

A Moisture Transfer Model for Drying of Grain

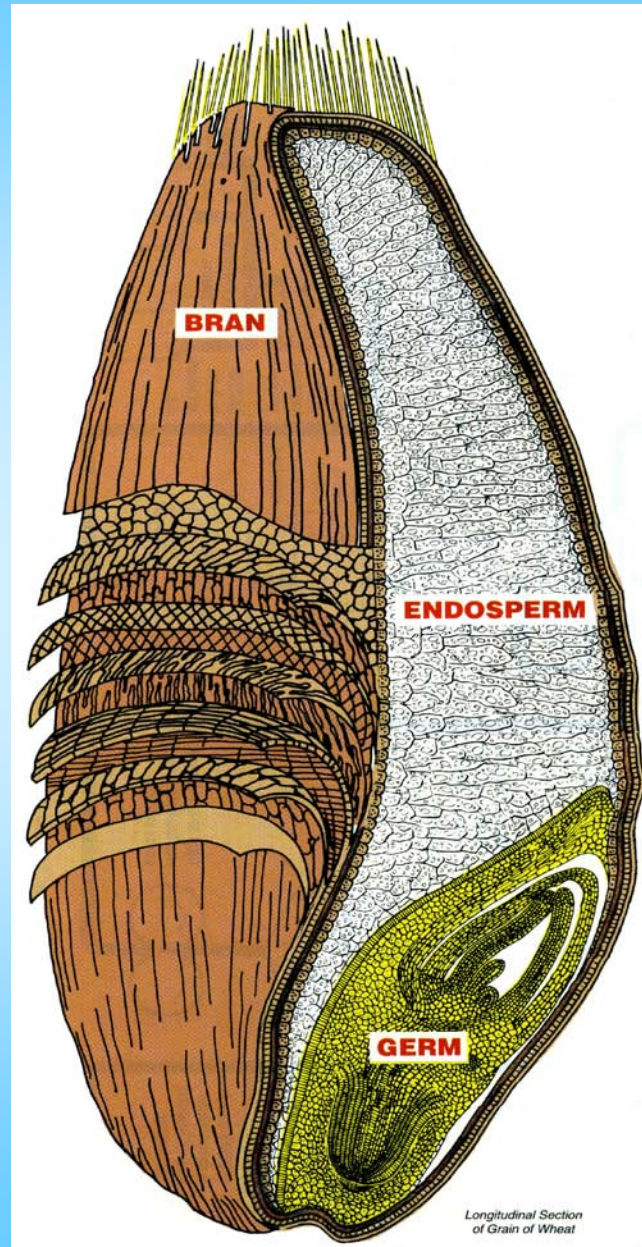
by

Kurt O. Lund

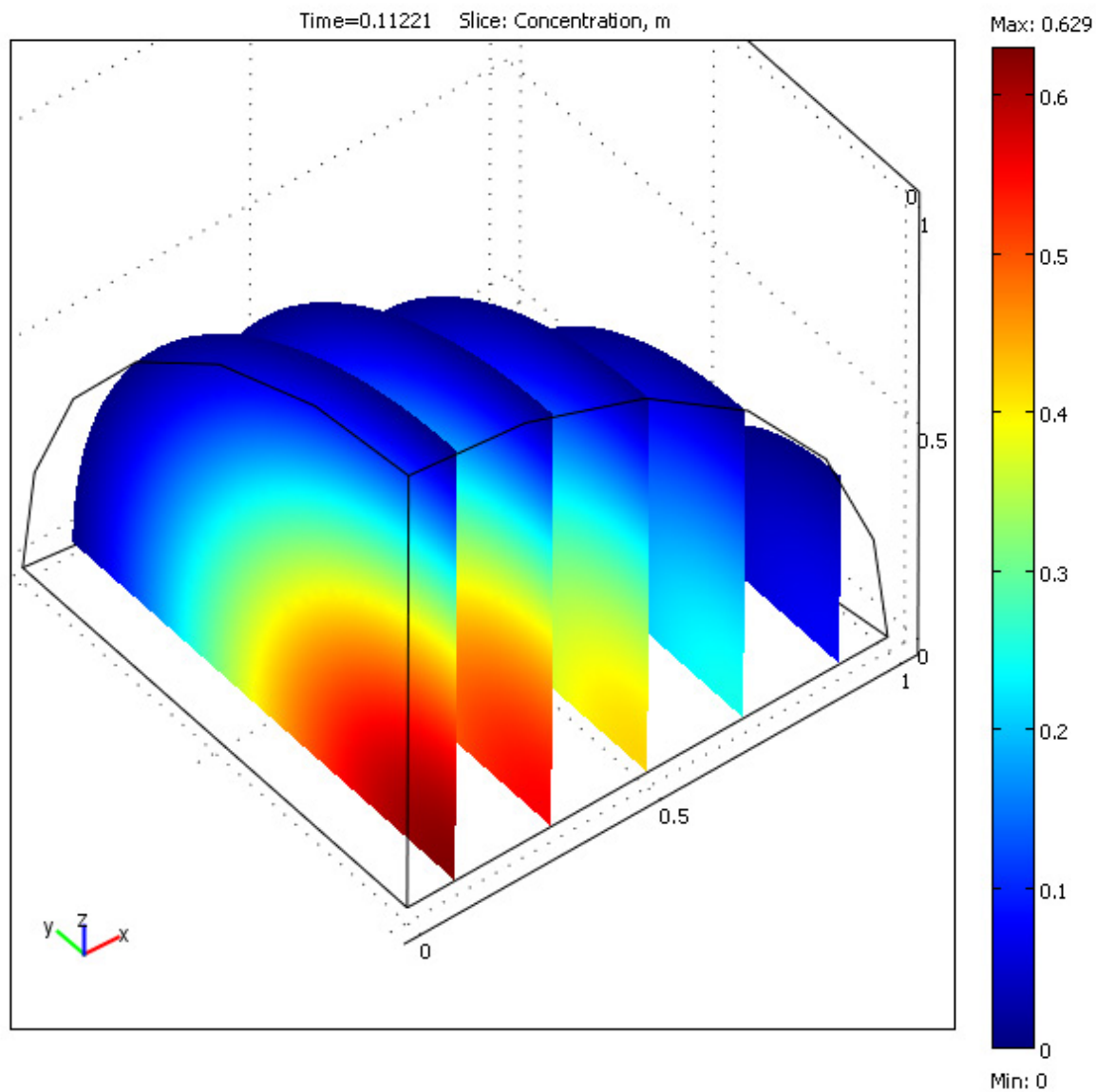
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Single-Kernel Moisture Transfer



Spherical Kernel Model



Single-Kernel Moisture Transfer

$$\frac{\partial M_k}{\partial t} = \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 D_k \frac{\partial M_k}{\partial r} \right) \quad h_m (M_k|_R - M_{eq}) = -D_k \frac{\partial M_k}{\partial r} \Big|_R$$

$$D_k = A_k \exp(-B_k/T_a)$$

$$\xi = r/R \quad \tau = t/t_k \quad t_k = d_k^2/D_k$$

$$m = (M - M_{eq}) / (M_0 - M_{eq})$$

$$Bi_m = h_m d_k / D_k \approx 10^7$$

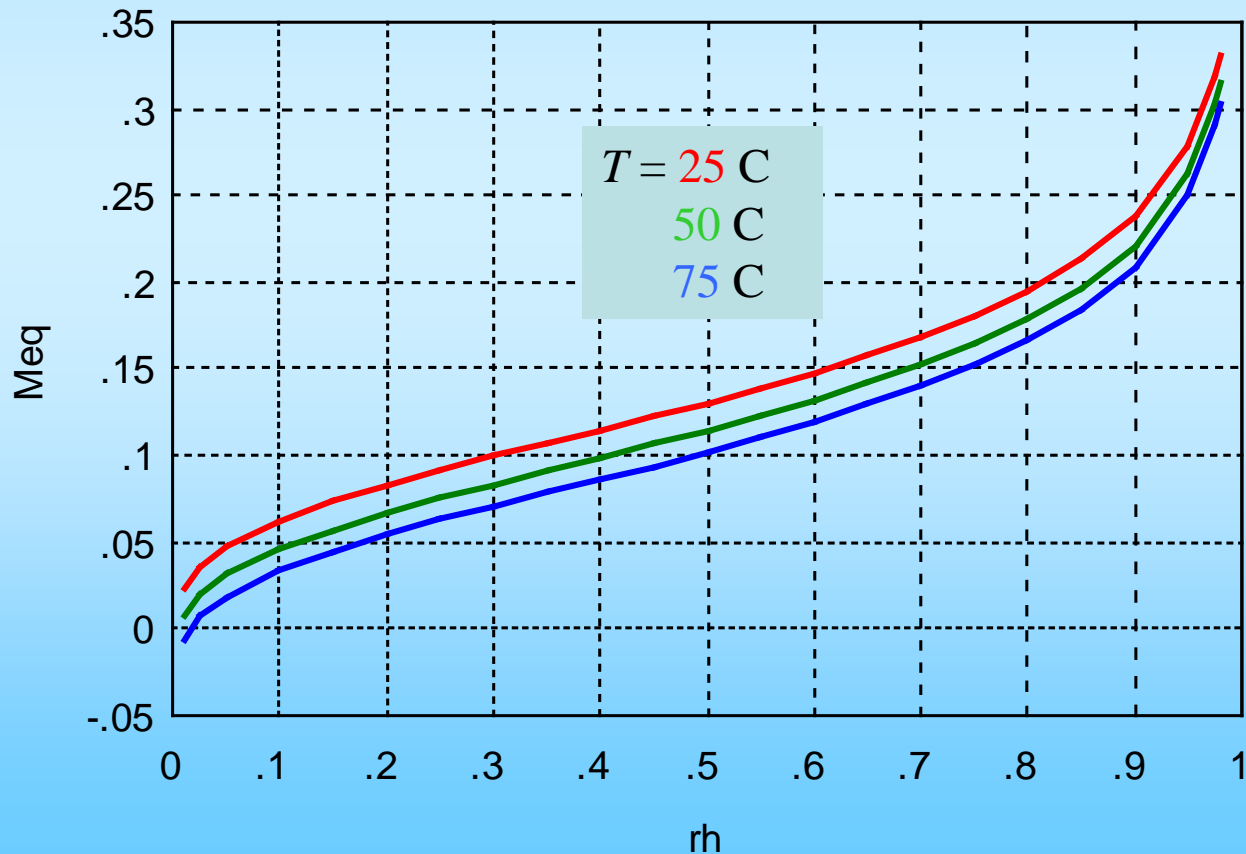
$$\frac{\partial m}{\partial \tau} = \frac{1}{\xi^2} \frac{\partial}{\partial \xi} \left(\xi^2 \frac{\partial m}{\partial \xi} \right)$$

$$m|_1 = -\frac{2}{Bi_m} \frac{\partial m}{\partial \xi} \Big|_1 \approx 0$$

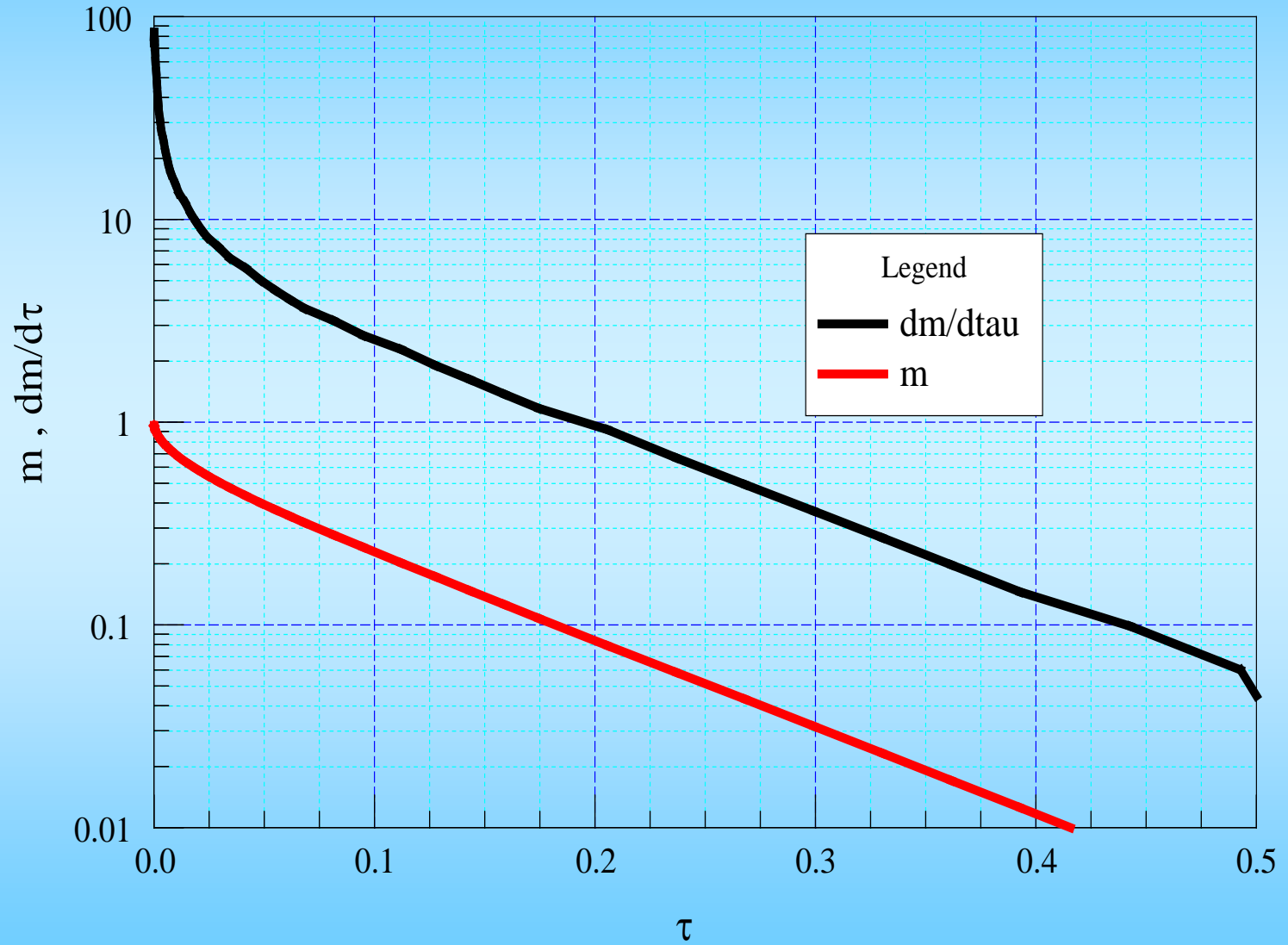
Equilibrium Moisture Content ($M_{eq} = EMC$)

Chung-Henderson Correlation:

$$M_{eq} = E_{eq} - F_{eq} \ln[-(T [C] + C_{eq}) \ln(rh)]$$



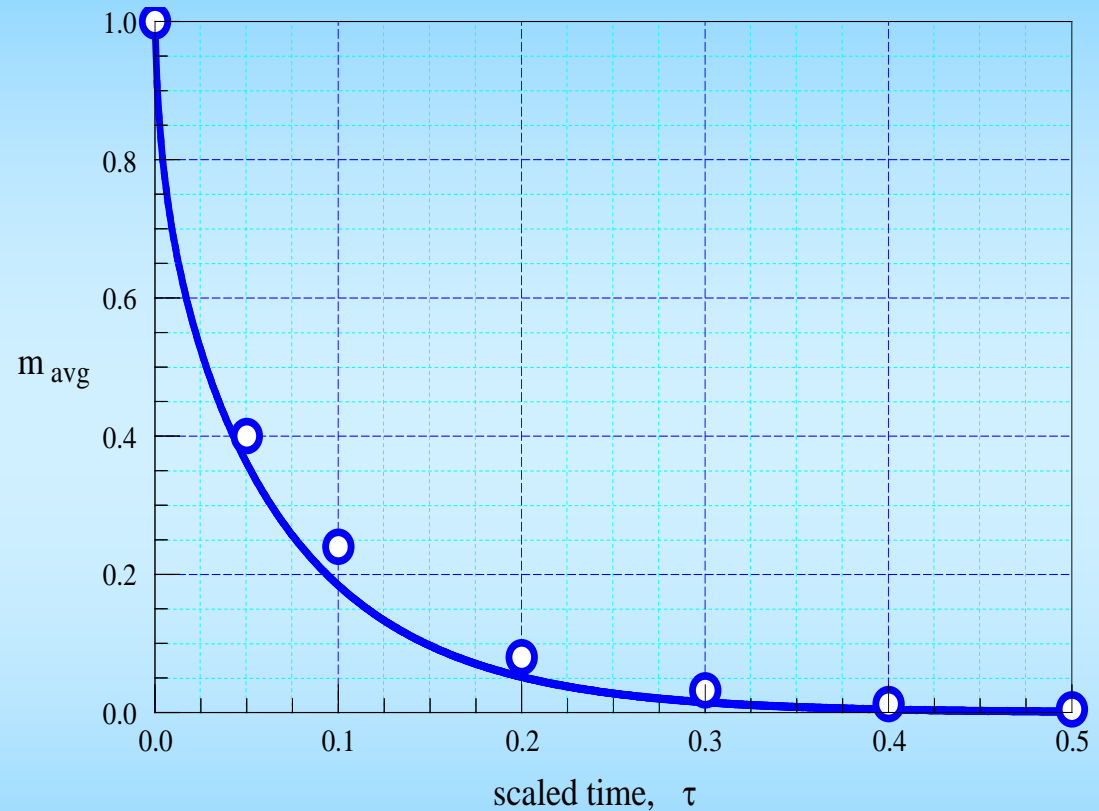
Volume-Average Concentration



Single-Kernel Moisture Transfer Correlation

$$-\frac{d\bar{m}}{d\tau} = \beta \bar{m}$$

$$\beta = \frac{12\tau + 0.11}{\tau + 0.0011}$$



$$-V_{1k} \rho_k \frac{d\bar{M}}{dt} = h_k S_{1k} \rho_k (\bar{M} - M_{eq})$$

$$h_k = \beta d_k / 6t_k$$

$$= 2/3 \beta D_k / d_k$$

Multiple-Kernel Moisture Transfer



One-Dimensional Mass Transport Equations

Volumetric Moisture Transfer

$$q_{Vm} = \frac{Q_m}{V_T} = (1 - \varepsilon) \rho_k \frac{6h_k}{d_k} (M - M_{eq})$$

Solid-Phase Moisture Transport

$$(1 - \varepsilon) \rho_k \left(\frac{\partial M}{\partial t} + U_s \frac{\partial M}{\partial x} \right) = -q_{Vm}$$

Air Humidity Transport

$$\varepsilon \rho_a \left(\frac{\partial \omega}{\partial t} + U_a \frac{\partial \omega}{\partial x} \right) = q_{Vm}$$

One-Dimensional Heat Transport Equations

Volumetric Heat Transfer

$$q_V = \frac{Q}{V_T} = (1 - \varepsilon) \frac{6h_a}{d_k} (T_a - T_s)$$

Solid-Phase Heat Transport

$$(1 - \varepsilon) \rho_s \left(\frac{\partial C'_s T_s}{\partial t} + U_s \frac{\partial C'_s T_s}{\partial x} \right) = q_V - u_m q_{Vm} - (1 - \varepsilon) \rho_s h_{fg} \frac{\partial M}{\partial t}$$

$$C'_s = C_s + C_m M$$

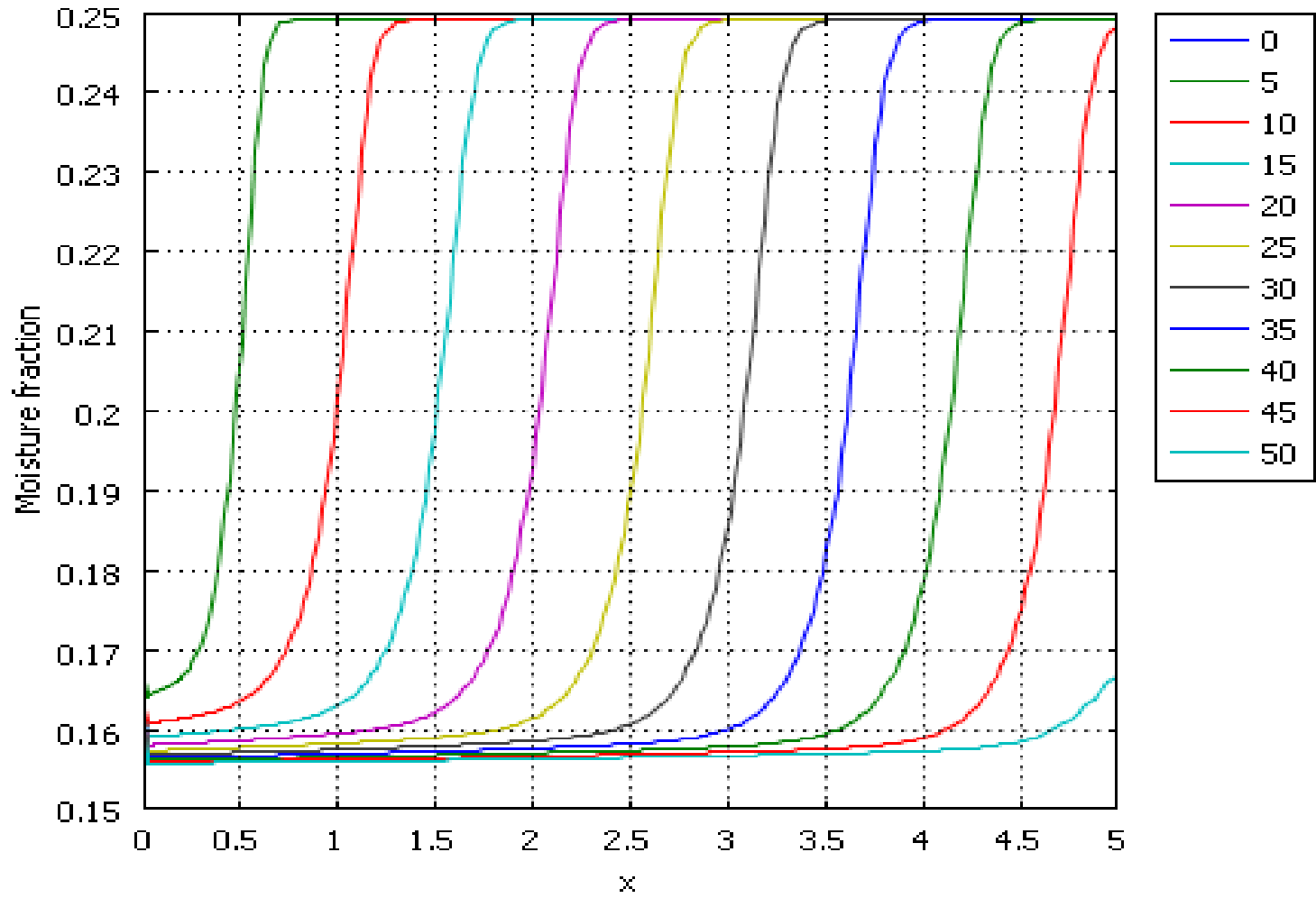
Air Heat Transport

$$\varepsilon \rho_a \left(\frac{\partial C'_a T_a}{\partial t} + U_a \frac{\partial C'_a T_a}{\partial x} \right) = -q_V + u_m q_{Vm}$$

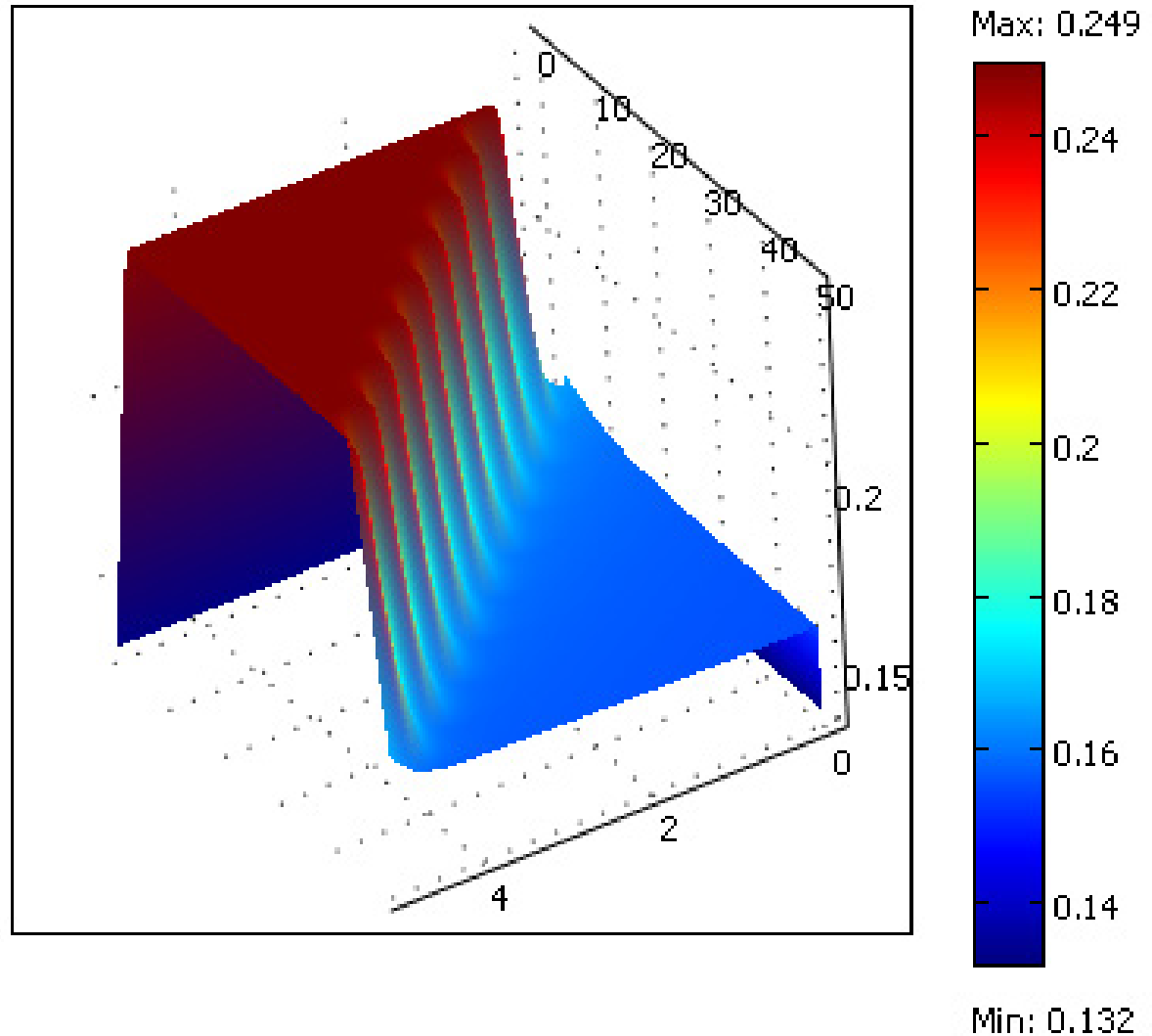
$$C'_a = C_a + \omega C_m$$

$$u_m - u_{m0} = C_m (T_s - T_{m0})$$

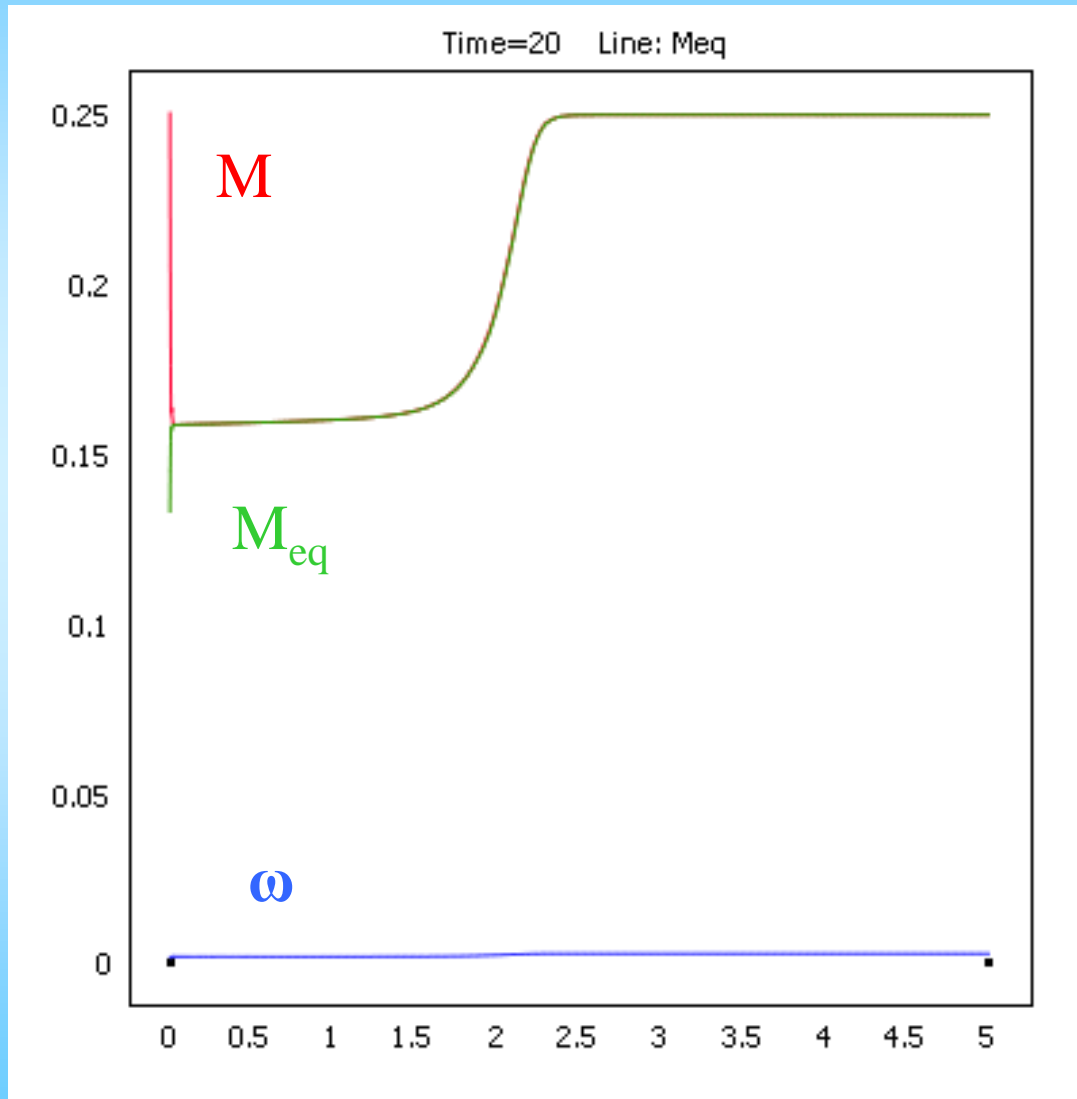
Moisture Fraction for Stationary Bed or Bin



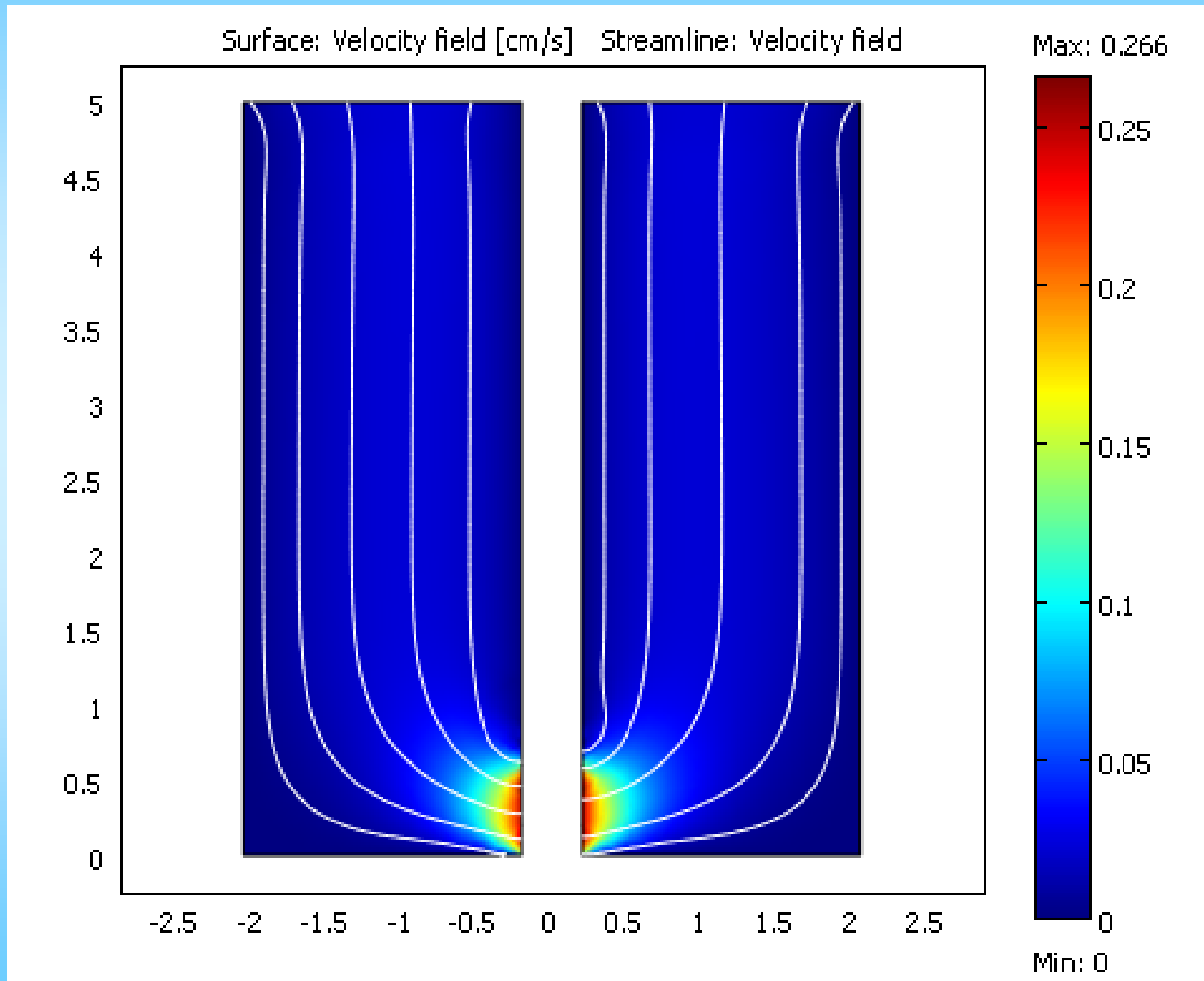
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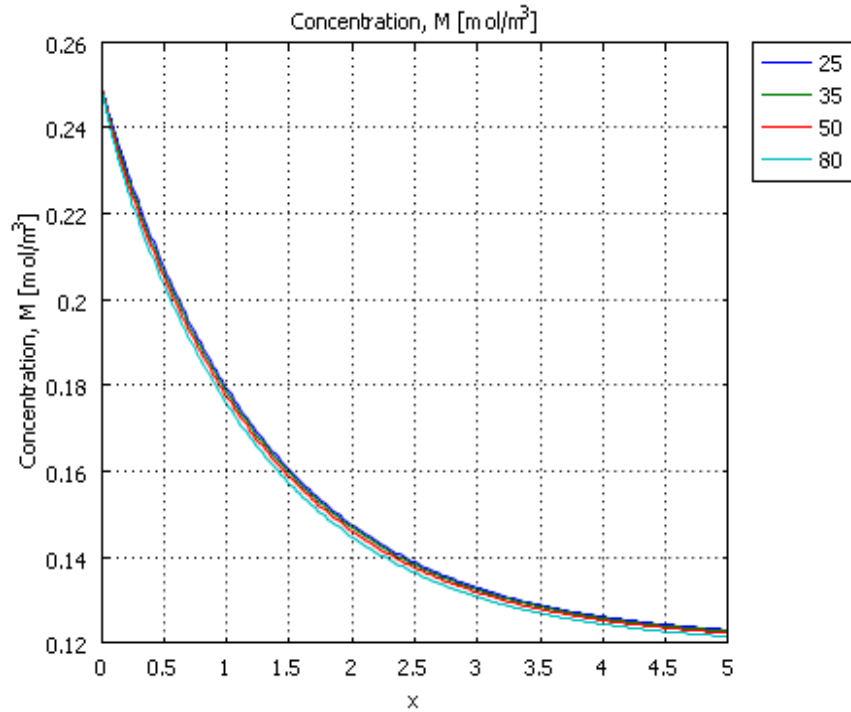
Moisture Fraction for Stationary Bed or Bin



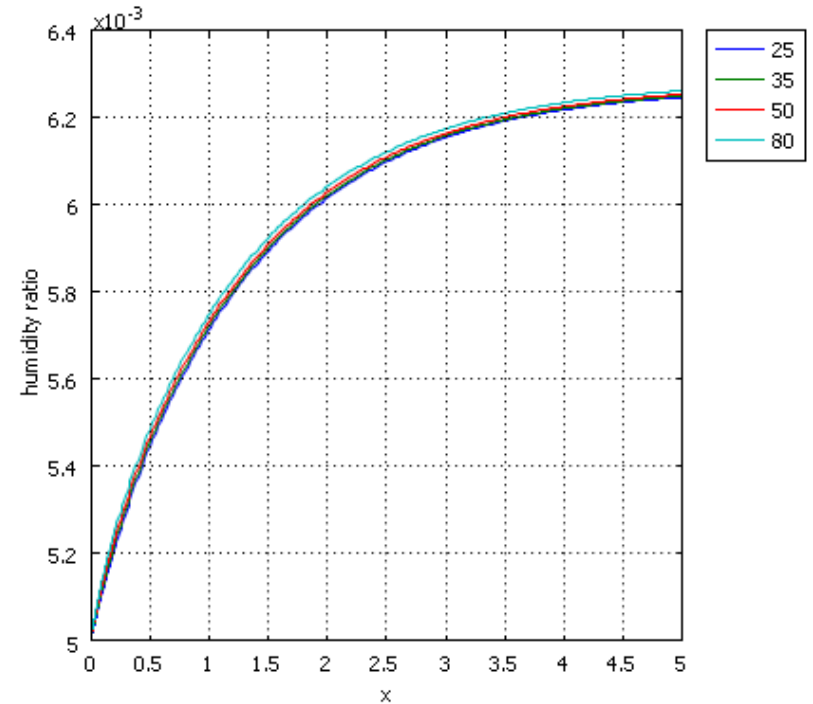
Moving Column of Grain



Kernels Moisture Fraction



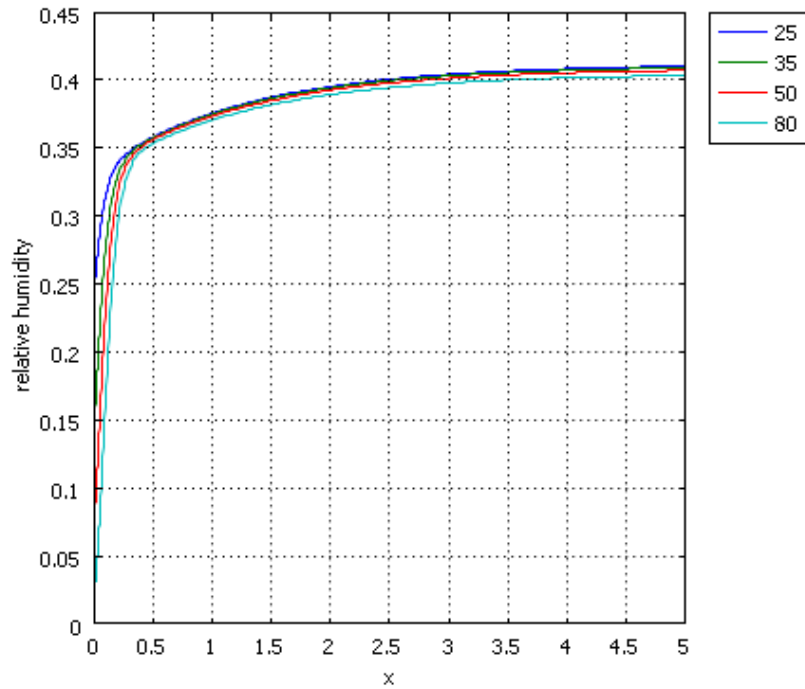
Air Humidity Ratio



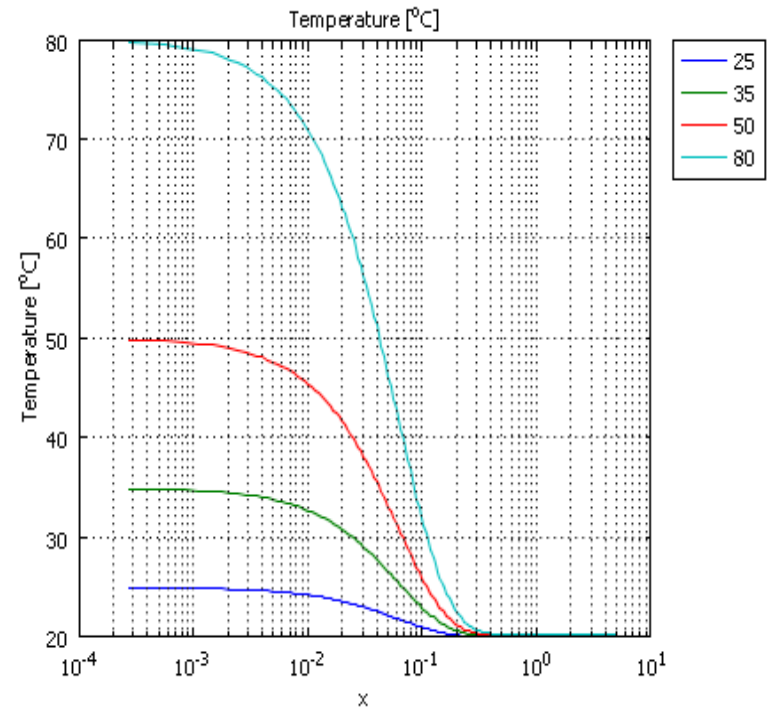
$U_s = 0.05\text{m/s}$, $U_a = 5\text{m/s}$

$\varepsilon = 85\%$

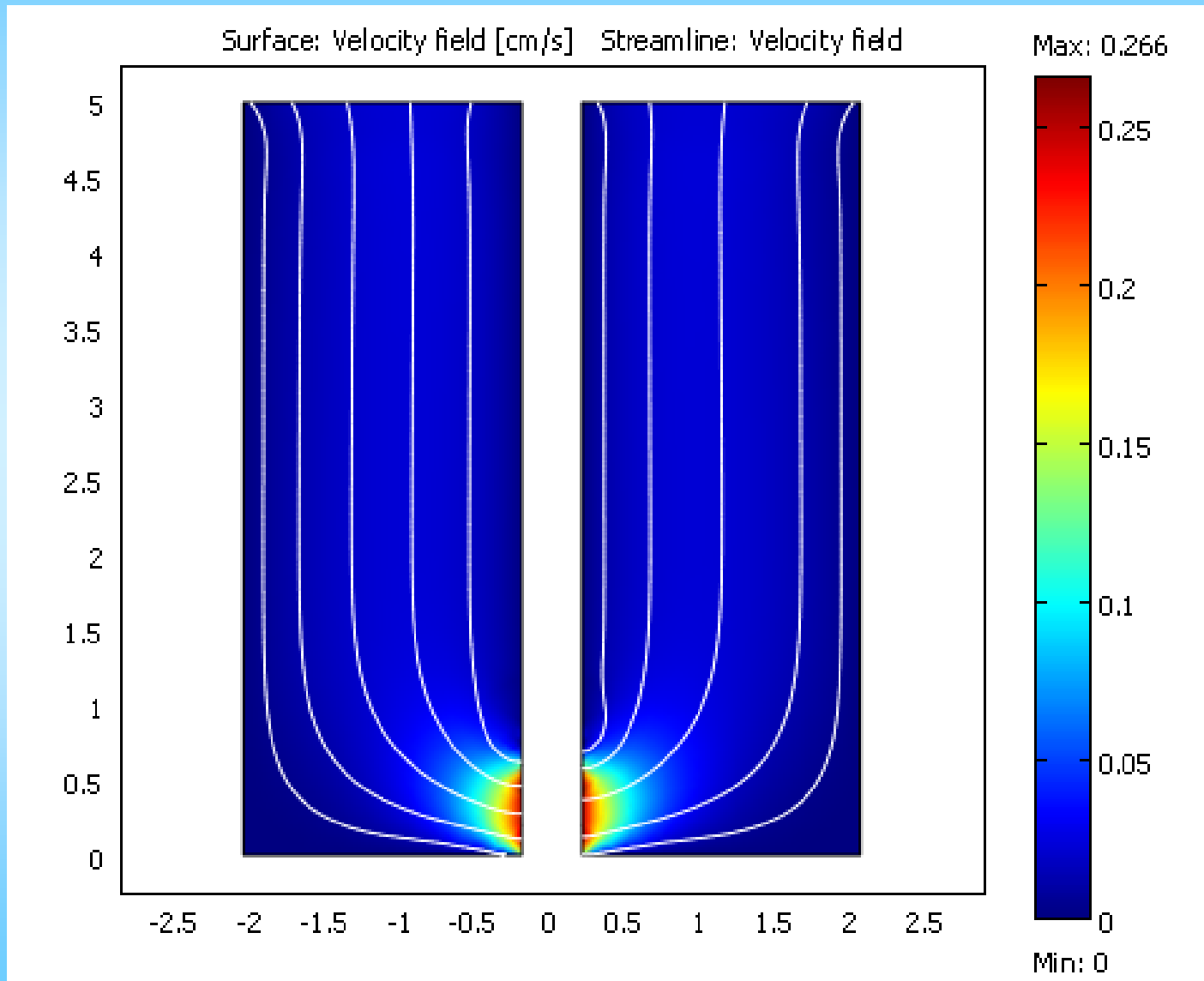
Air Relative Humidity



Air Temperatures



Moving Column of Grain



Time=0

Surface: Concentration, M [mol/m³] Streamline: Velocity field

