PRELIMINARY STUDY: MOISTURE-POLYMER INTERACTION
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Study Objectives

To develop methodology for predicting module temperature, humidity and surface moisture level versus time in field environment

- Water sorption
- Moisture diffusion
- Simulation using SOLMET weather tape

To apply the above temperature-moisture prediction methodology together with electrochemical corrosion temperature-moisture dependence to predict module corrosion lifetime in the field

Simulation Flow Diagram
Sorption Study

- **Objective**
  - To establish an analytical model for predicting moisture sorption isotherms for relevant polymers

- **Approach**
  - Gravimetric measurements using a Cahn balance
  - Isothermal system: humidity chamber
  - Relative humidity from 40% to 95%, no liquid water
  - Data fitting with an analytical model (modified B.E.T. equation)

### Water Sorption for PVB

![Graph showing water sorption for PVB](image-url)

- Fitting with modified B.E.T. Model
- Relative Humidity:
  - A - 40°C
  - B - 55°C
  - C - 70°C
  - D - 80°C
Water Sorption Isotherms

Modified B.E.T. Model for PVB

- **Status**
  - Limited samples were used (PVB)
  - Reasonable data fitting with a modified B.E.T. equation

- **Required R&D**
  - Expanded sorption data base for different materials, composite layers and conformal coatings
  - Sorption-desorption in non-isothermal conditions
  - Kinetics and thermodynamics of adsorption/absorption (both liquid and vapor water)
  - Factors influence moisture sorption in polymer; plasticizer, cross-linking agent
  - Free-to-bound water transformation
Moisture Diffusion

- **Objective**
  - To develop a moisture transport model and diffusion/permeation parameters

- **Approach**
  - Transient experimental data based on sorption measurements
  - Nodal network representation of Fick's diffusion model
    - 100-layer model
    - Isothermal system
    - Parametric iteration of constant diffusivity levels
  - Determination of diffusivity based on transient data
  - To establish equations to correlate diffusivity/permeability as a function of temperature and moisture content

- **Status**
  - Diffusivity increases with moisture content in PVB
  - Arrhenius-type variation with temperature
  - Good correlations between data and model

- **Required R&D**
  - Moisture diffusion in composite encapsulants
  - Diffusion of unbound water
    - Bulk water movement
    - Transition of bound and unbound water
    - Apparent diffusivity
  - Non-isothermal system
    - Models for simultaneous heat and mass transfer
    - Thermal diffusion
  - Factors affecting moisture diffusion and permeation
Moisture Sorption-Desorption

PVB RH: 85%-95%-85%

Sample Weight (grams)

Time (hrs)
Diffusivity Simulation at 55°C

Moisture in PVB RH 85%-95%-85%

Gross Sample Weight (Grams)

Time (Hrs)

A — 3E-4  B — 2E-4  C — 1.5E-4  D — 1E-4  E — 0.5E-4
Diffusivity of Moisture in PVB

Function of T and C

Concentration (mg of water/gm of PVB)

- 20°C
- 40°C
- 55°C
- 70°C
Bulk Conductivity of PVB

![Graph showing bulk conductivity of PVB with moisture content and temperature]  

**Electrochemical Corrosion**

- **Objective**
  - To simulate module leakage current vs time in operating environment

- **Approach**
  - Construct preliminary analytical model
    - Conduction across encapsulant
    - No surface resistance, no lateral volumetric conduction
    - Include equations for sorption and diffusivity
    - Nodal network analysis using thermal analyzer SINDA
    - Equation to represent bulk ionic conductivity as a function of temperature and moisture content
  - Exercise model with transient chamber boundary conditions
  - Exercise model with SOLMET field data
Moisture Content, PVB

55 C, RH % 42-64-85-95-85-64-42

Average Concentration (mg Water/gm PVB)

Time (hours)
Normalized Leakage Current

55 C, RH % 42-64-85-95-85-64-42

A — Measurement  Time (hours)  B — Simulation
Temperature Profiles

(Near Miami, August 1963)

- A: Dew Point
- B: Dry Bulb
- C: Module Temp.

Temperature (Degrees C)

0 4 8 12 16 20 24 28 32 36 40 44 48

15 20 25 30 35 40 45 50 55 60 65

Time (hrs)
Vapor Pressure and Relative Saturation

Miami August 1963

A — Pv mm Hg  B — RS In air  C — RS In Module

Time (hrs)
Concentration Distribution

Moisture in 5 mil PVB Encapsulant

Moisture in 50 mil PVB Encapsulant

Distance from Surface (mil)

Concentration (mg water/gm PVB)

213
Leakage Current in Field

5 mil PVB Encapsulant

Relative Leakage Current

Time (hrs)

A - Unsealed
B - No Moisture
C - Sealed @22°C 70% RH
Charge Transfer in Field

5 mil PVB Encapsulant

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A - Unsealed
B - No moisture
C - Sealed @ 22°C, 70% RH

50 mil PVB Encapsulant

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A - Unsealed
B - No moisture
C - Sealed @ 22°C, 70% RH
Summary

- Realistic lifetime prediction appears to be feasible
- Refinements in prediction techniques are required
- Research areas:
  - 2-dimensional ionic conduction model
  - Composite layers
  - Non-isothermal system
  - Effects of liquid water
  - Interfacial adsorption/absorption