# Model of Heat and Mass Transfer with Moving Boundary during Roasting of Meat in Convection-Oven

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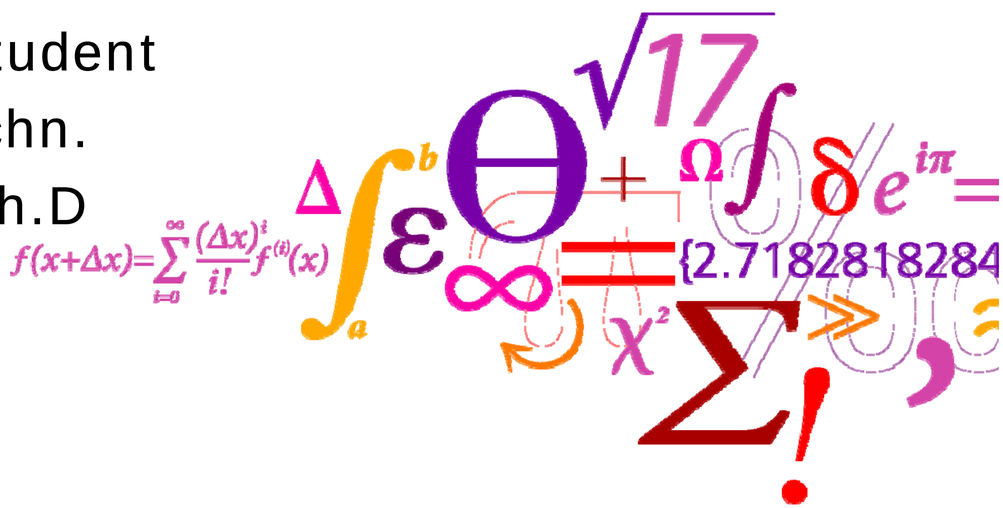

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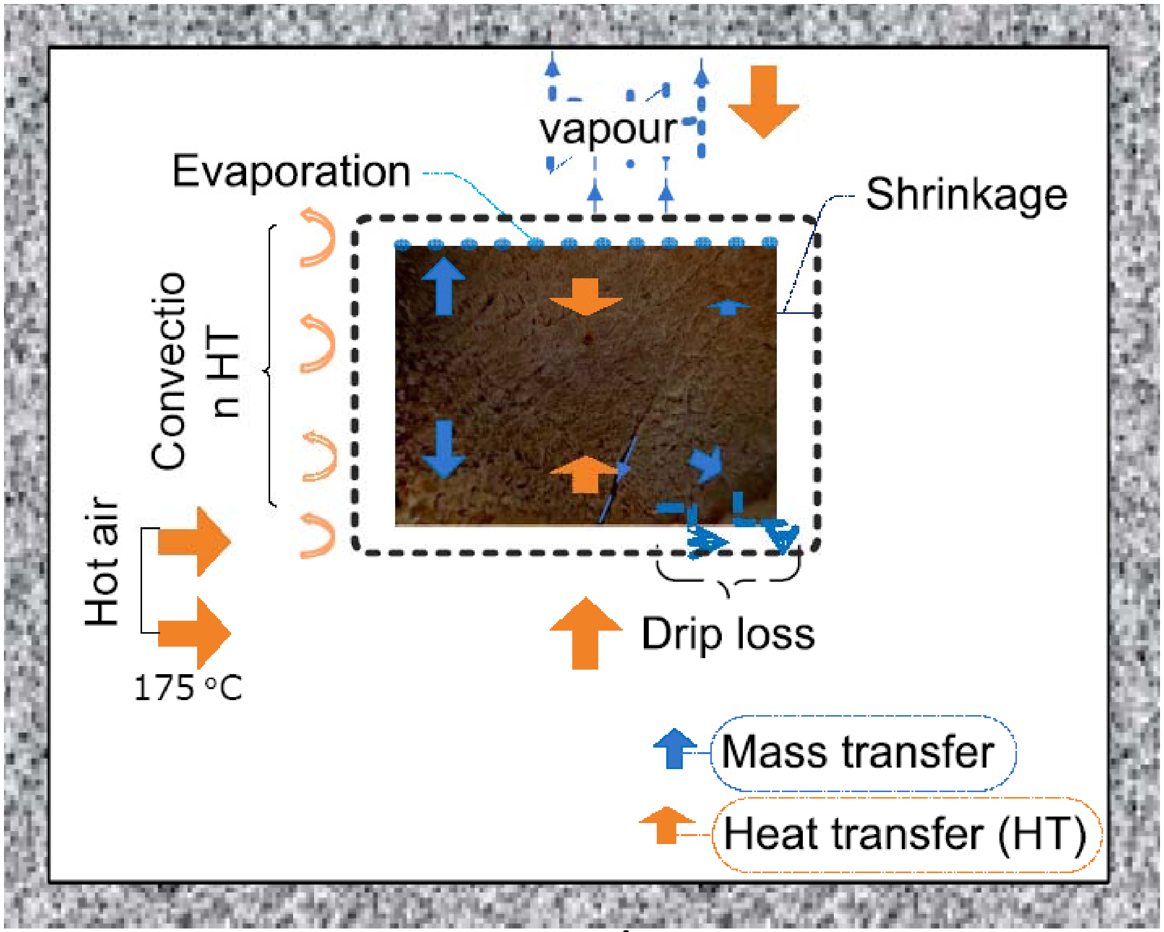
# Outline

- Introduction
- Theoretical background
- Modelling
  - Governing model equations
  - Boundary and initial condition
  - Model Solution
- Results
- Conclusion

# *Roasting process*




Transport processes during oven-convection roasting

- *Model*
  - Better quantitative knowledge
  - Prediction of T, C
  - Quality, safety
  - Minimize loss
    - Mass and energy
  - Upscale
  - Process control

# Water transport

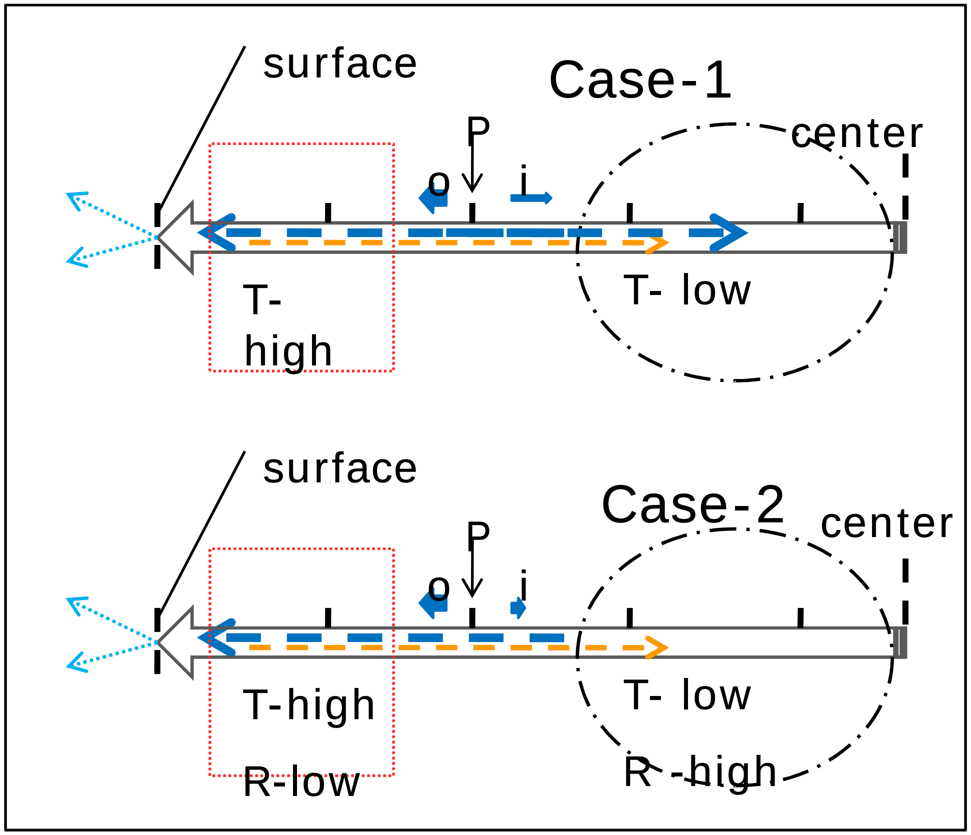
- *Pure diffusion (often assumed)*
  - But doesn't capture pressure
- *Convective*
  - T ↑
    - Denaturation
    - WHC ↓
    - Shrinkage (protein network)

→ Pressure gradient

velocity

# Change of microstructure

- Permeability(K)
- Elastic modulus (E)






Change of microstructure during roasting

(cross-sectional view)

# Assumptions

- Fat transport is negligible (lean meat)
- Evaporation takes place at the surface
- No internal heat generation and no chemical reaction
- Dissolved matter lost with water is small
- Reduction of water holding capacity and shrinkage are considered.

# Governing equation of heat and mass transfer

- Heat transfer

$$\rho_m c_{p_m}\frac{\partial T}{\partial t}+\nabla(-k_m\nabla T)+\rho_w c_{p_w} u_w \nabla T=0$$

$$\rho_m = f(C)$$
$$D = f(T)$$
$$c_{pm} = f(C)$$
$$\mu_w = f(T)$$

- Water transport

$$\frac{\partial C}{\partial t}+\nabla(Cu_w)=\nabla D\nabla C$$

- Velocity of water

$$u_w = \frac{-K}{\mu_w}\nabla P$$

*Darcy's* law

$$P=E(C-Ceq(T))$$

$$u_w = \frac{-KE}{\mu_w}\nabla\left(C-C_{eq}\right)$$

$$E_{(T)} = E_o + \frac{E_{mx}}{(1+\exp(-E_n(T-E_D)))}$$

$$C_{eq(T)} = 0.75 - \frac{0.345}{(1+30\exp(-0.25(T-T\sigma)))}$$

# Shrinkage / interface velocity

- Proportional to the volume of liquid water removed
- Formation of air filled pores

$$V = V_0 - \beta V_{w,l}$$

β=1, no pore formation

β = 0, no shrinkage

1-β= fraction of V*w,l replaced by air*

$$V = V_0\left(1-\frac{\beta V_{w,l}}{V_0}\right)$$

$$= \pi R_0^2\left(1-\frac{\beta V_{w,l}}{V_0}\right)^{2/3} Z_0\left(1-\frac{\beta V_{w,l}}{V_0}\right)^{1/3} = \pi R^2.Z$$

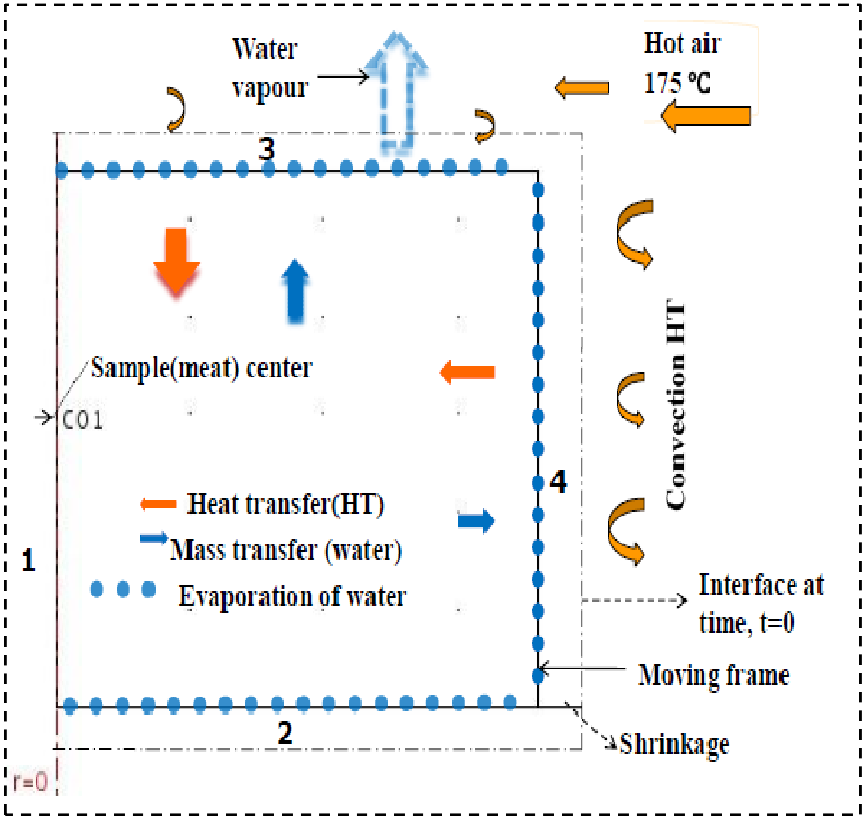
$$v_z = \frac{dZ}{dt} = -\frac{Z_0\beta}{3V_0}\left(1-\frac{\beta V_{w,l}}{V_0}\right)^{-2/3}\frac{d}{dt}\left(V_{w,l}\right)$$

$$v_r = \frac{dR}{dt} = -\frac{R_0\beta}{3V_0}\left(1-\frac{\beta V_{w,l}}{V_0}\right)^{-2/3}\frac{d}{dt}\left(V_{w,l}\right)$$

$$V_{w,l} = \frac{m_d\left(X_0-X\right)}{\rho_w} = \frac{\rho_0 V_0\left(1-C_0\right)}{\rho_w}\left(\frac{C_0}{1-C_0}-\frac{C_{av}}{1-C_{av}}\right)$$

$$\frac{dV_{w,l}}{dt} = -\frac{\rho_0 V_0\left(1-C_0\right)}{\rho_w}\left(\frac{1}{1-C_{av}}\right)^2\frac{dC_{av}}{dt}$$

# Boundary conditions and initial condition




**BC 1:**

Axial symmetry, vr=0

**BC (2, 3, and 4):**

- HT- heat flux
- MT- mass flux
- ALE- velocity

IC:

$$T(r,z) = T_0 = \text{const} \quad \text{at} \quad t = 0$$

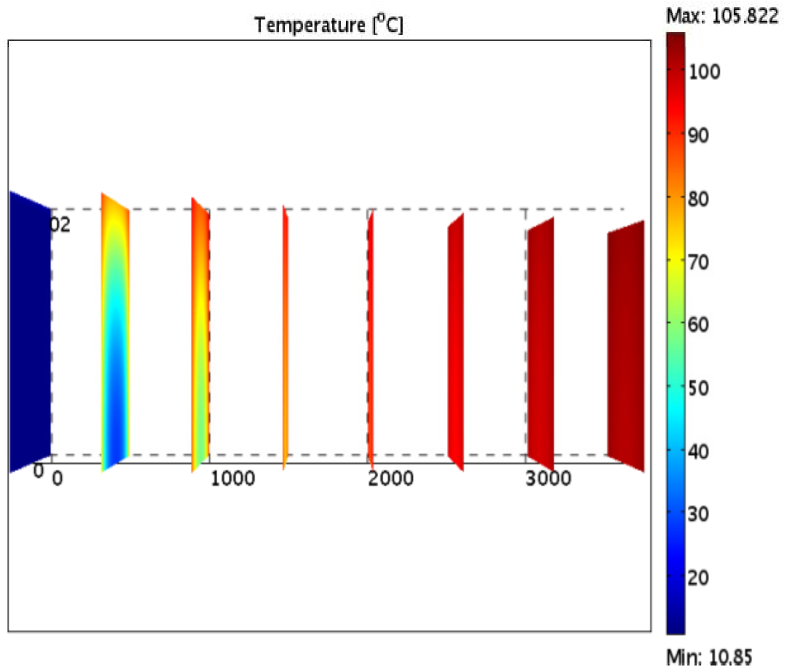
$$C(r,z) = C_0 = \text{const} \quad \text{at} \quad t = 0$$

# Solution

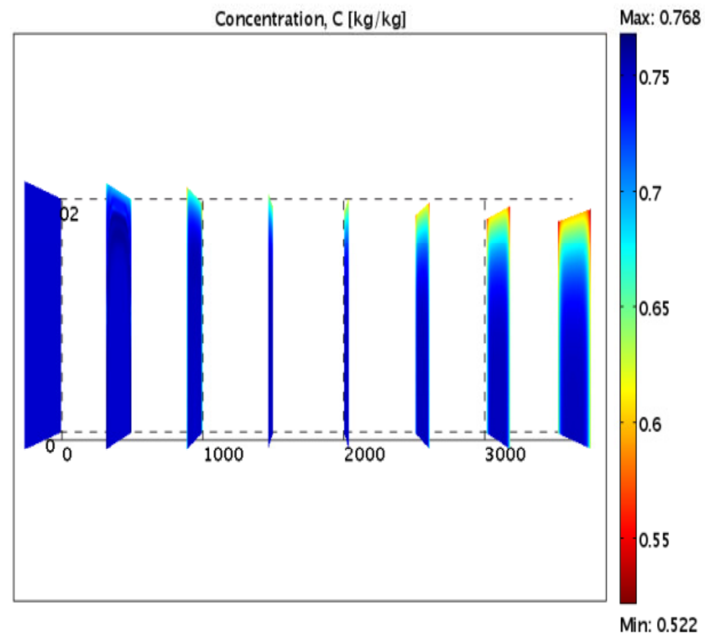
- COMSOL Multiphyics® version3.5
  - 2D cylindrical

    Radius of 20 mm and length of 54 mm
  - *Chemical Engineering module*
    - Transient heat transfer
    - Transient mass transfer
  - *Moving mesh module (ALE)*

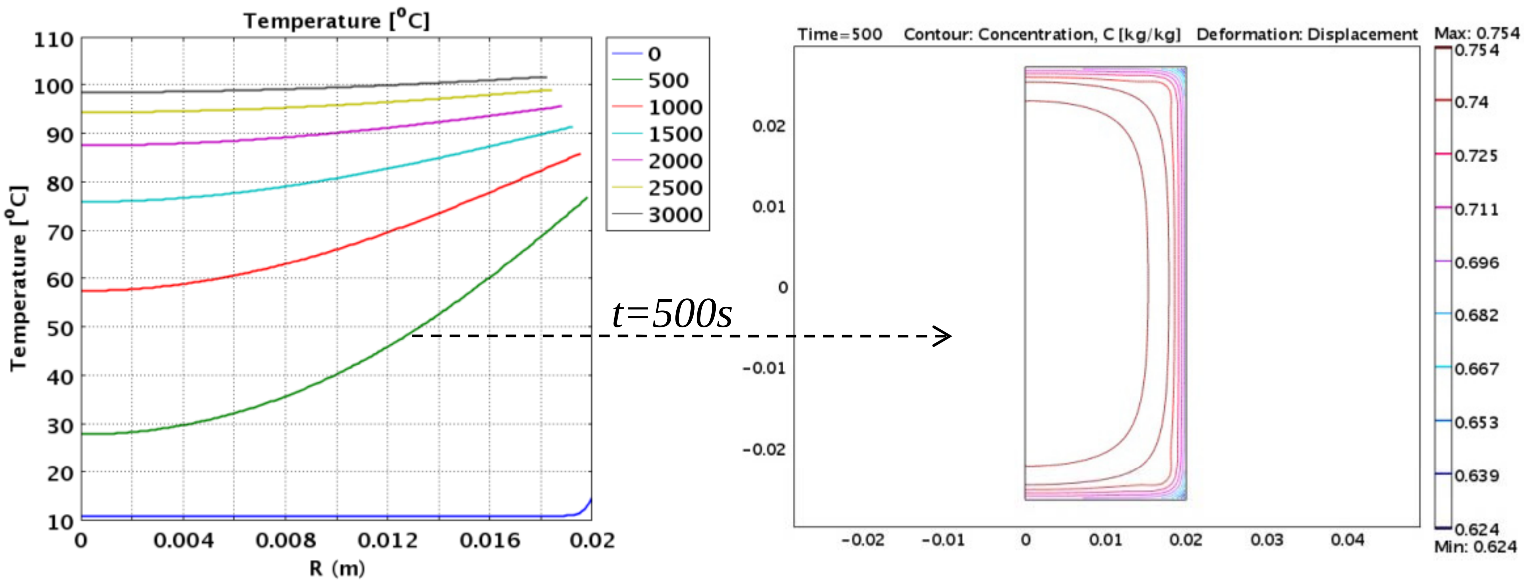
# Results




Temperature distribution




Water content distribution

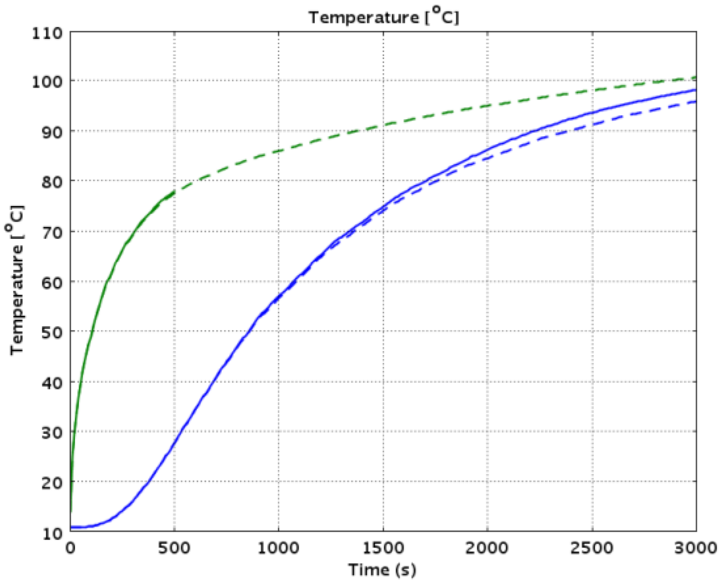


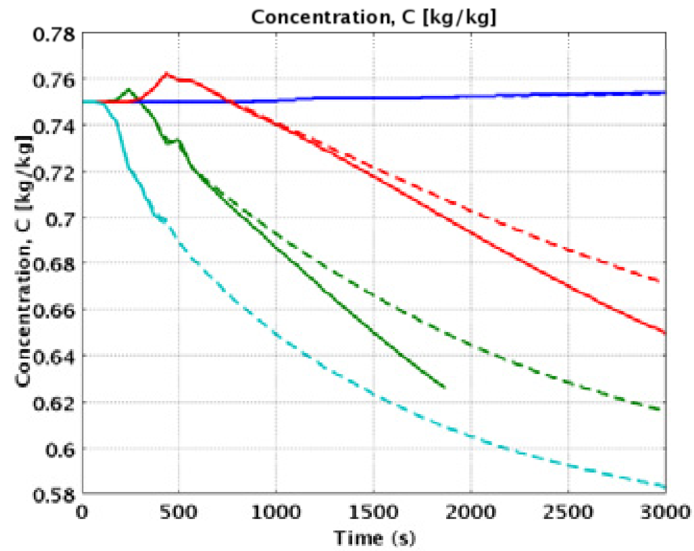

**Temperature profile across cylindrical sample (Z = 0)**

**Iso-concentration lines**

**C (kg/kg) at t = 500 s**

# Model prediction with (-) MB vs. with FB (--)




**Temperature profile**

**blue-center(0, 0)**

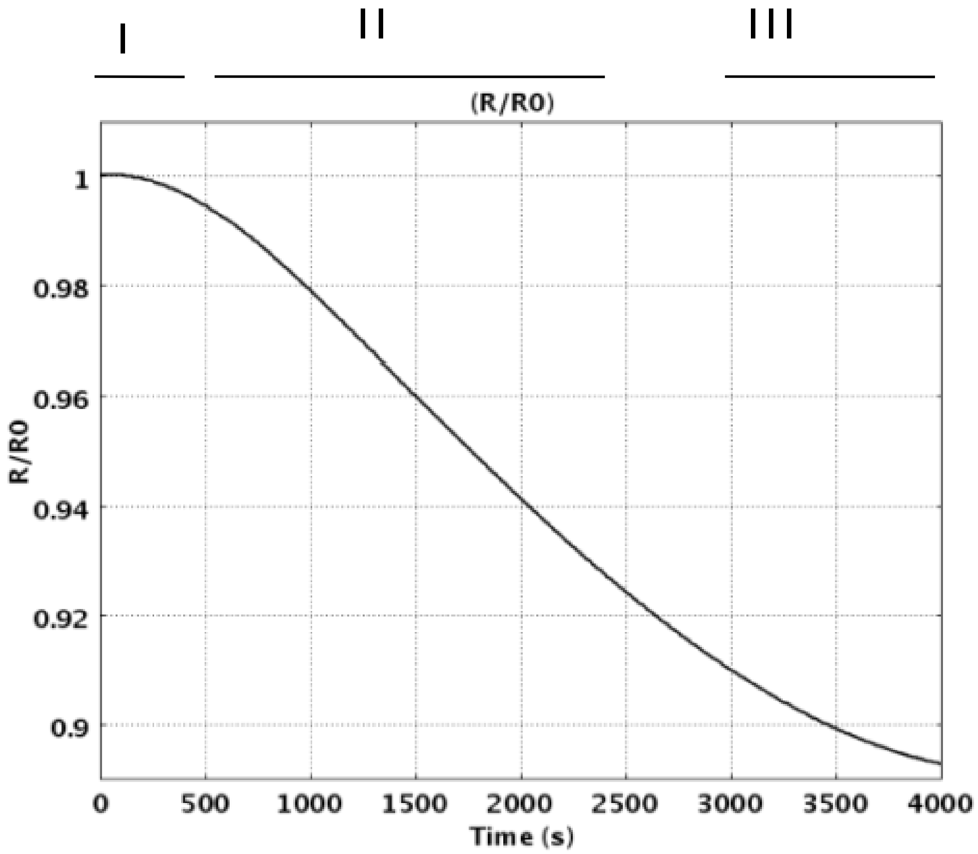
**green-surface (r = 0.02, z = 0)**

**Water content profile**

**blue(0, 0), red (0.017, 0)**

**green (0.019, 0), cyan (0.02, 0)**

# Radial shrinkage




**Relative radius of cylinder as function of time (R/R0)**

## Conclusion

- A 2D model of HMT with MB is developed and models equations were solved using COMSOL for convection roasting process.
- Effect of WHC and shrinkage are incorporated.
- Better insight is obtained.

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Thank you for your attention!