Presented at the 2011 COMSOL Conference in Boston

CORNING

Science & Technology

Microwave drying of cellular ceramic substrates: A conjugate modeling approach to understand surface moisture migration

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09-28-2011

Corning Incorporated

Founded:
1851

Headquarters:
Corning, New York

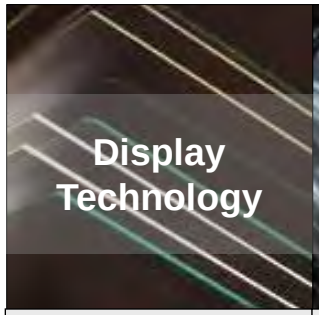
Employees:
~ 26,000 worldwide

2010 Sales:
$6.6 Billion

Fortune 500 Rank (2011):
350

- Corning is the world leader in specialty glass and ceramics.
- We create and make keystone components that enable high-technology systems for consumer electronics, mobile emissions control, telecommunications, and life sciences.
- We succeed through sustained investment in R&D, 160 years of materials science and process engineering knowledge, and a distinctive collaborative culture.

Corning Market Segments and Additional Operations

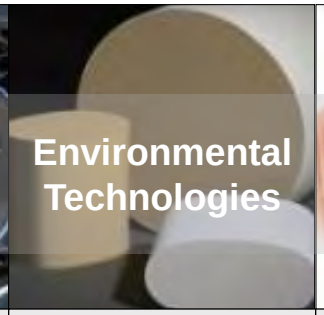


Display Technology

- LCD Glass Substrates
- Glass Substrates for OLED and LTPS-LCD

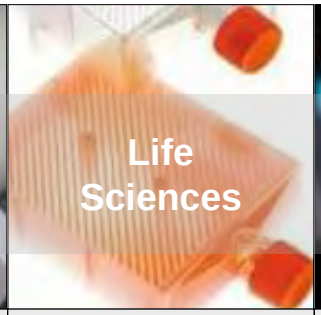
Telecom

- Optical Fiber & Cable
- Hardware & Equipment
  - Fiber optic connectivity products



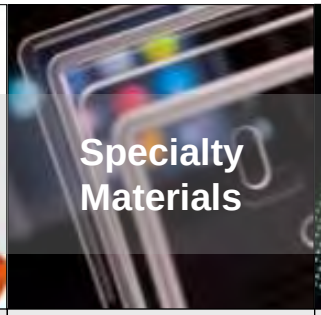
Environmental Technologies

- Emissions Control Products
  - Light-duty gasoline vehicles
  - Light-duty and heavy-duty on-road diesel vehicles
  - Heavy-duty non-road diesel vehicles
  - Stationary



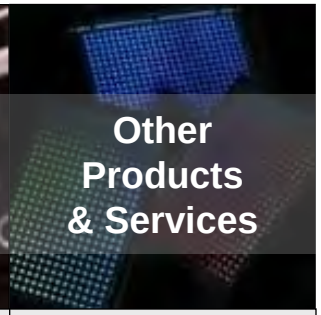
Life Sciences

- Cell Culture & Bioprocess
- Assay & High-Throughput Screening
- Genomics & Proteomics
- General Laboratory Products



Specialty Materials

- Corning® Gorilla® Glass
- Display Optics & Components
- Optical Materials
  - Semiconductor materials
  - Specialty fiber
  - Polarcor™
- Optics
- Aerospace and Defense
- Ophthalmic

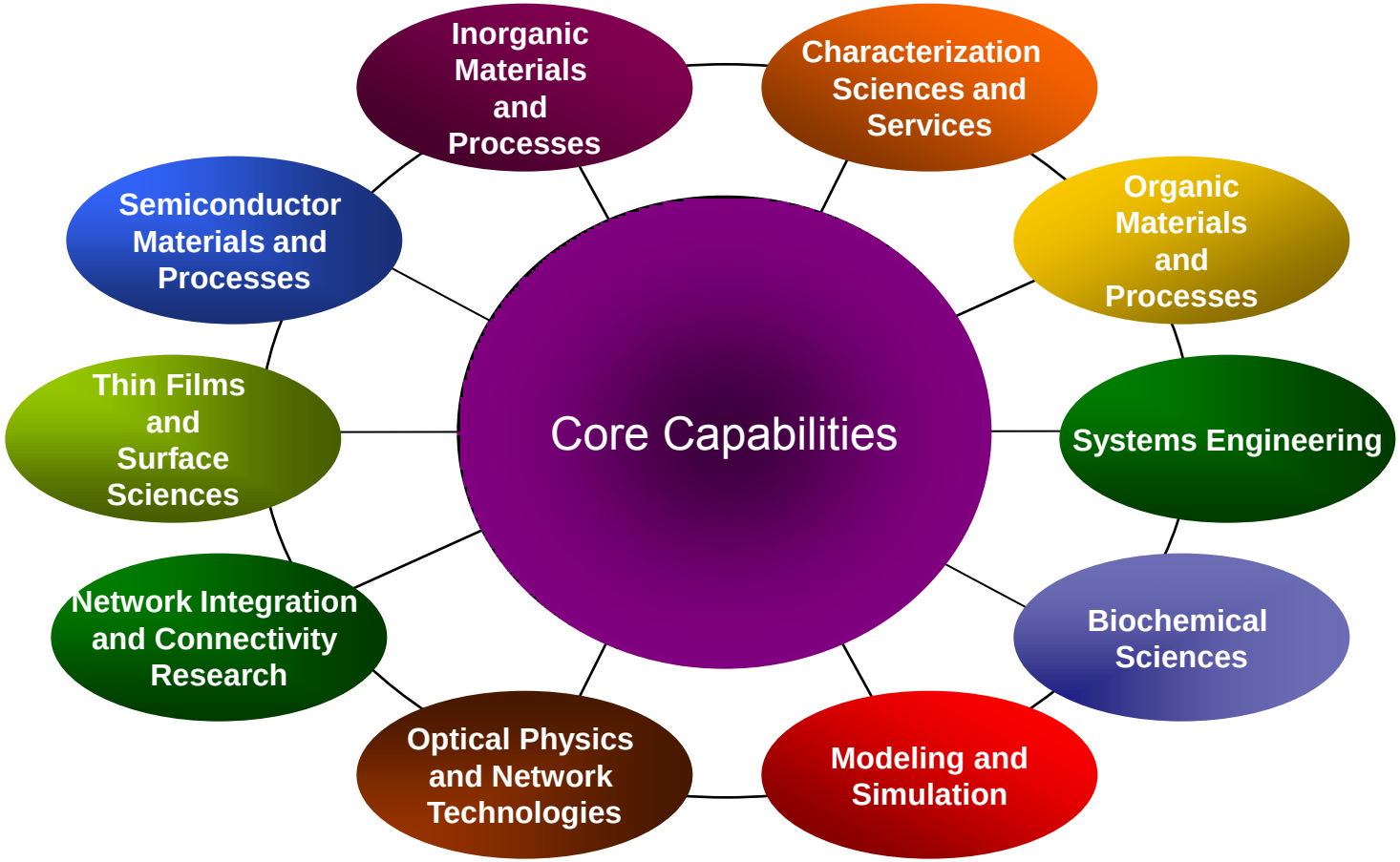


Other Products & Services

- Emerging Display Technology
- Drug Discovery Technology
- New Business Development
- Equity Companies
  - Cormetech, Inc.
  - Dow Corning Corp.
  - Eurokera, S.N.C.
  - Samsung Corning Precision Materials Co., LTD (SCP)

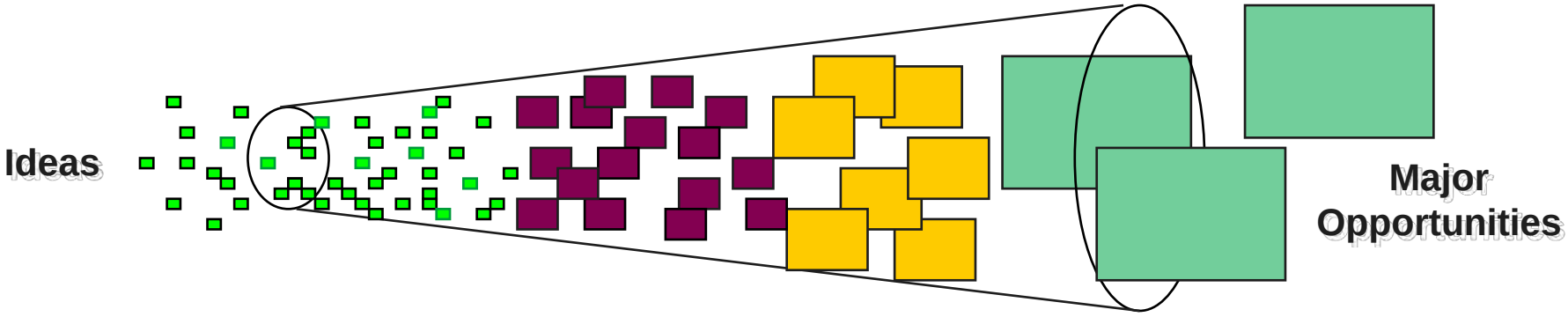
Research & Development

Corning's strength is based on a broad portfolio of core technologies…



… and the ability to integrate them.

Research & Development Pipeline Management



Research	Development	Engineering
Identify many high value ideas	Select highest value opportunities; Optimize value proposition	Scale up for commercial capacity

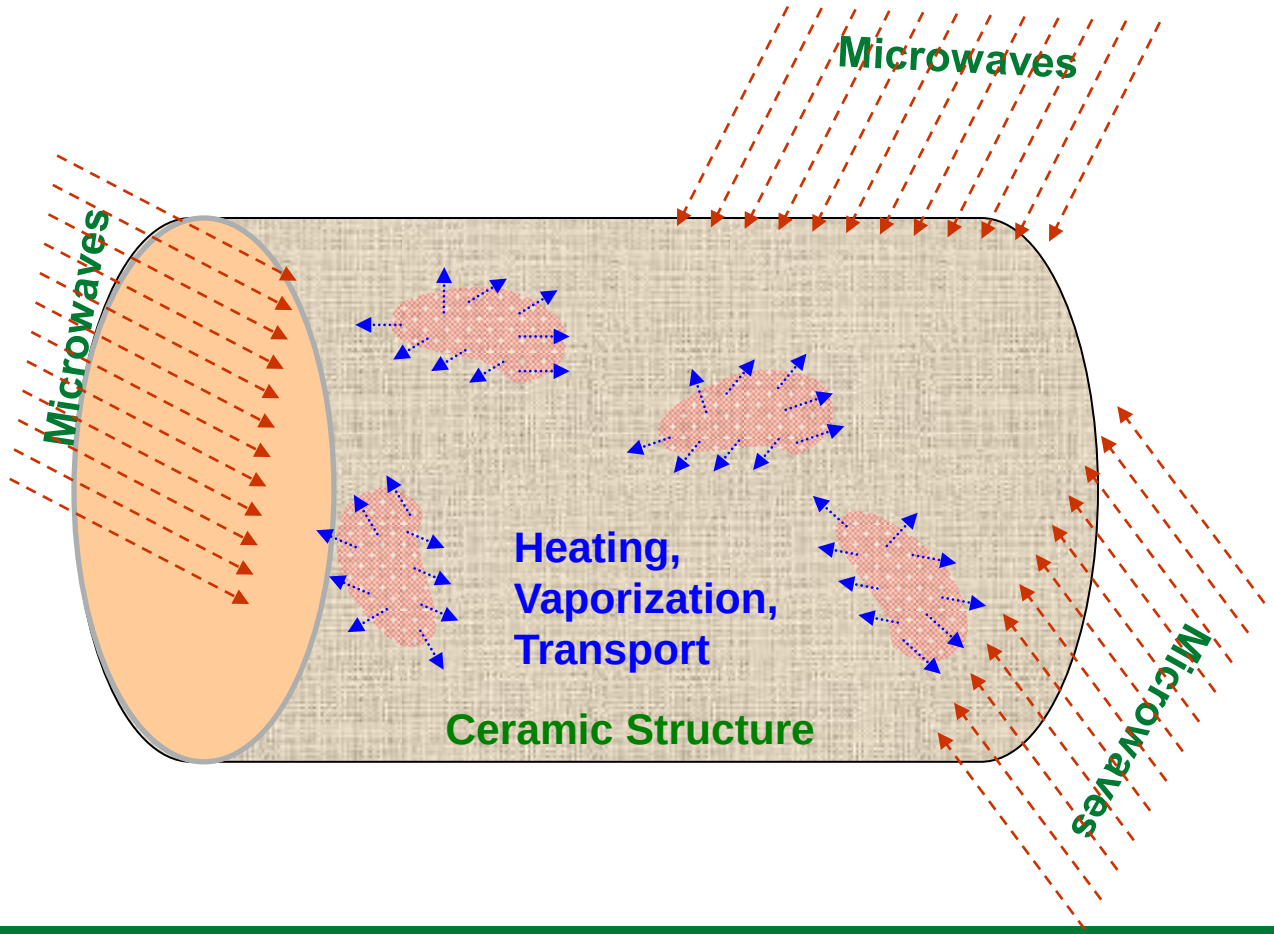
Customer & Market Understanding

Microwave drying of ceramic substrates

Mixing → Extrusion → Drying → Firing

- Microwave drying is one of the steps in the process
  - Faster and cheaper
- Models are critical in analysis and optimization

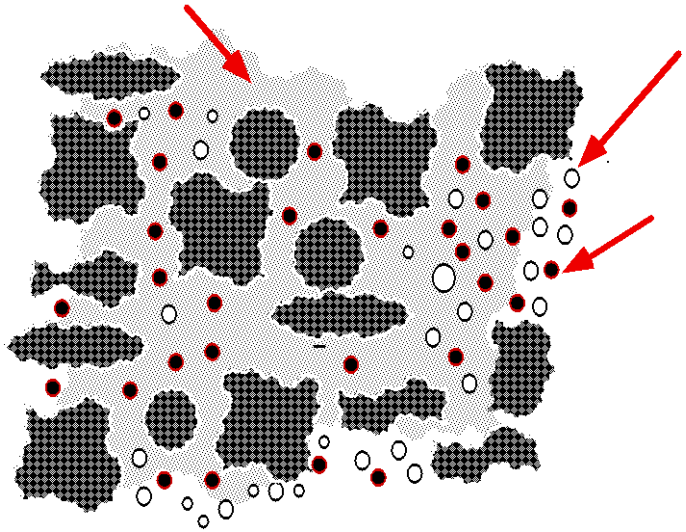
How is microwave drying taking place?



Transport Model: Porous Media Assumption

Water
- Pressure driven
- Capillarity (sat, temp) driven

Equilibrium
- Moisture & vapor pressure

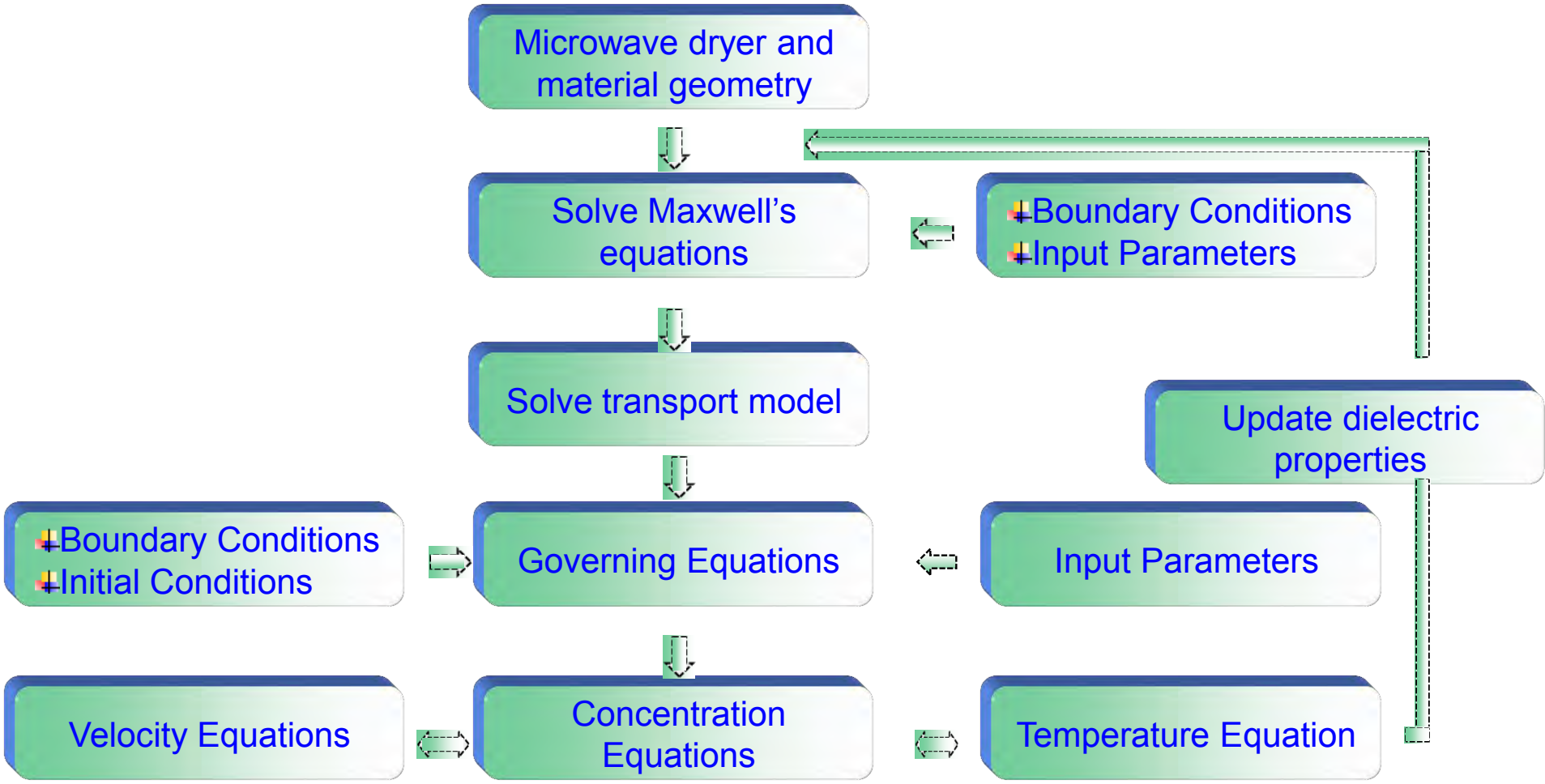


Vapor
- Pressure driven
- Diffusion in air

Air
- Pressure driven
- Diffusion in vapor

Energy
- Convection & Conduction
- Evaporation
- Microwave absorption

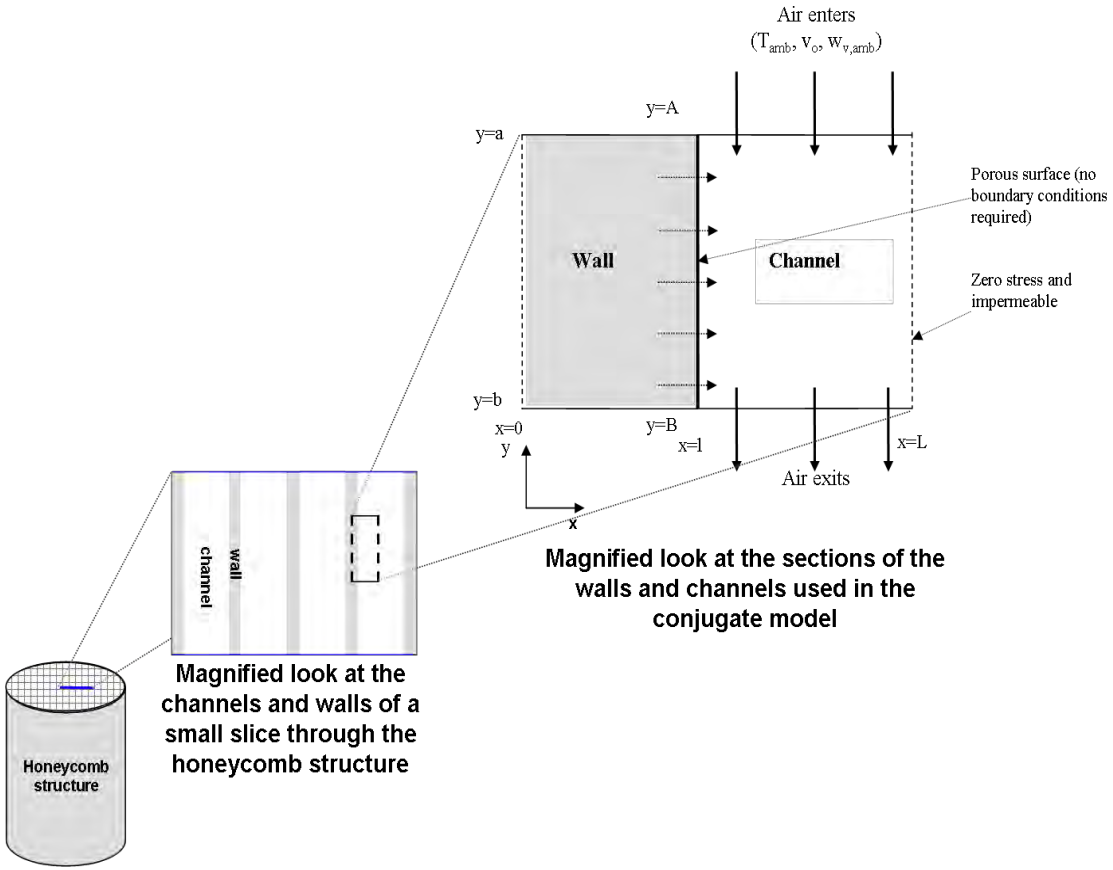
Modeling Strategy



Require a robust model

- Computationally intensive if all physics included
- Reduce the problem to include important physics
  - Experiments
  - Modeling
    - Micro scale models
- Reduced model
  - Robust
  - Scale up easier

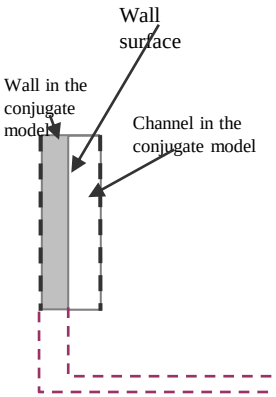
Conjugate model (half channel + half wall)

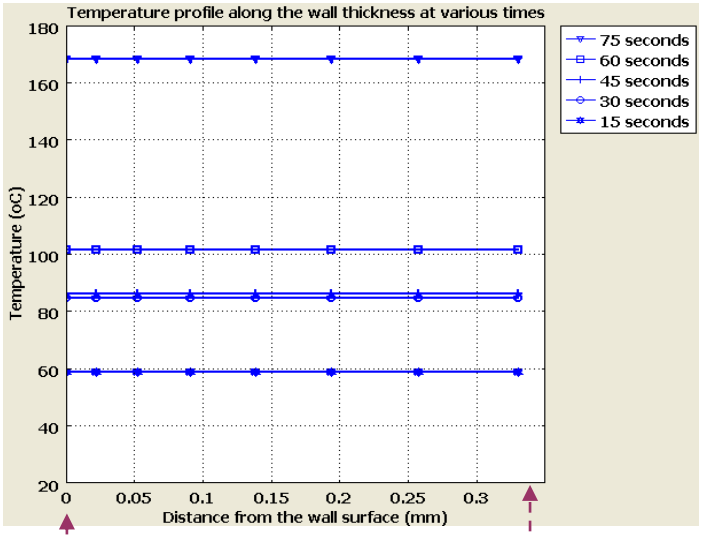


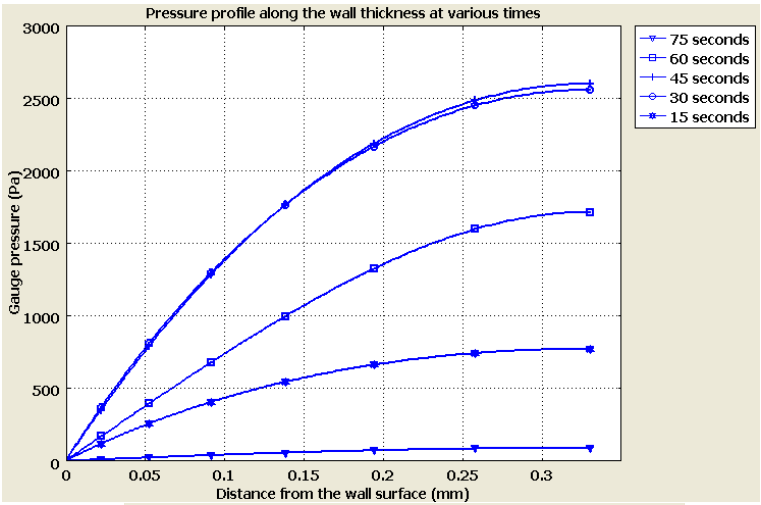
Multiphase heat and mass transport model: Equations

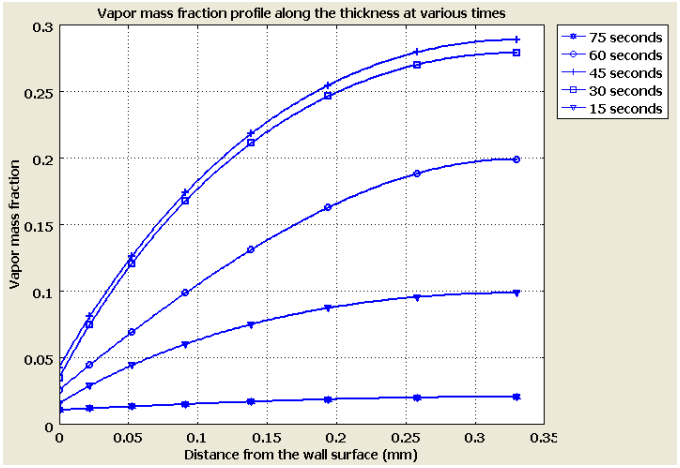
		Comsol Implementation
Liquid phase and Gas phase mass balance	$\frac{\partial}{\partial t}(\phi\rho_w S_w)+\nabla.(\overline{n_w})=-\dot{I}$ $S_w+S_g=1$ $\overline{n_w}=-\rho_w\frac{k_w^p}{\mu_w}\nabla(P-P_{cap})=-\rho_w\frac{k_w^p}{\mu_w}\nabla P+\rho_w\frac{k_w^p}{\mu_w}\nabla P_{cap}=-\rho_w\frac{k_w^p}{\mu_w}\nabla P-D_w\nabla c_w$ $\dot{I}=K\left(\rho_{v,eq}-\rho_v\right)S_g\phi$	Convection and diffusion equation Scalar expressions
Mass balance of Air and Vapor in the gas phase	$\frac{\partial}{\partial t}(\phi\rho_g S_g\omega_v)+\nabla.(\overline{u_g}\rho_g\omega_v)=\phi S_g\frac{C_g^2}{\rho_g}M_v M_a D_g\nabla x_v+\dot{I}$ $\omega_v+\omega_a=1$	Stefan-Maxwell's multi species diffusion equation
Momentum balance of gas phase	$\frac{\partial}{\partial t}(\phi S_g\rho_g u_g)+\nabla.\left((\phi S_g)^2\rho_g u_g u_g\right)=-\nabla P-(\phi S_g)\frac{\mu_g}{k_g^p}u_g+\mu_e\nabla^2 u_g$ $\frac{\partial}{\partial t}(\phi\rho_g S_g)+\nabla.(\overline{u_g}\rho_g)=\dot{I}$	Weakly compressible Navior-Stokes equation
Energy balance of mixture	$\rho_{eff}C_{p,eff}\frac{\partial T}{\partial t}+\left(C_{p,fluid}\overline{n_{fluid}}\right)\nabla T=\nabla.\left(k_{eff}\nabla T\right)+\lambda\dot{I}+Q$	Conduction and convection equation

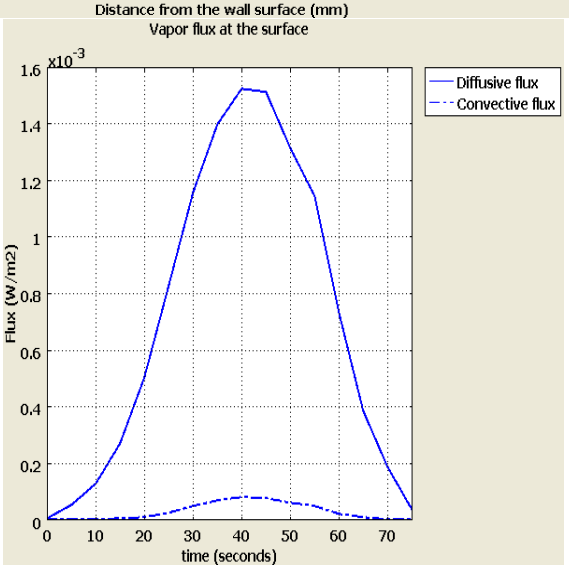
Results:
Transient pressure and mass flux profiles along the wall











Conclusions

- Micro scale model of one channel and one wall developed
- Model is qualitatively validated against experiments
- Fundamental understanding of drying phenomenon is enhanced by using conjugate model