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
RELIABILITY PHYSICS

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 with fitted B.E.T. model](image-url)
Water Sorption Isotherms

**Modified B.E.T. Model for PVB**

- **Moisture Content (mg water/gm PVB)**
- **Vapor Pressure (mm Hg)**

### Moisture Sorption

- **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%
Diffusivity Simulation at 55°C

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

Gross Sample Weight (Grams)

0 2 4 6 8

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)

$D \times 10^{-4}$ cm$^2$/hr
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
Temperature Profiles

(Miami, August 1963)

A — Dew Point  
B — Dry Bulb  
C — Module Temp.

Time (hrs)  Temperatures (Degrees C)
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

Concentration (mg water/gm PVB)

Distance from Surface (mil)

Moisture in 50 mil PVB Encapsulant

Concentration (mg water/gm PVB)

Distance from Surface (mil)
Leakage Current in Field

5 mil PVB Encapsulant

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

Relative Leakage Current

Time (hrs)

0 2 4 6 8 10 12 14 16 18 20 22 24
Charge Transfer in Field

5 mil PVB Encapsulant

Relative Charge Transfer

Time (hrs)

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

50 mil PVB Encapsulant

Relative Charge Transfer

Time (hrs)

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