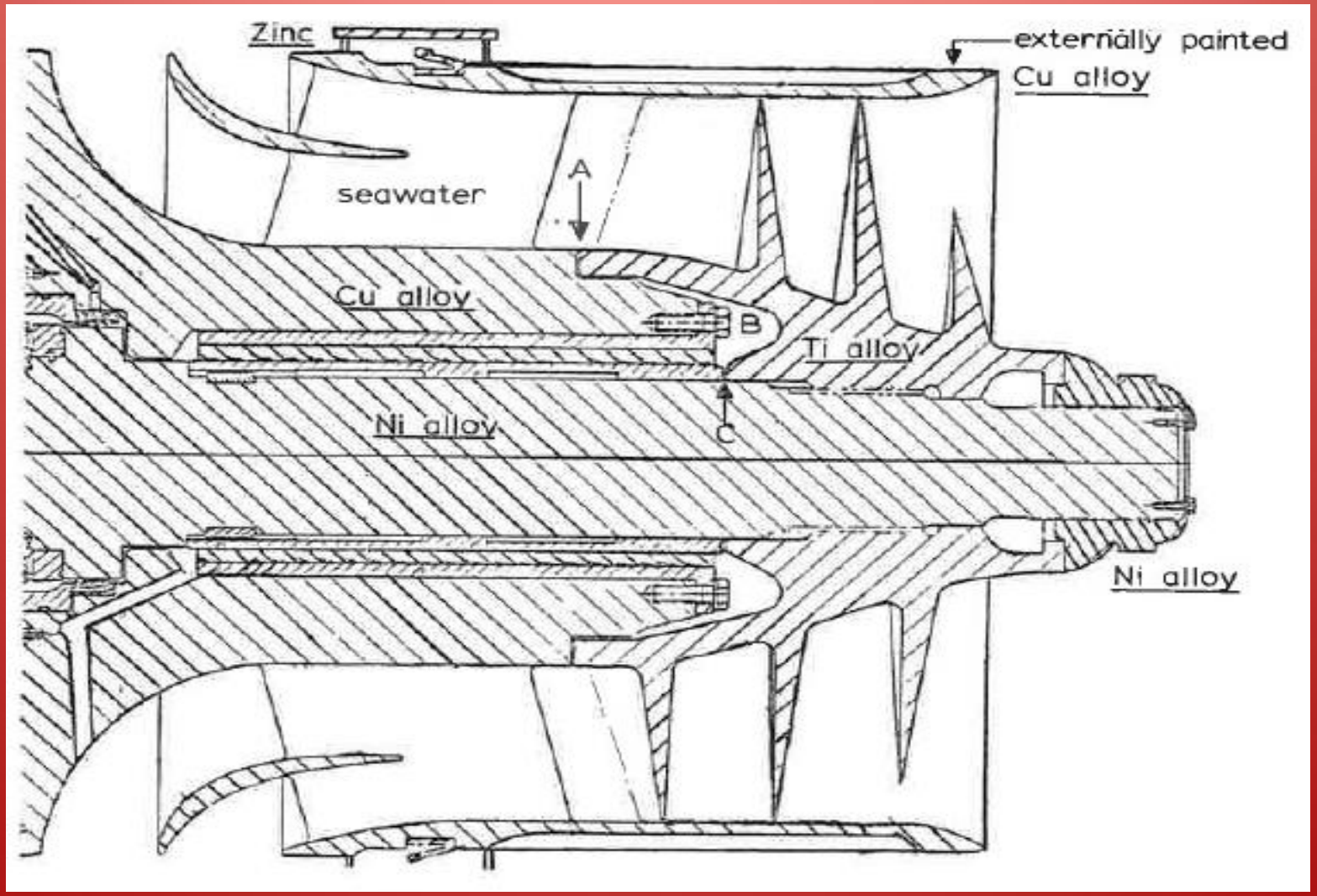
Motivation: Marine Propulsion Systems



Corrosion Facts

- Corrosion costs up to 5% of a nation's GDP
- Corrosion Types
  - Uniform
  - Pitting
  - Crevice
  - Intergranular
  - Flow Assisted
  - Galvanic
- Elements of a Corrosion System
  - Electrodes (Cathode and Anode - Metallic)
  - Electrolyte (Aqueous Solution)
  - Electrode-Electrolyte Interfaces
- The science of Electrochemistry is used to study corrosion

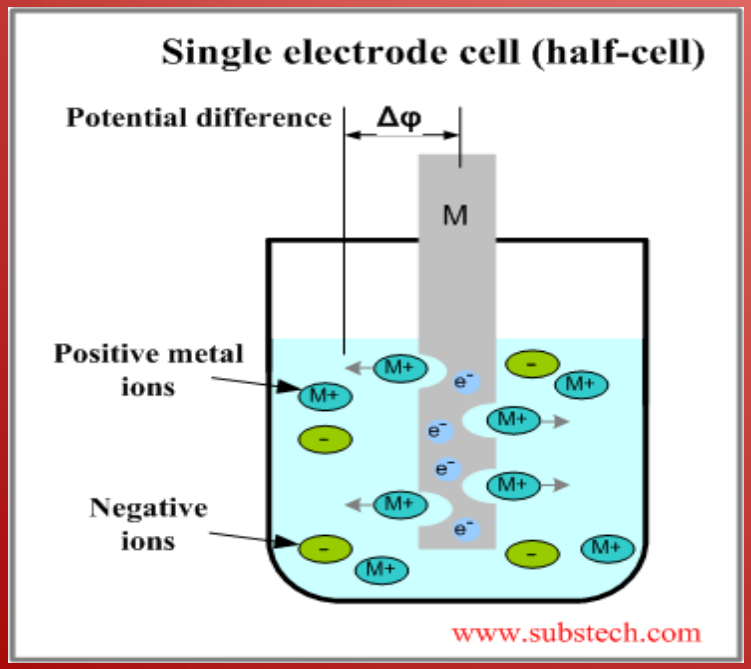
Electrode Thermodynamics

- RedOx Reaction at an Electrode-Electrolyte Interface

$$Ox + ne \leftrightarrow Red$$

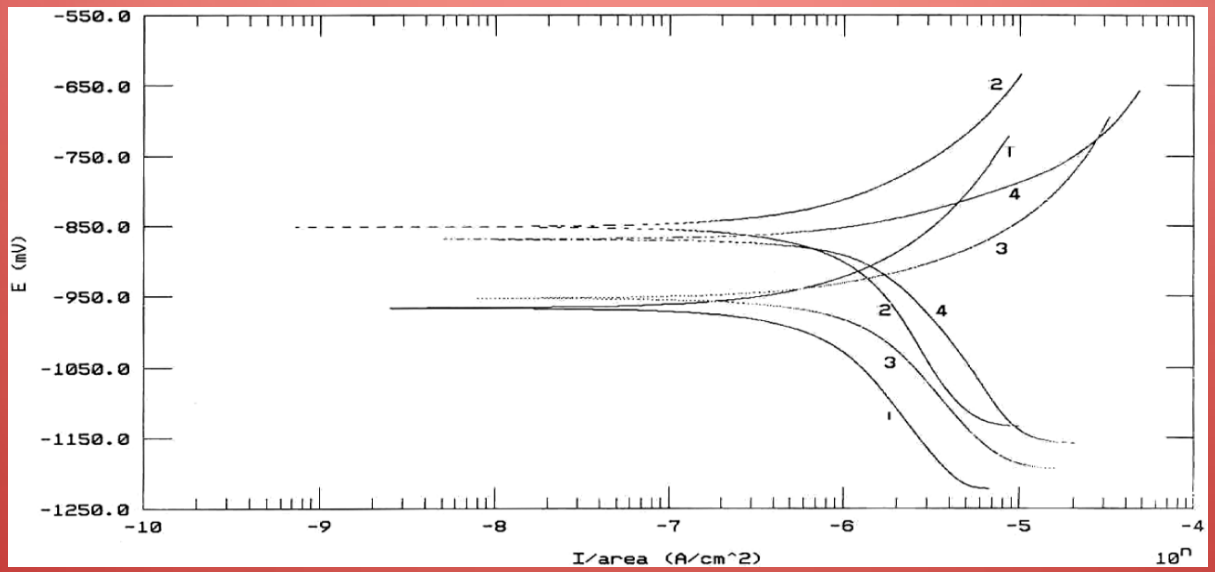
- Single Electrode Potential (equilibrium -Nernst)

$$E = E^0 + (RT/zF) \ln (a_{Red}/a_{Ox})$$



Electrode Kinetics

Electrode polarization takes place when E is induced to move away from E^0 . The metal can thus become more noble or more reactive depending on the polarization direction



- The Butler-Volmer Equation relates current density at the interface **i** to **E**

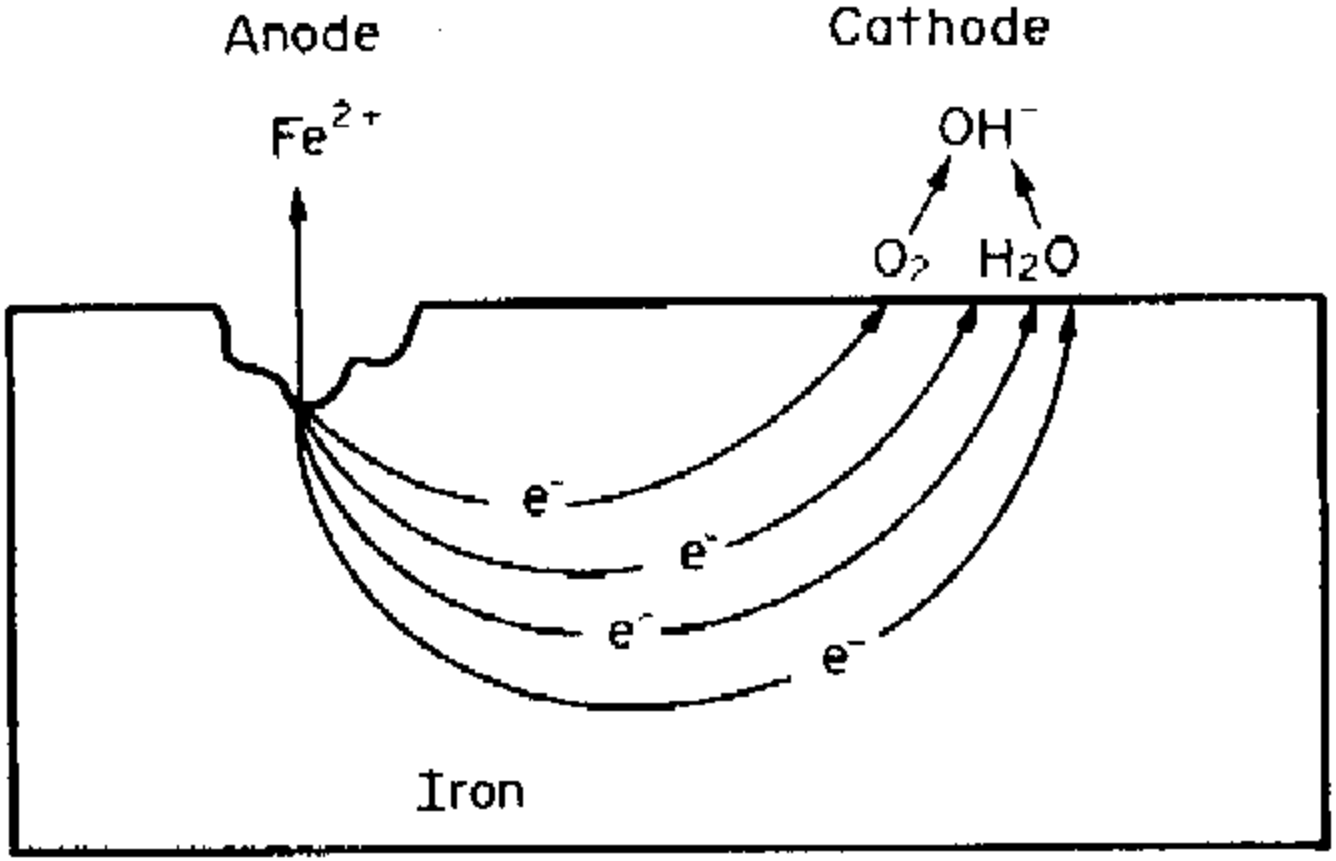
$$i = i_o \left[\exp(\alpha_a z F (E-E^0) /RT) - \exp(-\alpha_c z F (E-E^0)/RT) \right]$$

- Once the current density **i** has been determined, Faraday's Law gives the reaction rate

$$v = i/zF \quad (\text{mol/m}^2\ \text{s})$$

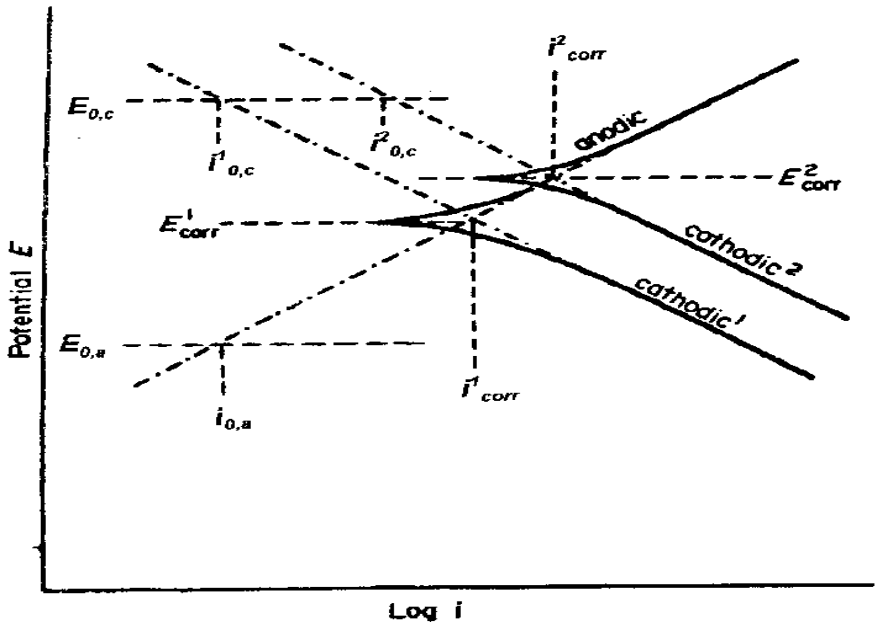
Pitting Corrosion of Iron

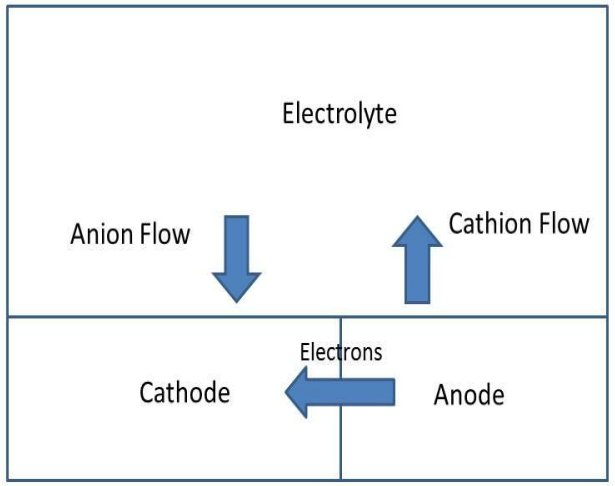
(Anode and Cathode in different regions of the same material)



Galvanic Corrosion

(Anode and Cathode in entirely different materials)

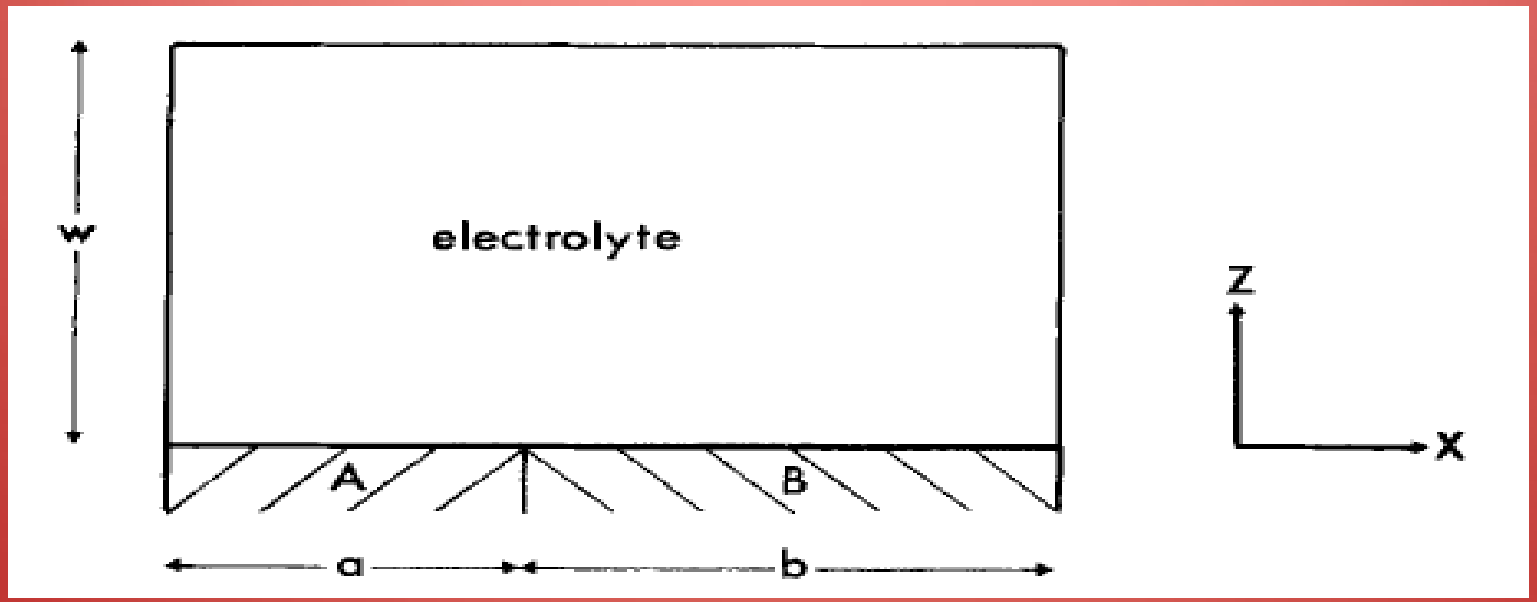




At the anode, metal atoms give up electrons and convert into electrolyte ions. This process is called oxidation.

At the cathode, ions from the electrolyte take up electrons and transform metal atoms or into something else. This process is called reduction.

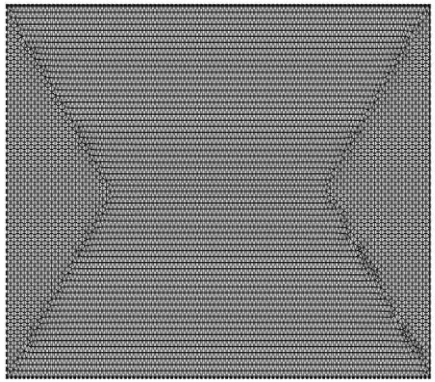
Prior Galvanic Corrosion Modeling

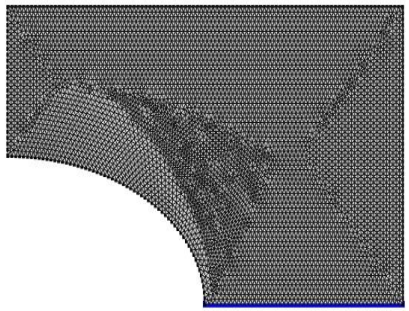


- Laplace's Equation (steady state conditions; flow in the electrolyte neglected)
- Waber (J. Electrochem. Soc. 1954) Series Solution
- Doig-Flewitt (J. Electrochem. Soc. 1979) FDM (SOR)

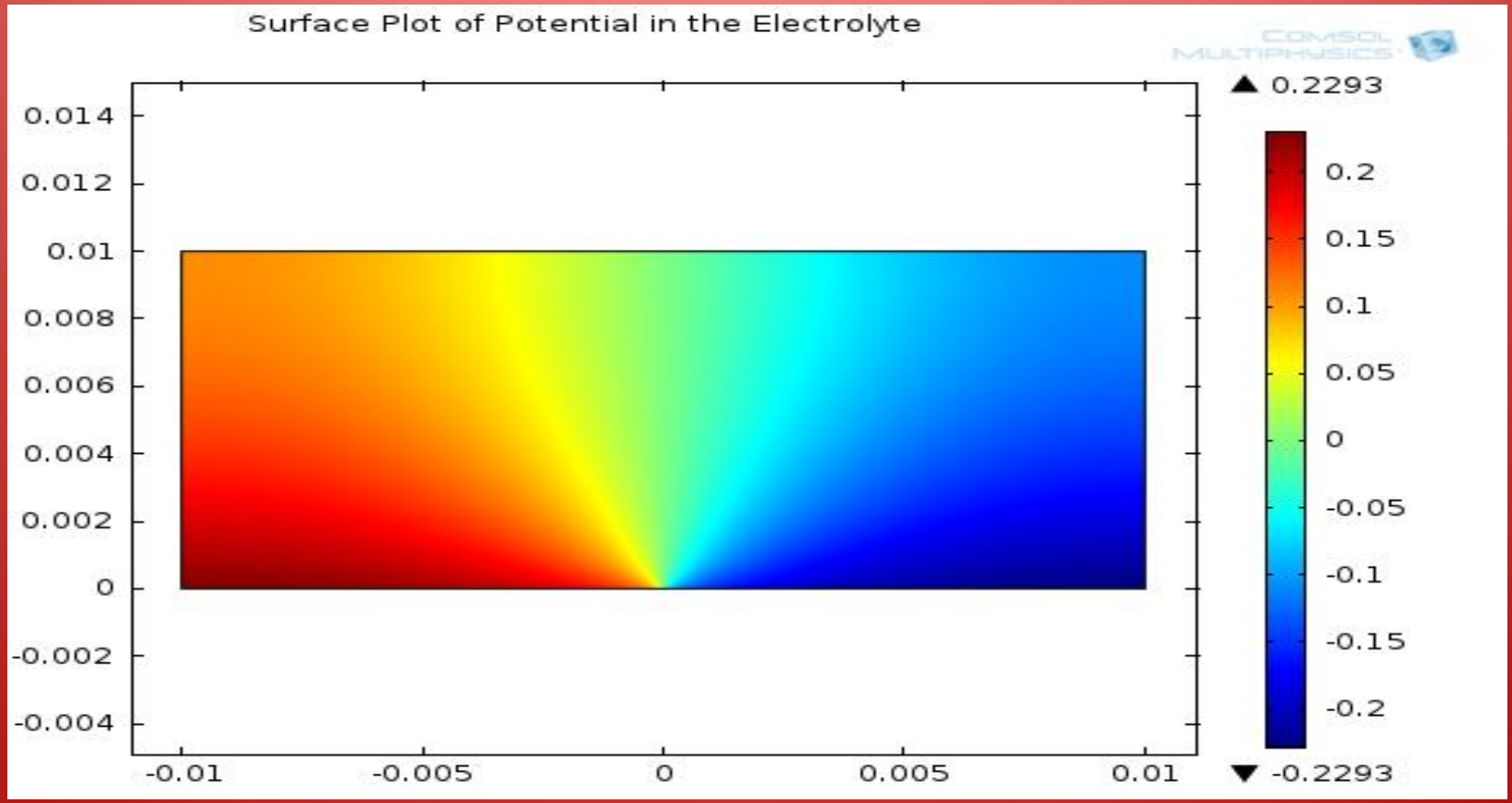
Galvanic Corrosion Modeling in COMSOL

- Math Module, Coefficient Form PDE
- Co-planar electrodes ; Other Geometries

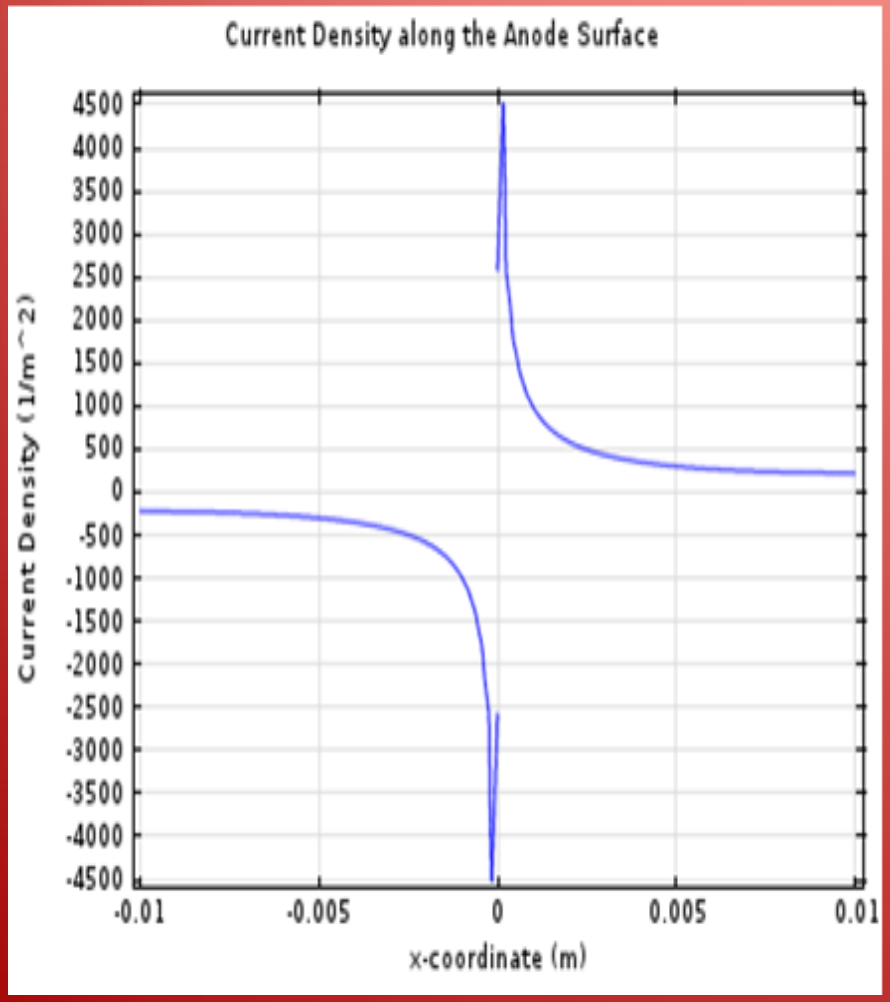


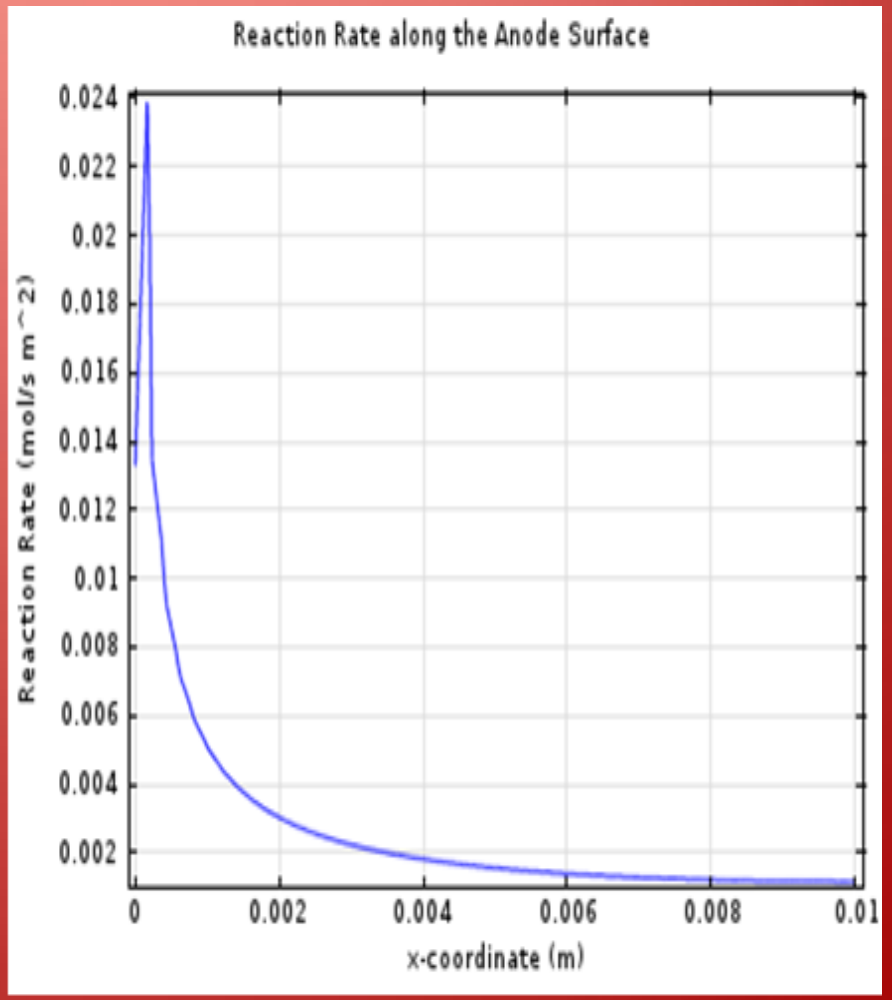


Waber-Doig-Flewitt Test Problem

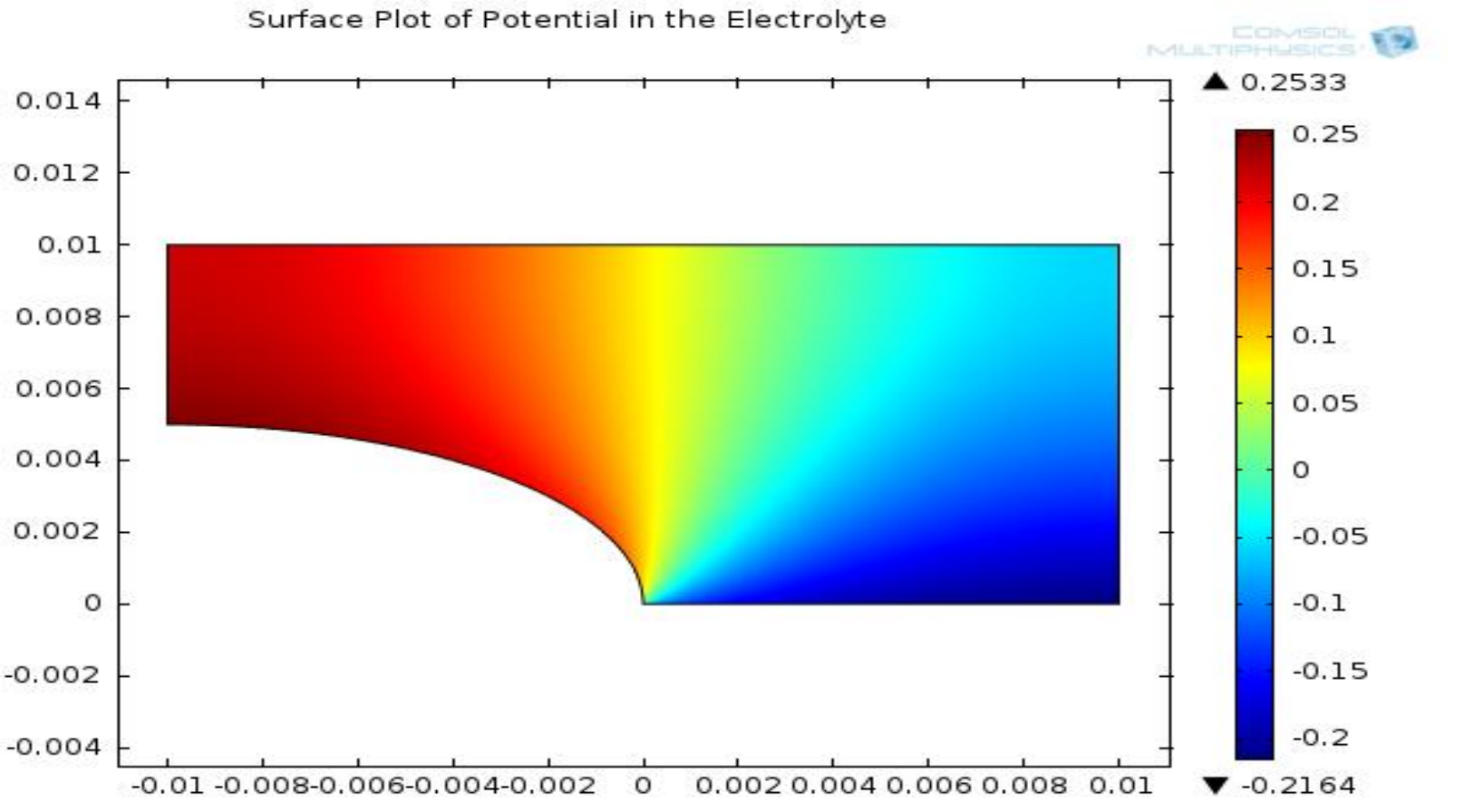


Current Density and Reaction Rate





Elliptical Step



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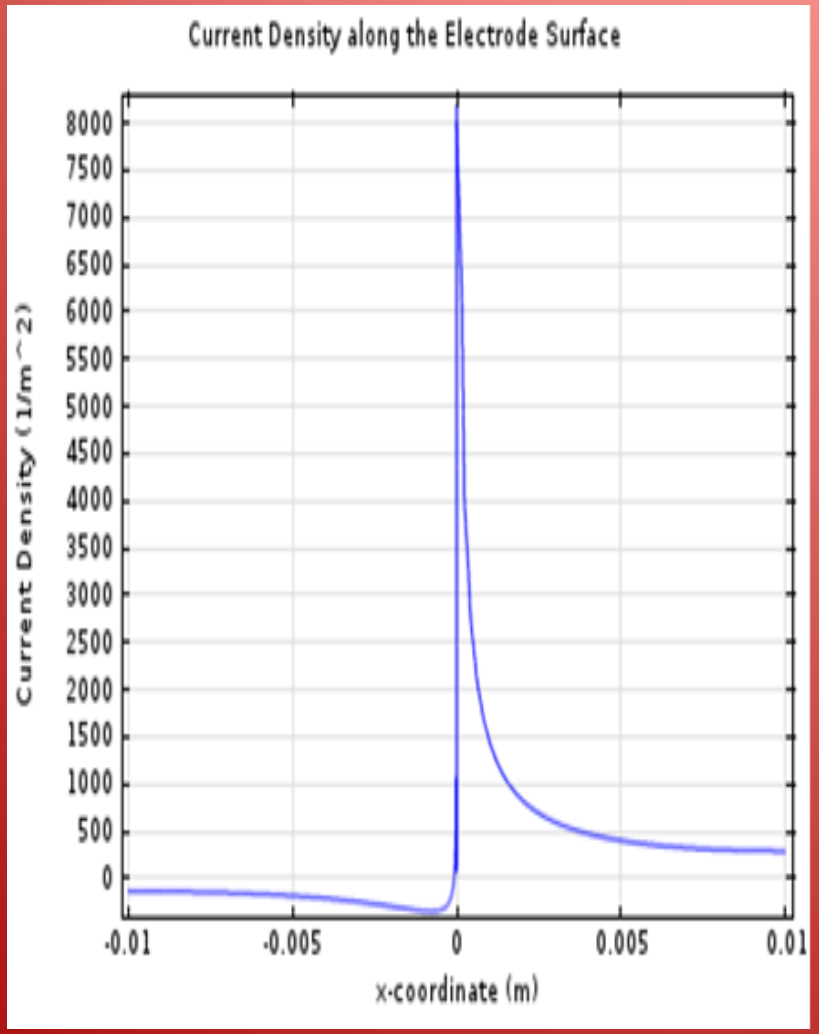
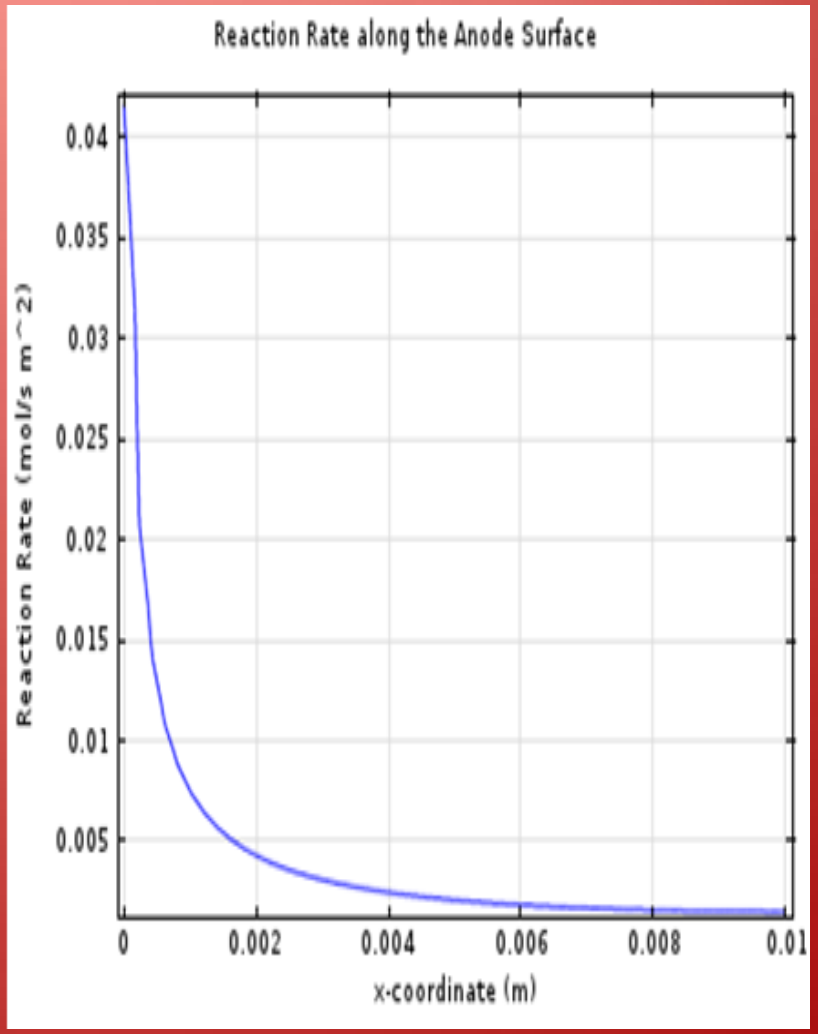
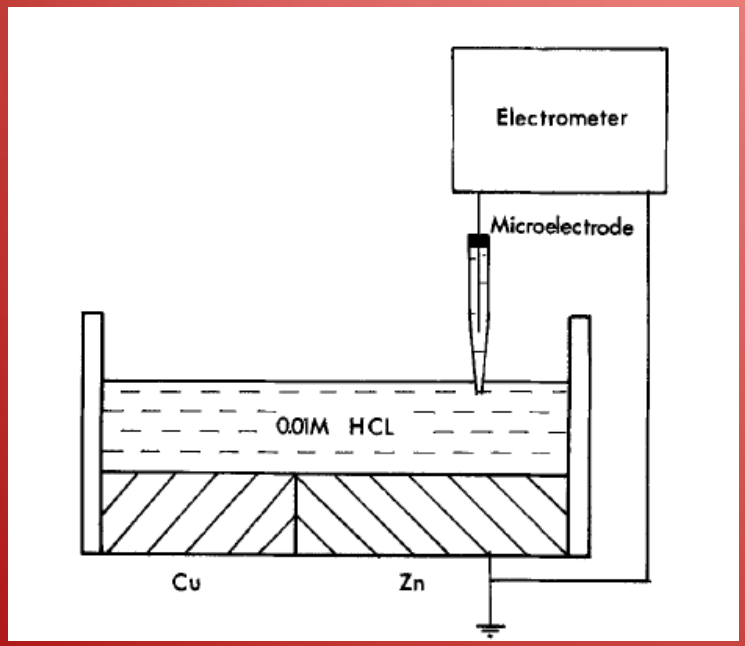
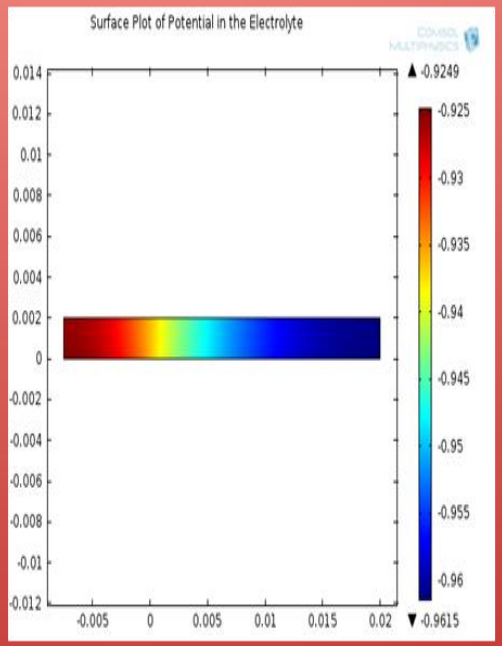
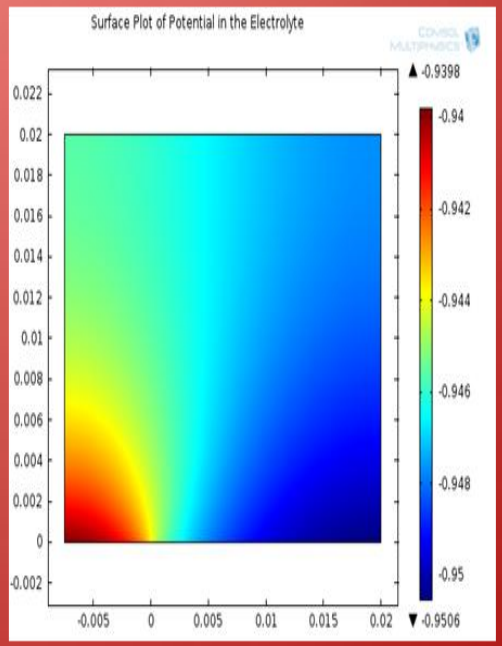




Cu-Zn Galvanic Couple







Summary

- Accurate Models of Galvanic Corrosion Systems can be created using COMSOL
- Solutions to simple two-dimensional sample problems have been investigated and validated.
- Extensions to realistic corrosion configurations are straightforward and worth pursuing.
- Fluid motion and moving boundary effects introduce complexity