N87-16441

LEAKAGE-CURRENT PROPERTIES OF ENCAPSULANTS

JET PROPULSION LABORATORY

L. C. Wen

Study Objectives

- Establish reliability assessment methodology associated with module leakage current
  - Leakage current conduction model
  - Dynamic simulation of charge transfer in field conditions
  - Module design considerations
  - Accelerated chamber testing
- Establish leakage-current properties of encapsulant materials
  - Characteristics of ionic conductivity
  - Material property degradation
  - Recommendations for future investigations

Approach

- Quantify basic encapsulant properties associated with module leakage currents
  - Sorption isotherms
  - Ionic conductivities
- Develop generic models of module conduction including:
  - Bulk conduction
  - Surface conduction
  - Interface conduction
- Conduct sensitivity studies of relevant parameters
- Perform simulation analyses of leakage currents and charge transfer in field environments

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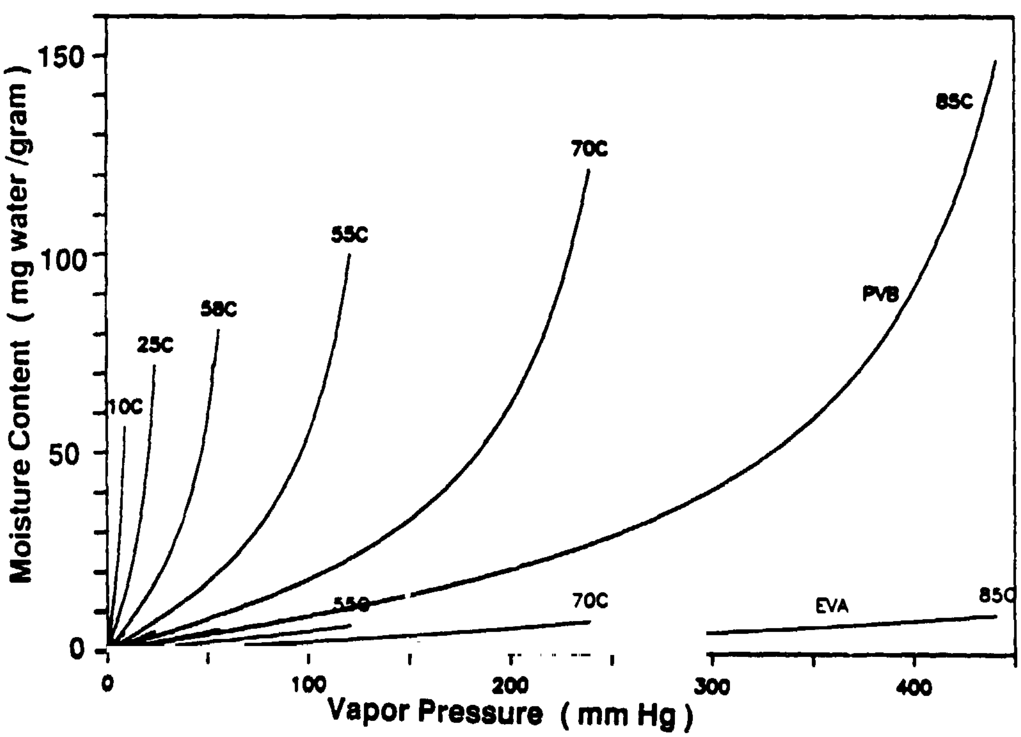
Water Vapor Sorption

- Sorption isotherms for pristine materials
    - Temperature/humidity
    - Manufacturing process
    - Lamination/curing process
- Thermal degradation
    - Severe plasticizer loss for PVB
    - Negligible effect on EVA
- Hydrolysis
    - Significant increase in water sorption capacity of EVA and PVB after exposure in high temperature, high humidity environments

Water Sorption Isotherms



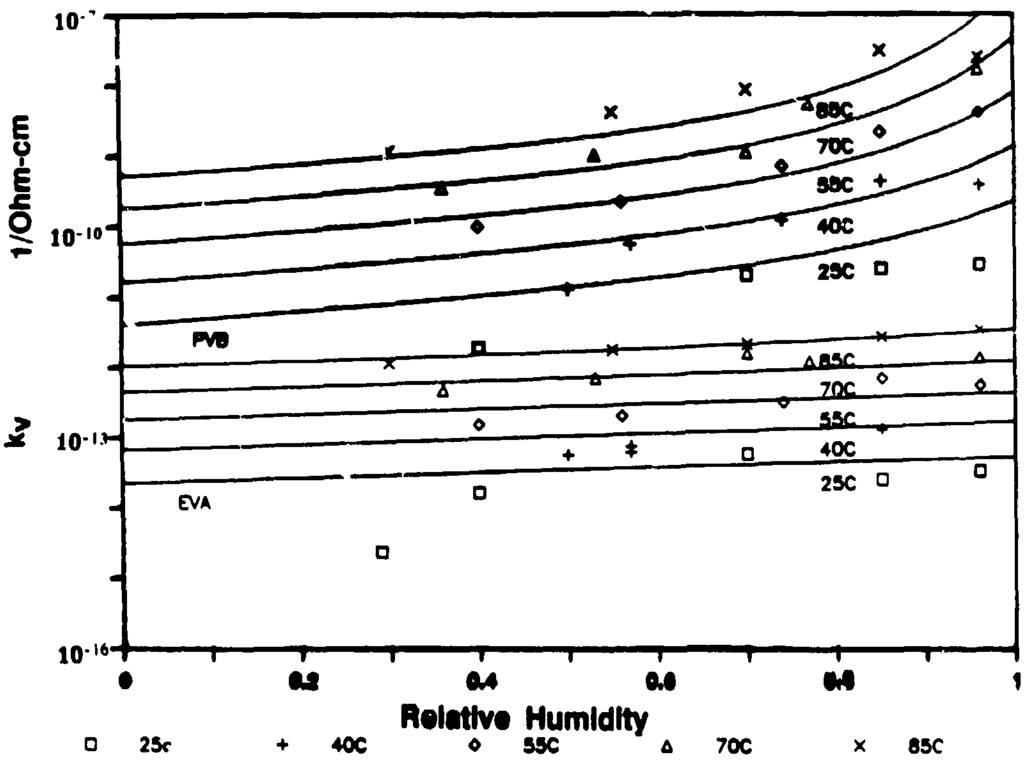
Bulk Conductivity: Theory

- Sensitive to both temperature and humidity level

$$K_V = M_V \, Exp \, [\, (-E_O/RT)(Z_p/Z_W)^C]$$

E_O = Activation energy
Z_p, Z_W = permittivity of polymer and water
R = Gas constant
T = Temperature (in absolute scale)
C = Moisture concentration
M_V = property constant

Bulk Conductivity: Measurements



Surface and Interface Conductivities: Theory

- Polymer surfaces

$$K_s = M_s \, Exp \, [\, (-E_s/RT)(\, 1 - RH\{ \, 1 - (Z_p/Z_w)\}]$$

- Glass surfaces

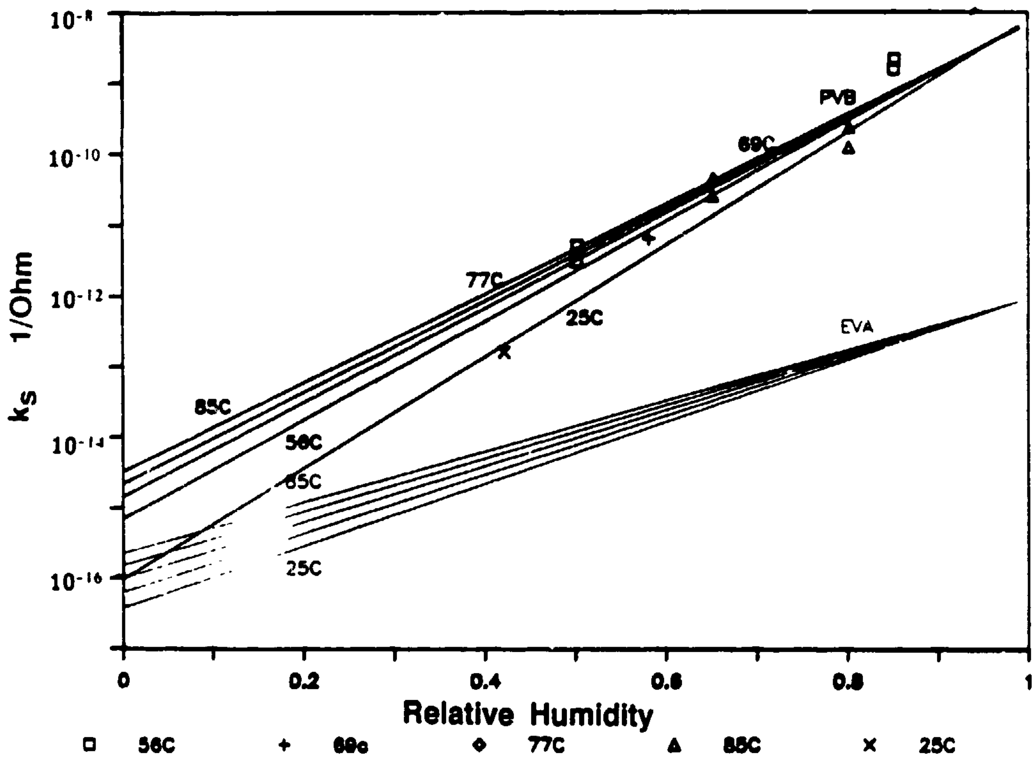
$$K_s = M_s \, Exp \, [\, (-E_s/RT)(\, 1 - \, y \, RH\{ \, 1 - (Z_g/Z_w)\}]$$

RH = Relative humidity
y = SURFACE MOISTURE factor
Z_g = permittivity of glass

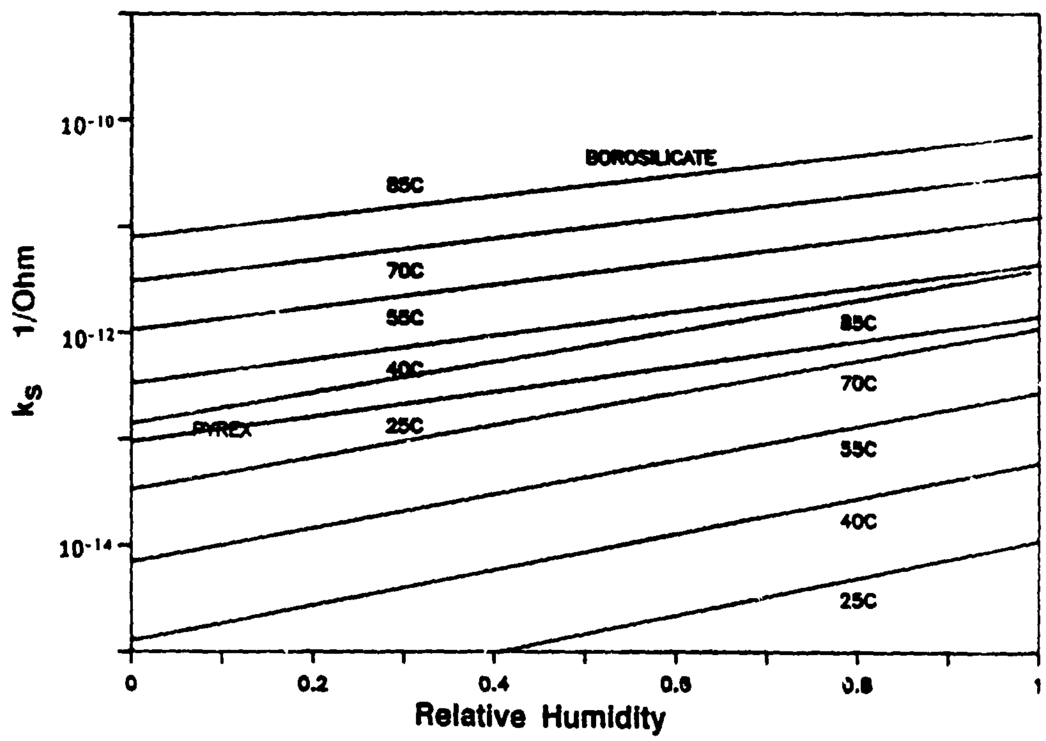
- Interfaces

$$K_i = K_{s1} + K_{s2}$$

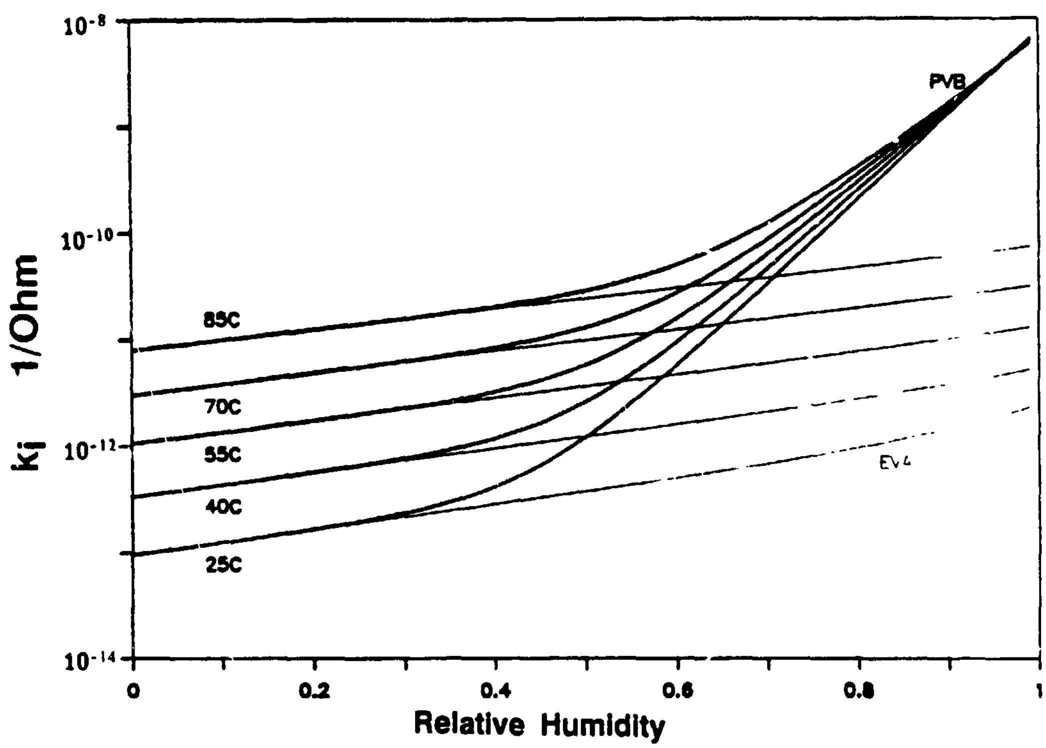
Surface Conductivity: PVB and EVA at Various Relative Humidities and Temperatures



Surface Conductivity: Borosilicate and Pyrex Glasses at Various Relative Humidities and Temperatures



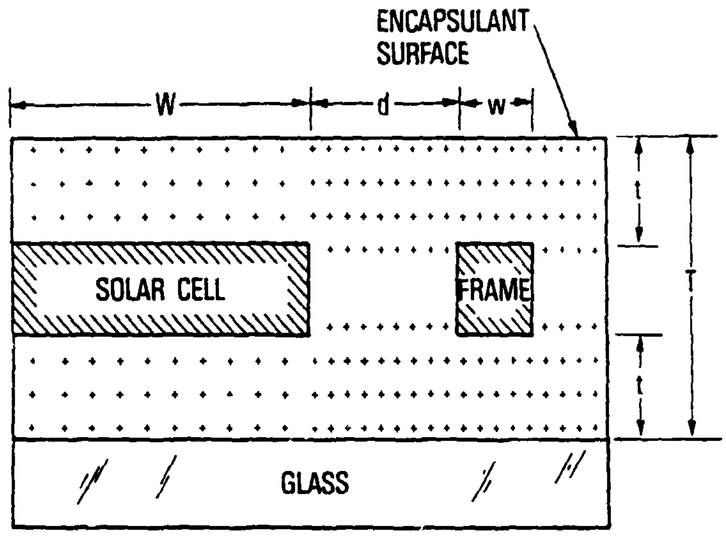
Interface Conductivity: Measurements of PVB and EVA



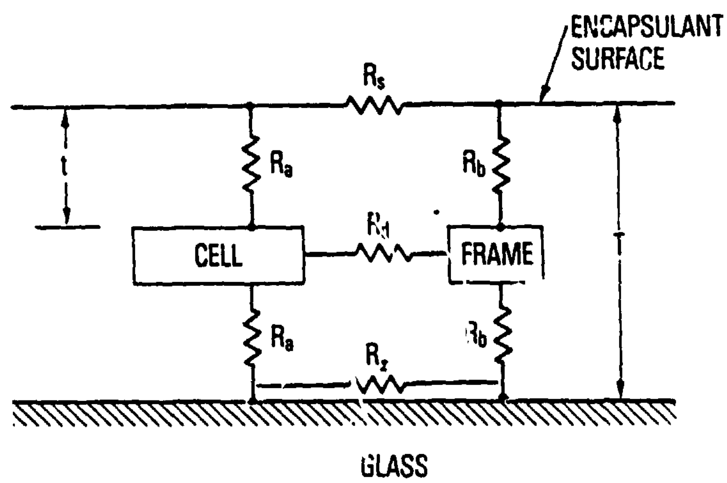
Leakage-Current Simulation

- 2-dimensional ionic conduction model
- Composite conductive paths
- Parametric study of the interplay of bulk, surface and interface conductivities
- Comparison with experimental results

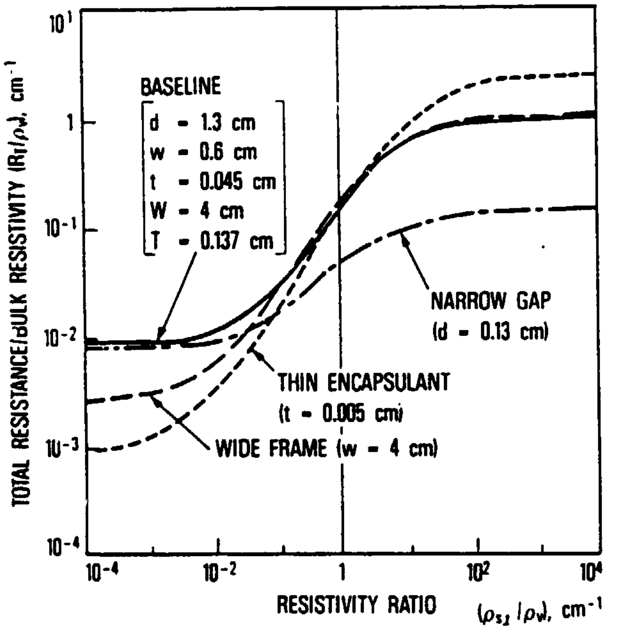
Cross-Sectional View of Test Coupons



Network Conduction Model



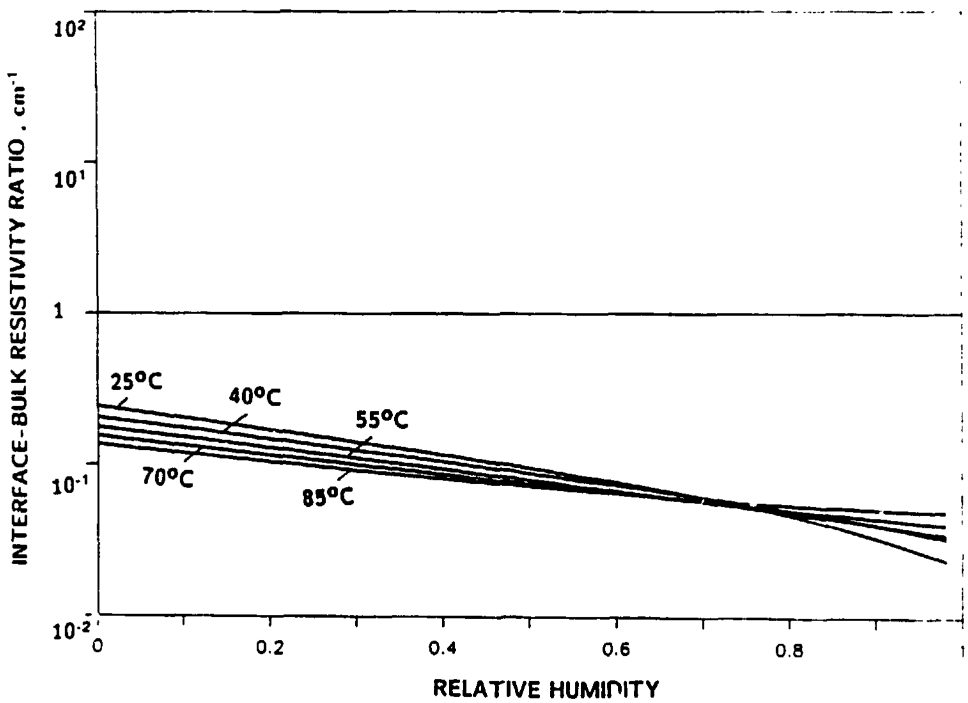
Ionic Conduction Characteristics



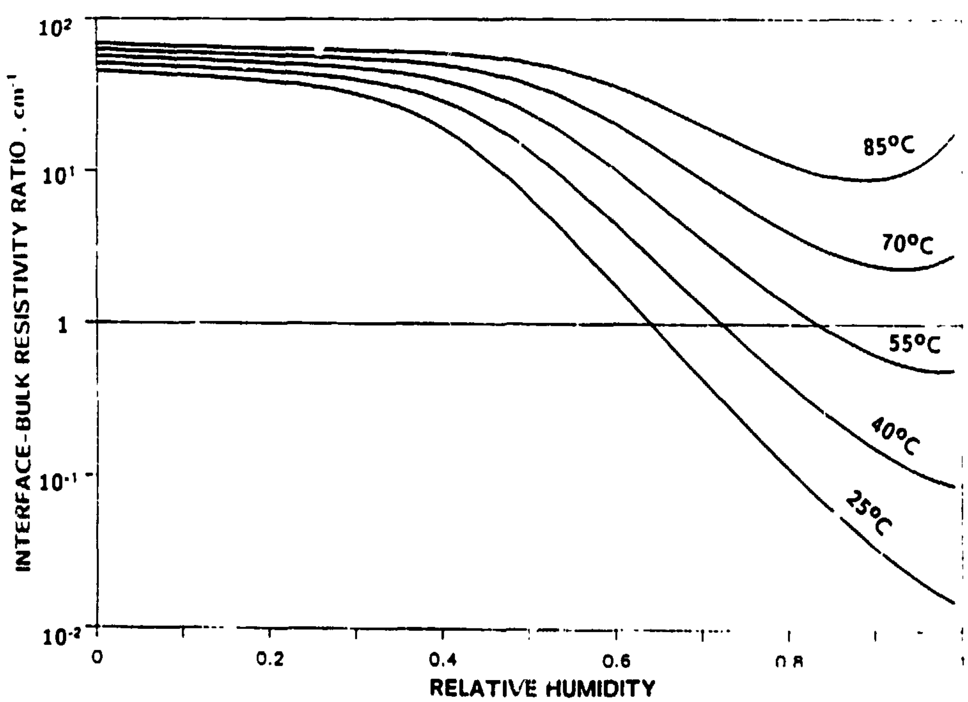
Ionic Conductivities and Their Temperature-Humidity Sensitivities

	Magnitude	Temperature sensitivity	Humidity sensitivity
• **Bulk encapsulants**			
• PVB	High	High	High
• EVA	Low	Modest	Low
• **Encapsulant free surface**			
• PVB	High	Very low	High
• EVA	Very low	Low	Modest
• **Encapsulant-glass interface**			
• PVB	High	Low	High
• EVA	Modest	Modest	Modest

EVA Resistivity Ratio



PVB Resistivity Ratio



Leakage-Current Sensitivity

- Exposed low-conductivity encapsulant (EVA)
  - Key contributor to module leakage-resistance is bulk resistivity of encapsulant between cell and interface
    - High temperature sensitivity
    - Low humidity sensitivity
- Exposed high-conductivity encapsulant (PVB)
  - Key contributors to module leakage resistance are resistivity of interfaces and free surfaces
    - Low temperature sensitivity
    - high humidity sensitivity
- Foil-protected encapsulant
  - Key contributor to module leakage-resistance is bulk resistivity of encapsulant between cell and foil
    - High temperature sensitivity
    - Humidity sensitivity depends on edge seal

Summary

- Have achieved fairly good fundamental understanding of leakage-current paths internal to module and their temperature-humidity sensitivities
- Evaluation of the acceleration factor between test chamber and field condition is a very complex process
- Research areas
  - Effect of liquid water versus water vapor
  - Effect of polymer aging on encapsulant sorption-conductivity properties
  - Non-isothermal and non-equilibrium conditions
    - Transient permeation of moisture
    - Non-equilibrium moisture states