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Boundary Conditions in Multiphase, Porous Media Transport Models

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Goal

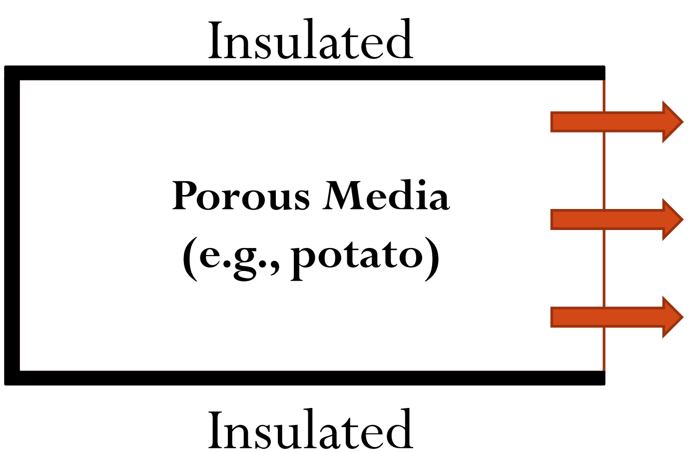
- Develop a fundamental based model which can
  - Simulate a number of processes (e.g., frying, baking, meat cooking, microwave , etc.)

Deep-fat Frying

Microwave heating

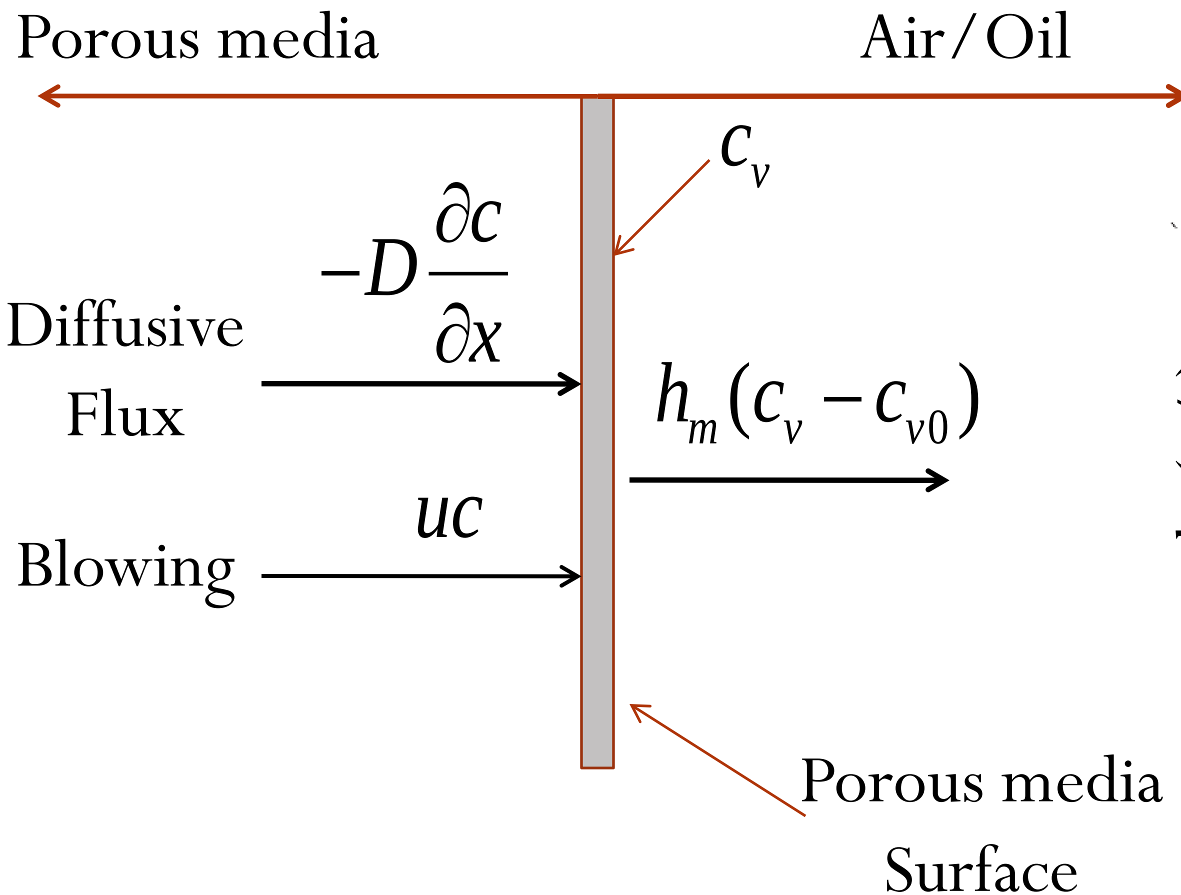
Baking

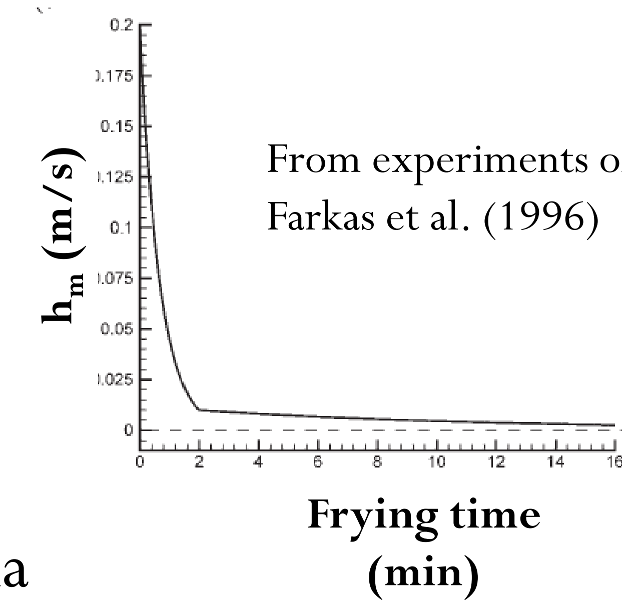
Grilling of meat



Heat and mass transfer coefficients needs to be specified at the boundary

Exchange at the boundary

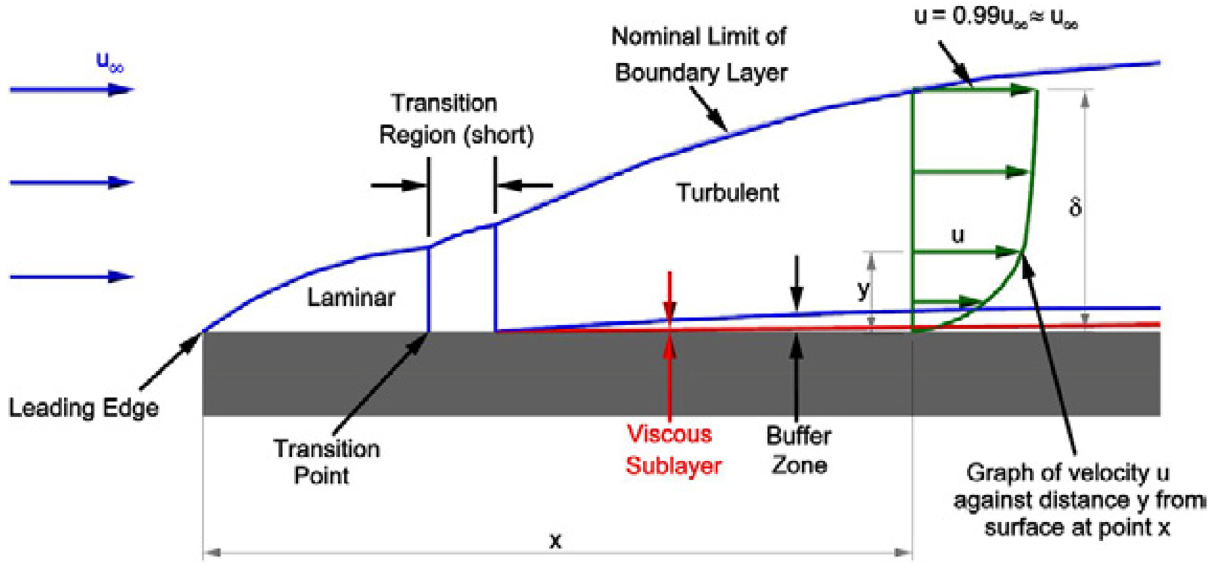




$$-D\frac{\partial c}{\partial x} + uc = h_m(c_v - c_{v0}) \qquad \text{OR} \qquad -D\frac{\partial c}{\partial x} + uc = h_m(c_v - c_{v0}) + uc$$

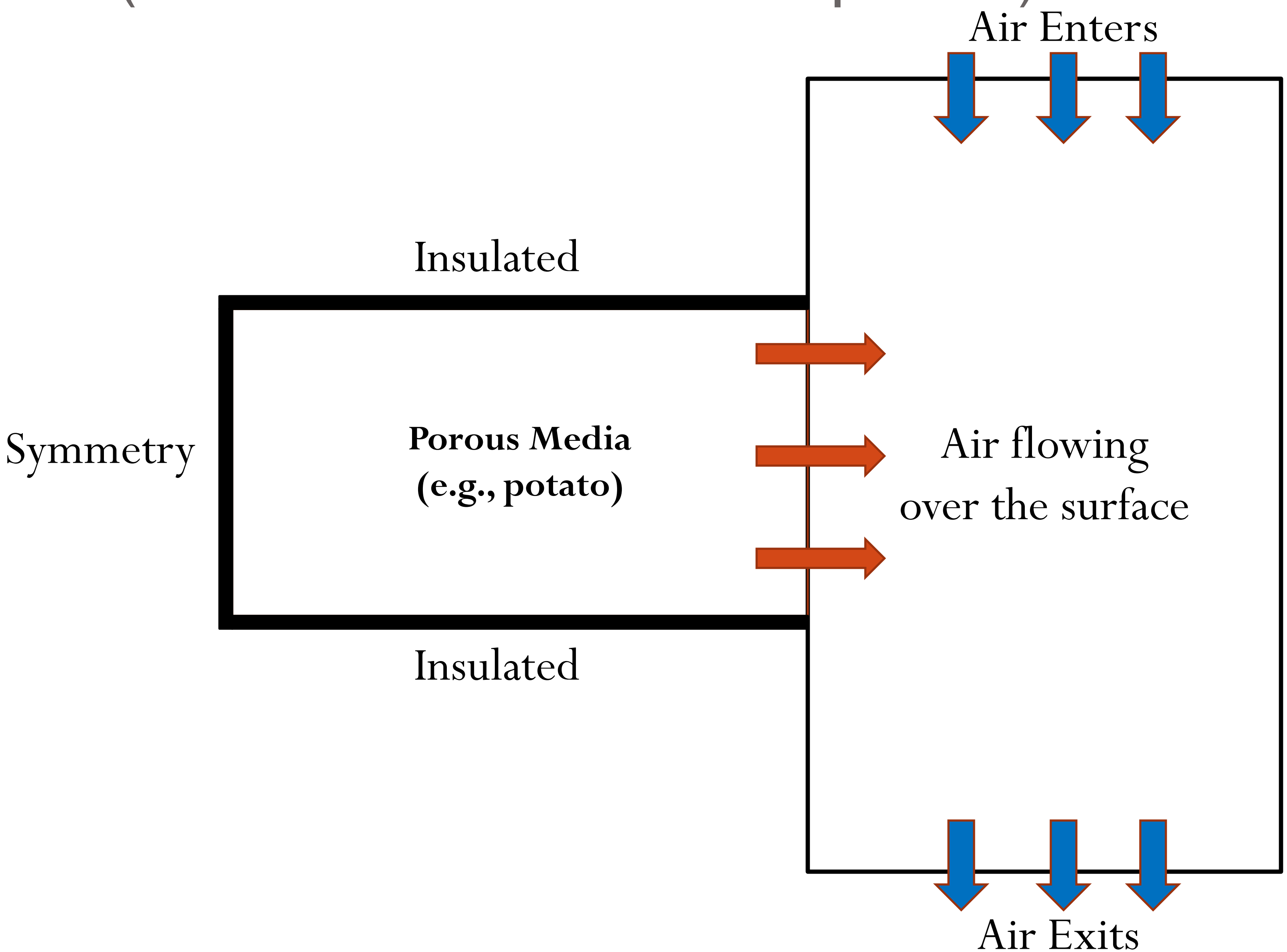
How to get the heat and mass transfer coefficients?

- Boundary layer assumption $(Re_L)^{1/2} >> 1$ (slenderness ratio) might not be satisfied.



- Therefore, the whole Navior-Stokes equation needs to be solved.

Conjugate problem (Porous media+Atmosphere)



Only boundary conditions needed are

- Inlet air velocity
- Inlet air temperature
- Inlet air concentration
- Outlet pressure (ambient pressure)

Advantages of the conjugate model

- Gives the interface heat and mass fluxes
- Interface velocities

Same governing equations for both the domains with different properties

Maxwell Stefan diffusion equation (gives vapor and air concentration)

$$\frac{\partial(\phi\rho_g S_g \omega_v)}{\partial t} + \nabla\cdot(u_g \rho_g \omega_v) = \nabla\cdot\left(\phi S_g \frac{C_g^2}{\rho_g} M_a M_v D_{eff,g} \nabla x_v\right) + \dot{I}$$

$$\omega_v + \omega_a = 1$$

	Porous Media	**Atmosphere**
ϕ	potato	1
S_g	gas volume fraction (solved for)	1

Same governing equations for both the domains with different properties

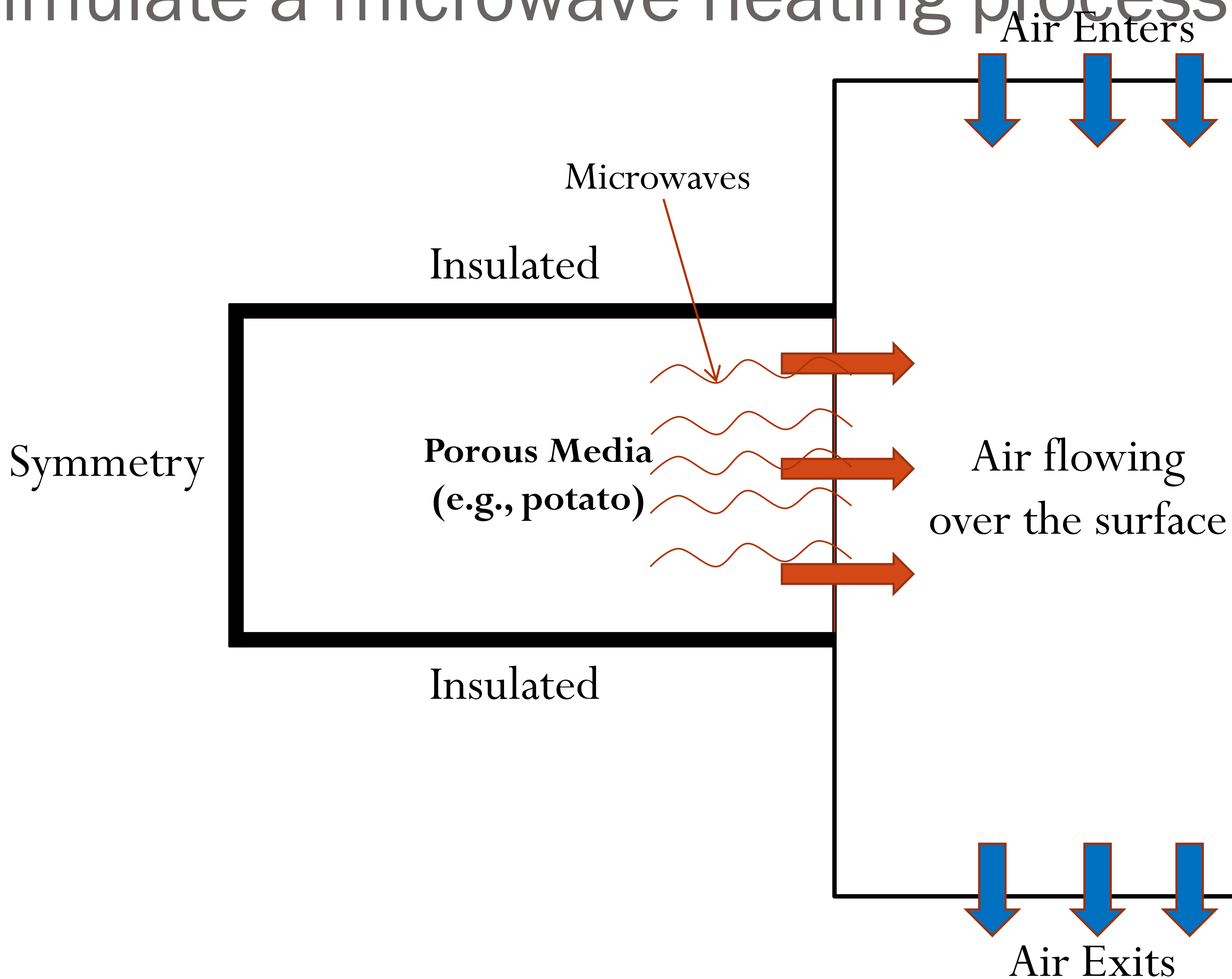
Navior-Stokes equation (gives u, v, p of the gas phase)

$$\frac{\partial((\phi S_i)\rho_i u_i)}{\partial t} + \nabla.((\phi S_i)^2 \rho_i u_i u_i) = -(\nabla P - \rho_i g) - (\phi S_i)\frac{\mu_i}{k^p_{r,i} k^p_{in,i}} u_i$$

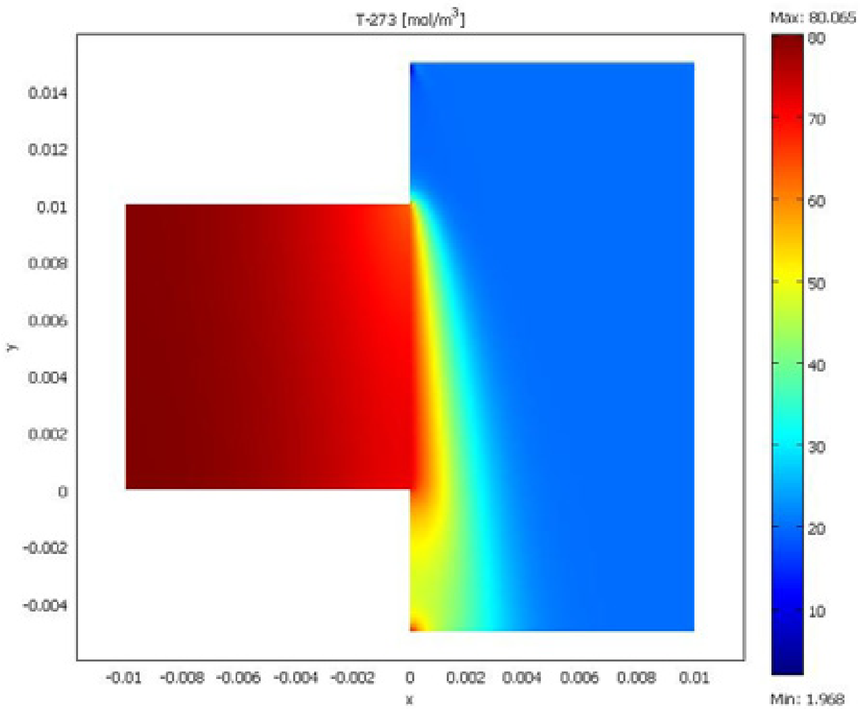
$$\frac{\partial}{\partial t}(\phi S_g \rho_g) + \nabla \cdot \mathbf{n_g} = \dot{I}$$

	Porous Media	Atmosphere
$S_g\ \phi$	gas volume fraction (solved for)	1
$\frac{\mu}{k} u_i$	Darcy's term (solved for)	0

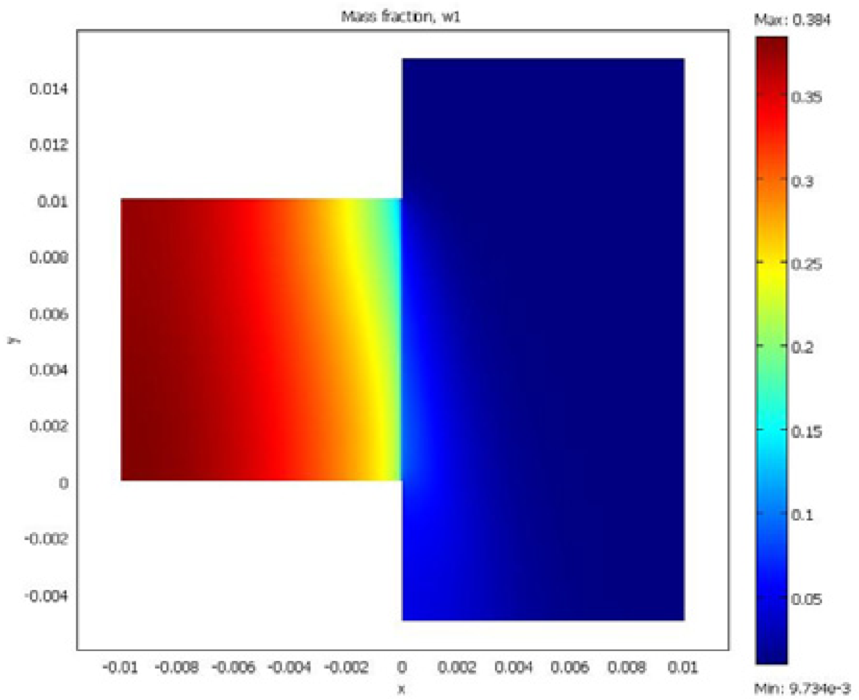
Simulate a microwave heating process



Results



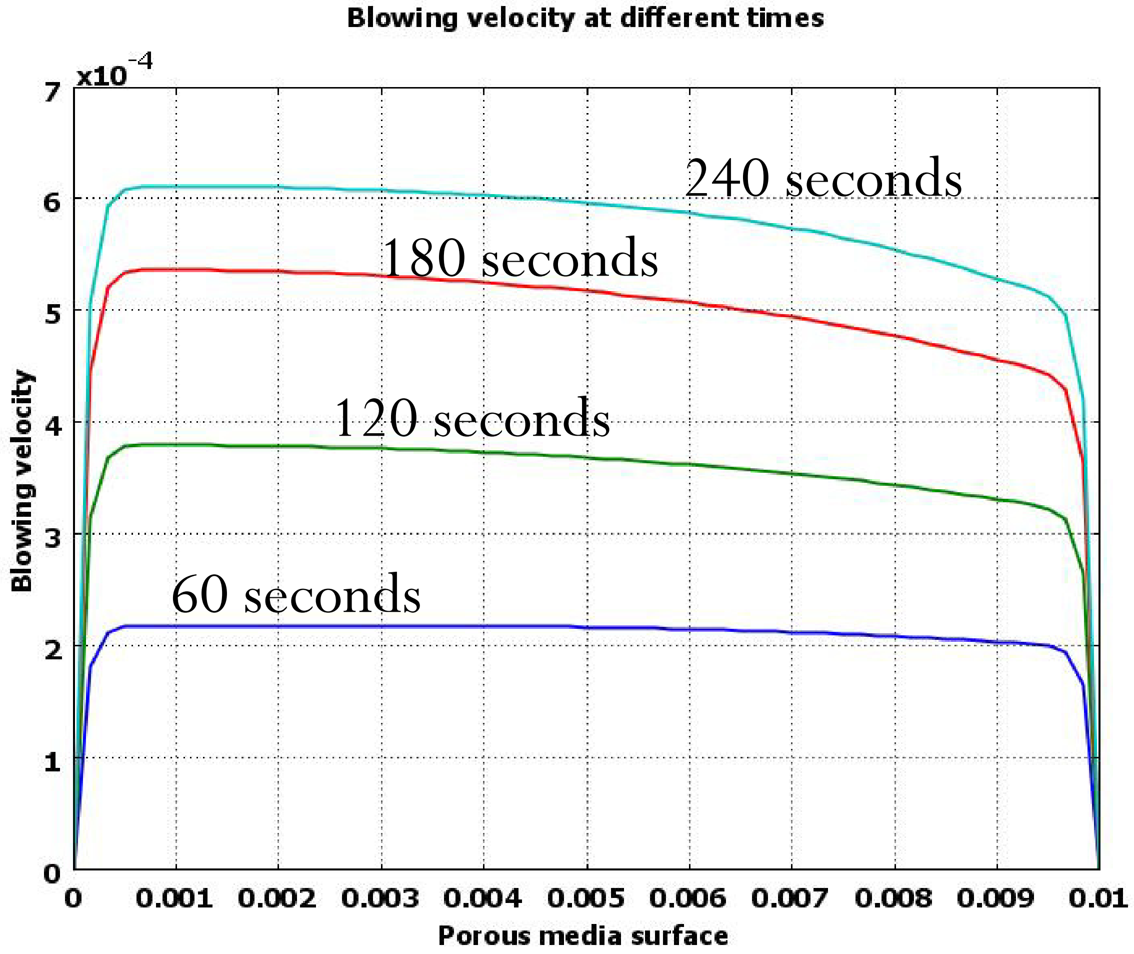
Temperature profiles
after 5 minutes



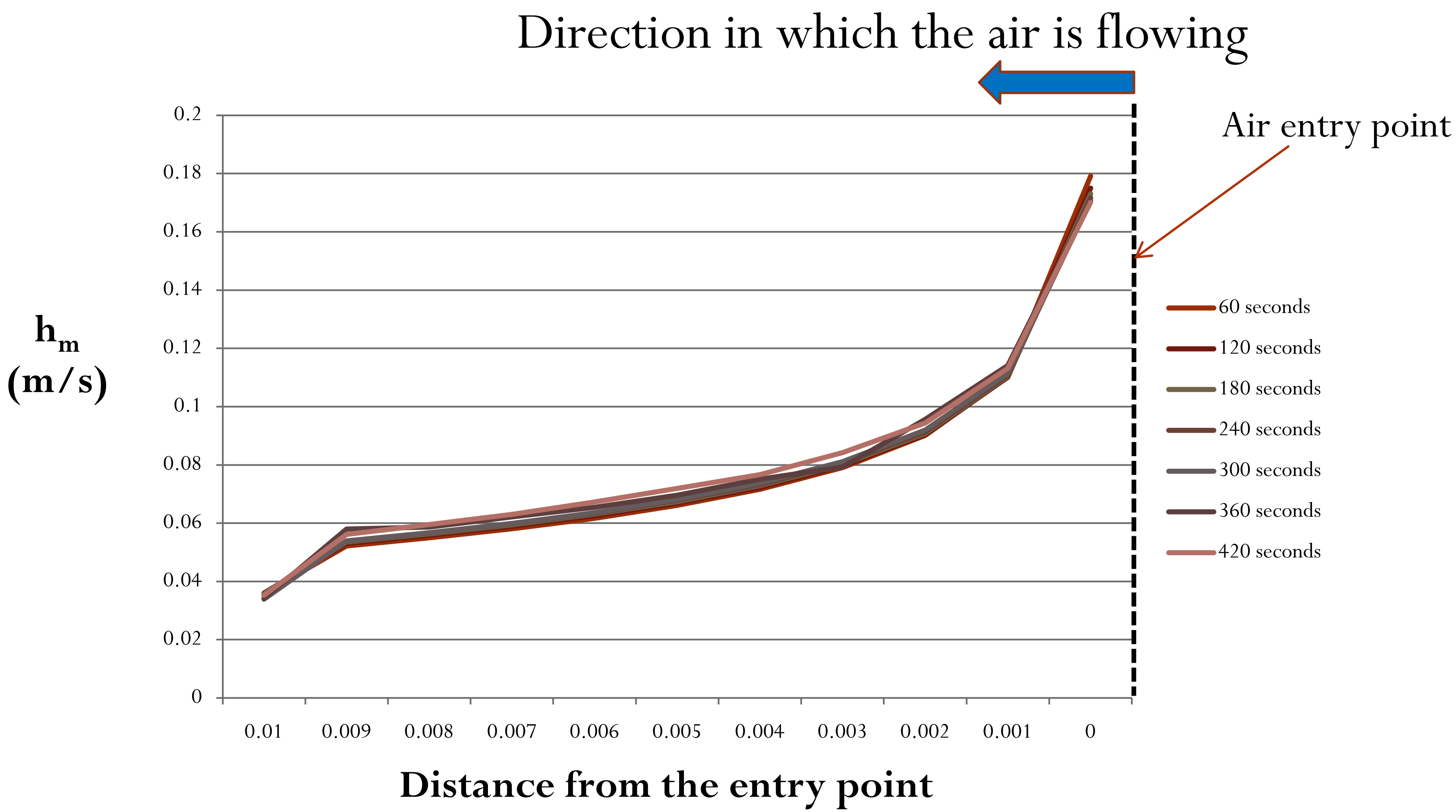
Vapor mass fraction profiles
after 5 minutes

Blowing velocities at the interface at different times

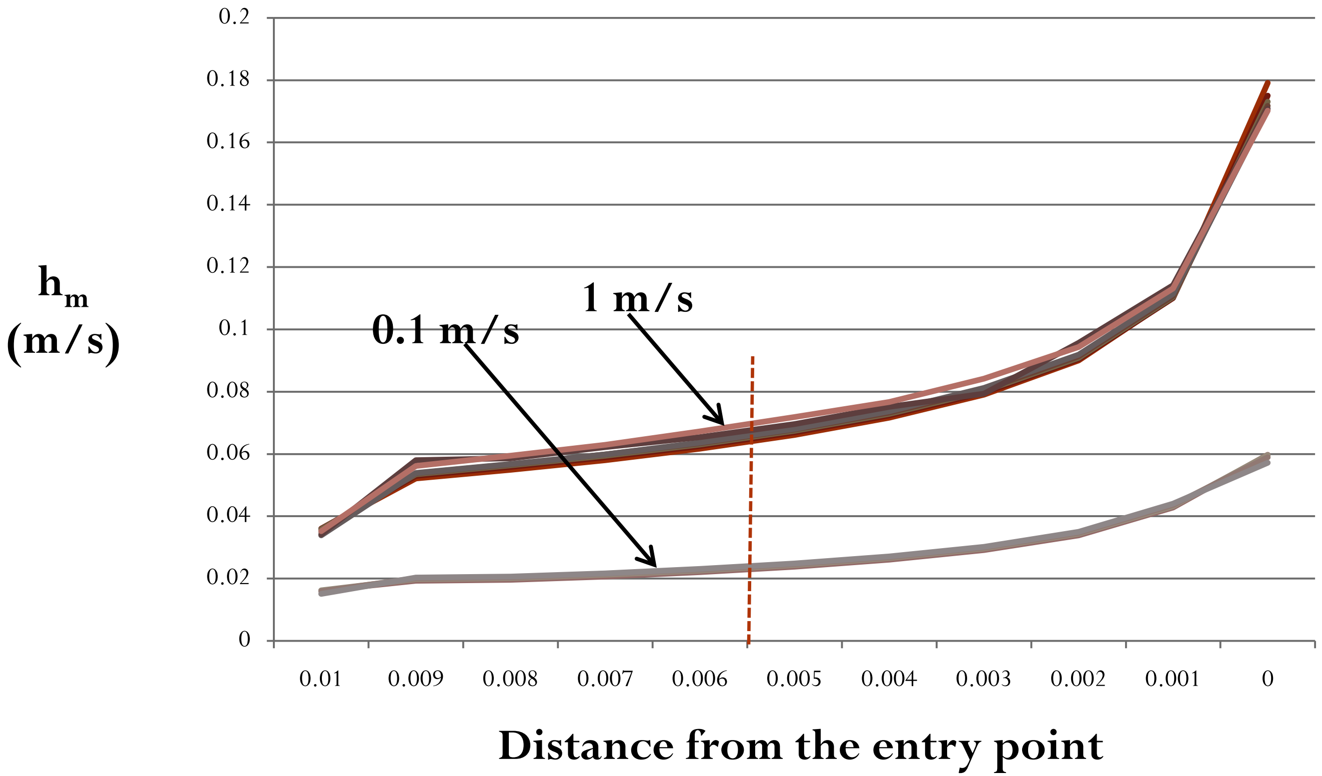
- Blowing velocity at the interface is 10^3 times smaller than free stream velocity



Blowing velocities are not significant enough to affect h_m

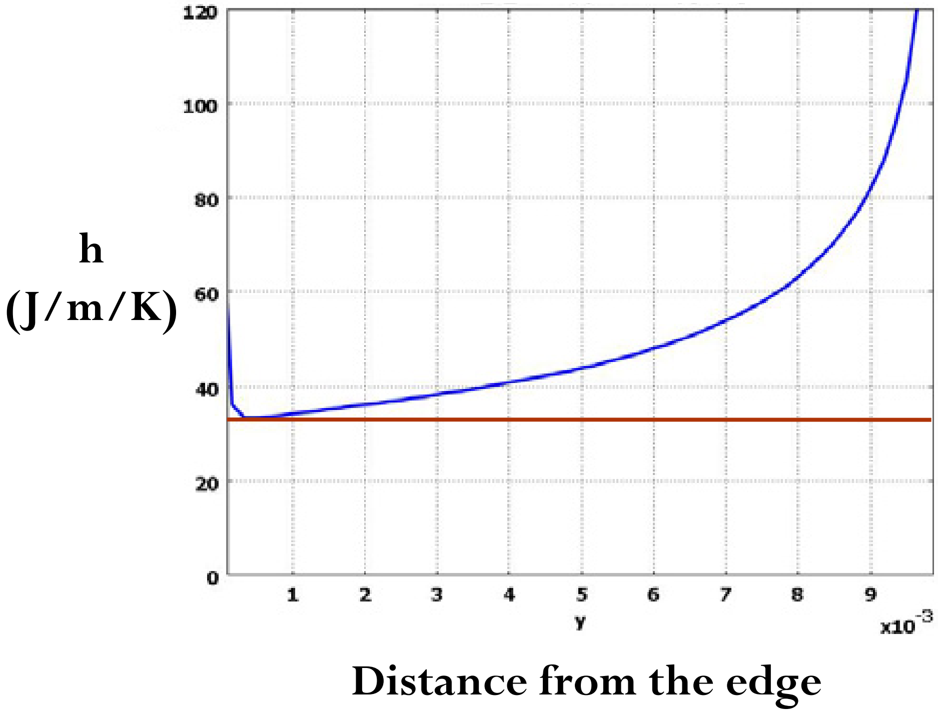


Mass transfer coefficients for different air velocities



Average mass transfer coefficient is 3 times when velocity of air blowing the surface is decreased by 10 times.

Heat transfer coefficient



Similar results seen for heat transfer coefficient also. High values at the entry point and towards the exit, the value matches the boundary layer solution.

Conclusion

- Conjugate model developed which can
  - Solve processes without assuming any transfer coefficients at the boundary
    - Microwave heating is solved and h & h_m is estimated from the simulation.
  - h and h_m calculated from the conjugate problem can be used in non-conjugate problem to give faster and accurate results
  - Demonstrates the transient effects of blowing on heat and mass transfer coefficients

Future work

- Conjugate problem for intensive heating processes
  - Higher heating rate therefore blowing is significant

- Conjugate problem for frying simulation where instead of air, there is hot oil outside
  - Challenges like huge density change at the boundary, vanishing of a phase in domain, turbulence needs to be answered in this model

Thank you.