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Modeling deep-bed grain drying using Comsol Multiphysics©

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Outline

- Introduction
- Modeling
- Results
- Conclusion

Introduction

- ✓ Various mathematical models have been proposed to simulate grain deep-bed drying.

The main differences between the simulation results of the deep-bed and the experimental data are due to (Zare and Chen, 2009):

(1) The simplification **assumption** made when building the mathematical model,

(2) The lack of accuracy of the **thin layer** grain drying **equation**,

(3) The inadequacy of the precise equation for estimating the volumetric **heat transfer coefficient** of paddy in a packed bed,

(4) The errors in measurement of input parameters and actual performance of the grain dryer.

Introduction

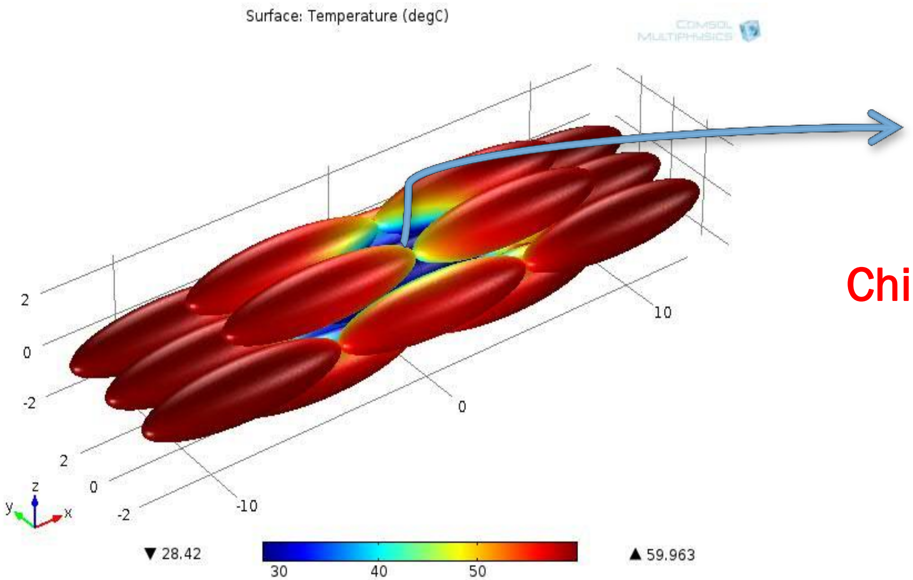
Study Objective:

The main objective of the present study was to develop a simulation model of the deep-bed drying for rough rice.

- developing a correlation for the convective heat and mass transfer coefficients as a function of drying air flow rate.
- considering a different approach to characterize the drying of rice in a thin layer.
- developing a deep-bed model assuming no thermal equilibrium between drying air and grain in the bed.

Modeling

- Heat and mass transfer coefficients determination



$$-k\frac{\partial T}{\partial n} = h_c(\theta_\infty - T_s) \qquad (1)$$

Chilton and Colburn (1934)

$$h_m = h_c\left(\frac{D_w Le^{-\frac{2}{3}}}{k}\right) \qquad (2)$$

$$Le = \left(\frac{\alpha}{D_w}\right) \qquad (3)$$

$$h_c = -2130.4G^4 + 2928.8G^3 - 1541.8G^2 + 455.7G + 3.85 \qquad (4)$$

$$h_m = -2.068G^4 + 2.85G^3 - 1.50G^2 + 0.445G + 0.0036 \qquad (5)$$

h_c	heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$)
h_m	mass transfer coefficient ($m \cdot s^{-1}$)
Le	Lewis number
α	Thermal diffusivity ($m^2 \cdot s^{-1}$)
G	Air flow rate ($kg \cdot m^{-2} \cdot s^{-1}$)

Modeling

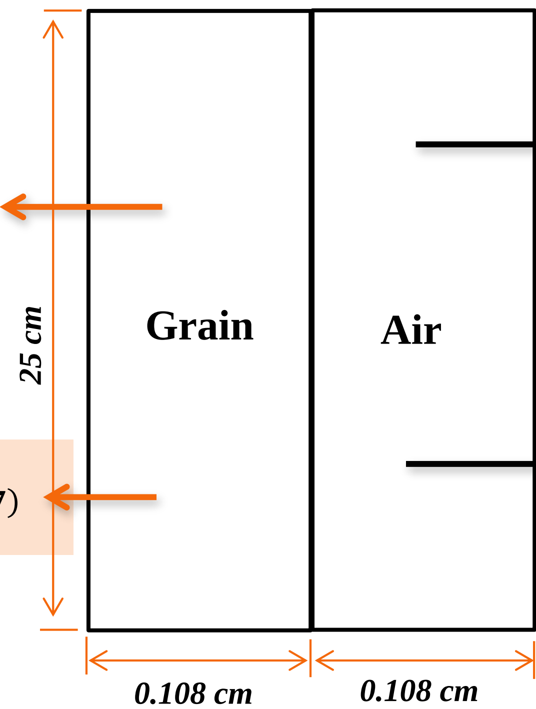
- **Transport equations**
- **Modeled Deep-bed**

Conservation of mass (water):

$$\frac{\partial M}{\partial t} = \nabla \cdot (D(T)\nabla M) \qquad (6)$$

Conservation of energy:

$$\rho_p C_p(M)\frac{\partial T}{\partial t} = \nabla \cdot \left(k_p(M)\nabla T\right) \qquad (7)$$



Conservation of mass (water vapor):

$$\frac{\partial W}{\partial t} + u \cdot \nabla W = \nabla \cdot (D_w(\theta)\nabla W) \qquad (8)$$

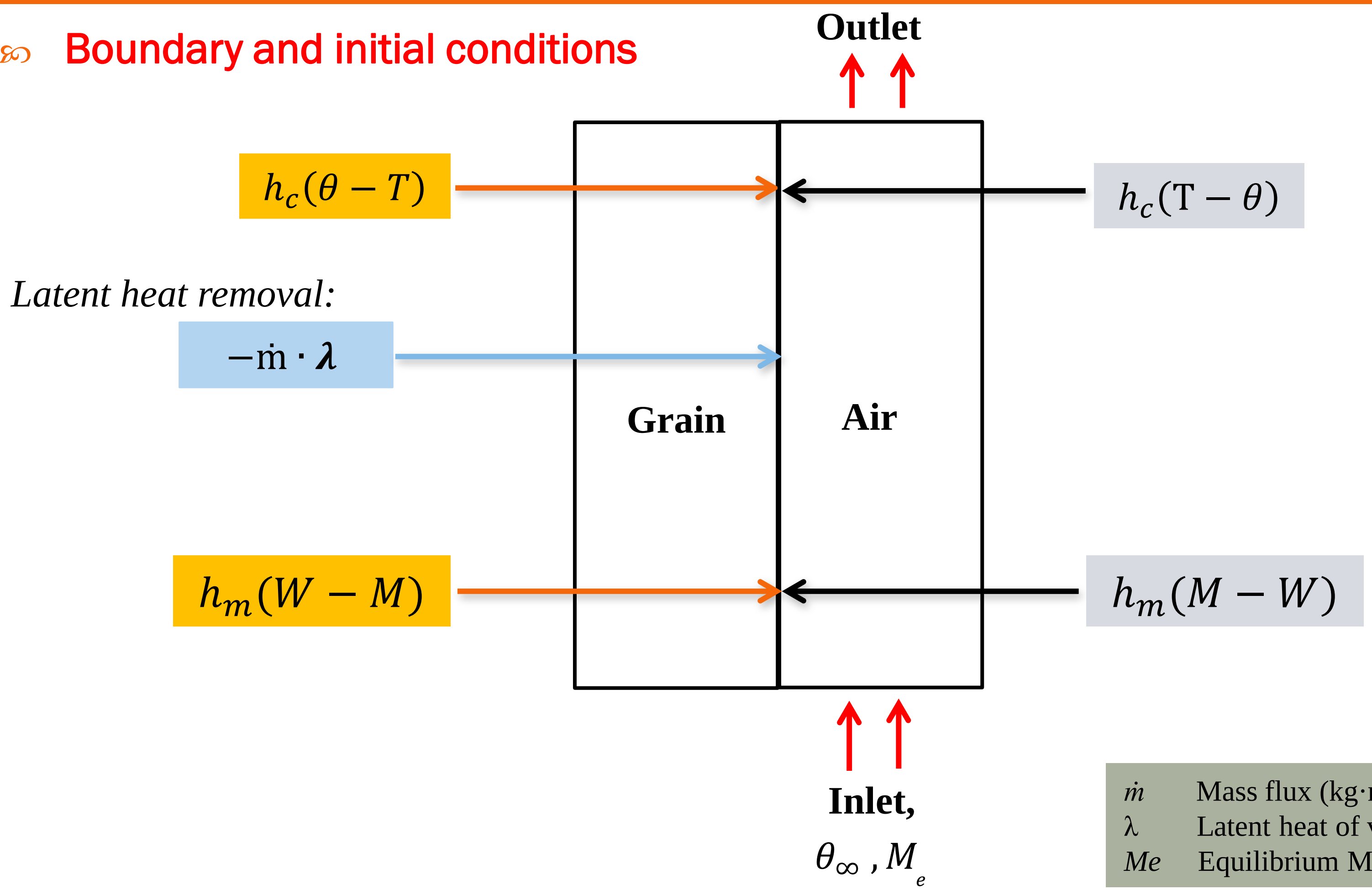
Conservation of energy:

$$\rho_a C_a(W)\frac{\partial \theta}{\partial t} + \rho_a C_a(W) u \cdot \nabla \theta = \nabla \cdot (k_a(W)\nabla \theta) \qquad (9)$$

C	Specific heat ($J \cdot kg^{-1} \cdot K^{-1}$)
D	Moisture diffusivity ($m^2 \cdot s^{-1}$)
k	Convective heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$)
M	Grain moisture content, % (d.b.)
t	Time (s)
T	Grain temperature (K)
u	Air velocity ($m \cdot s^{-1}$)
W	Air moisture content, % (d.b.)
ρ	Density ($kg \cdot m^{-3}$)
θ	Air temperature (K)

Modeling

- Boundary and initial conditions

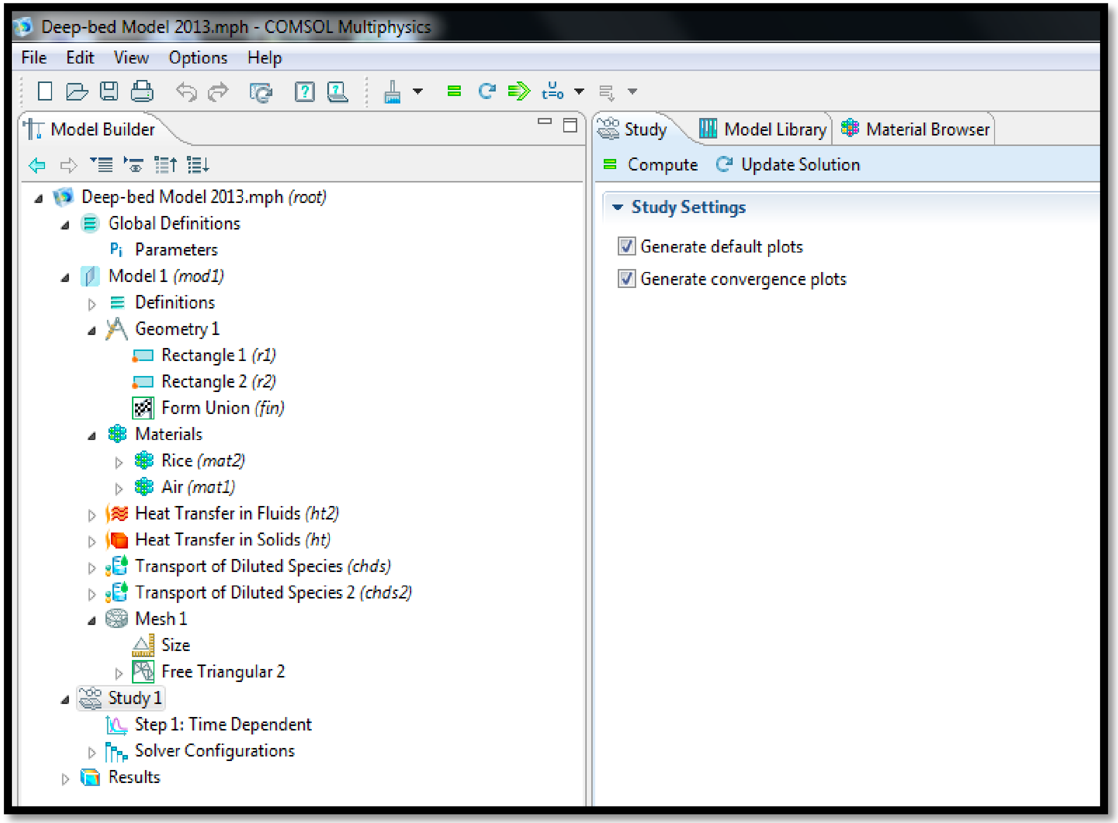


$\dot{m}$	Mass flux ($kg \cdot m^{-2} \cdot s^{-1}$)
λ	Latent heat of vaporization ($J \cdot kg^{-1}$)
Me	Equilibrium Moisture content

Modeling

Using Comsol Multiphysics®

Comsol Multiphysics® v4.3b was used for all simulations



Model Validation

- The experimental results of **Zare et al. (2006)** were used for validation.

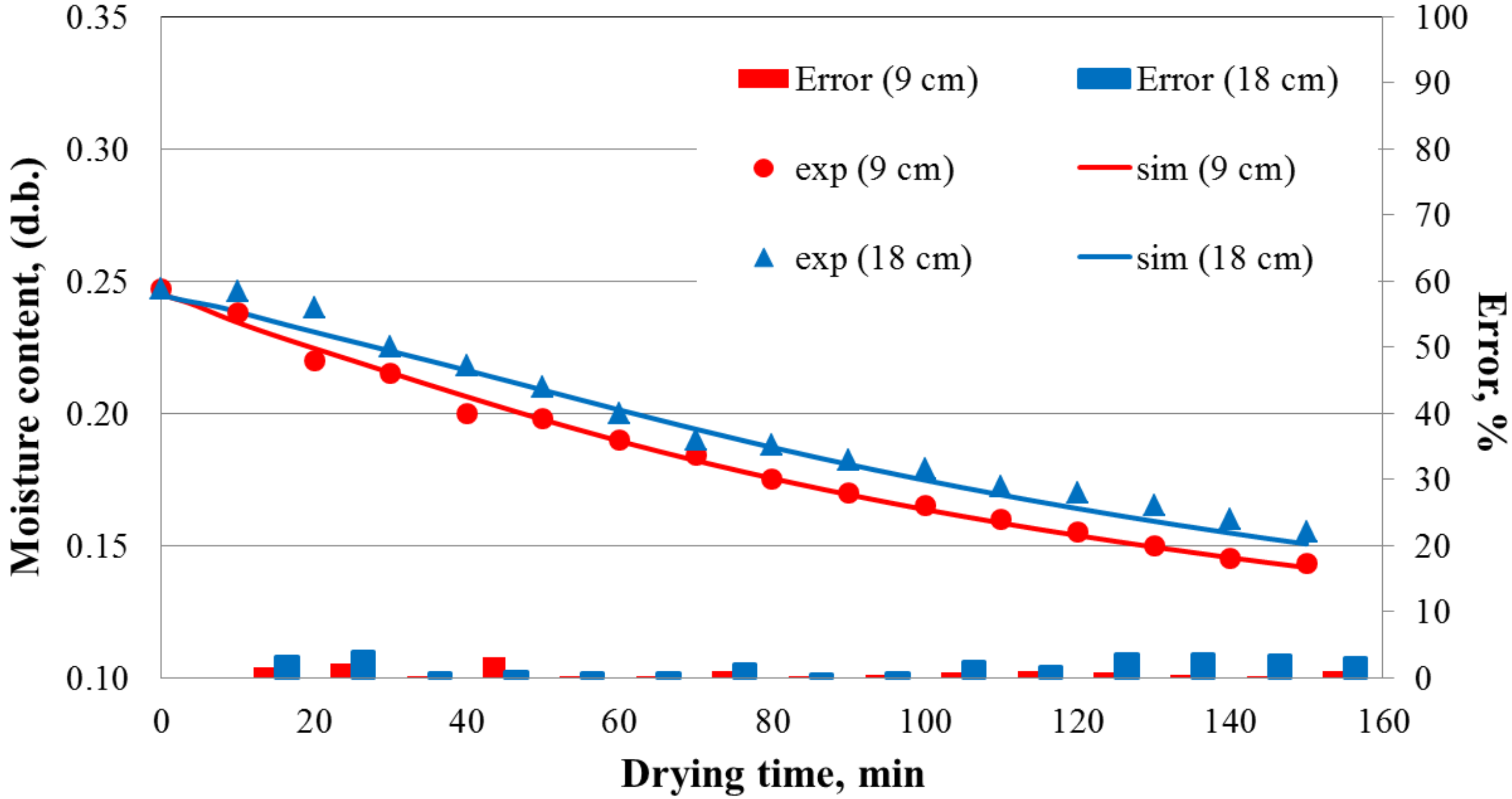
- The simulation model performance was determined by calculation of the **relative error** (*E*) and **mean relative deviation** (*MRD*) as follows:

$$E = \frac{\left|M_j - \widehat{M}_j\right|}{\widehat{M}_j} \times 100 \qquad (10)$$

$$MRD = \left[\frac{1}{n}\sum_{j=1}^{n}\left(\frac{M_j - \widehat{M}_j}{\widehat{M}_j}\right)^2\right]^{0.5} \times 100 \qquad (11)$$

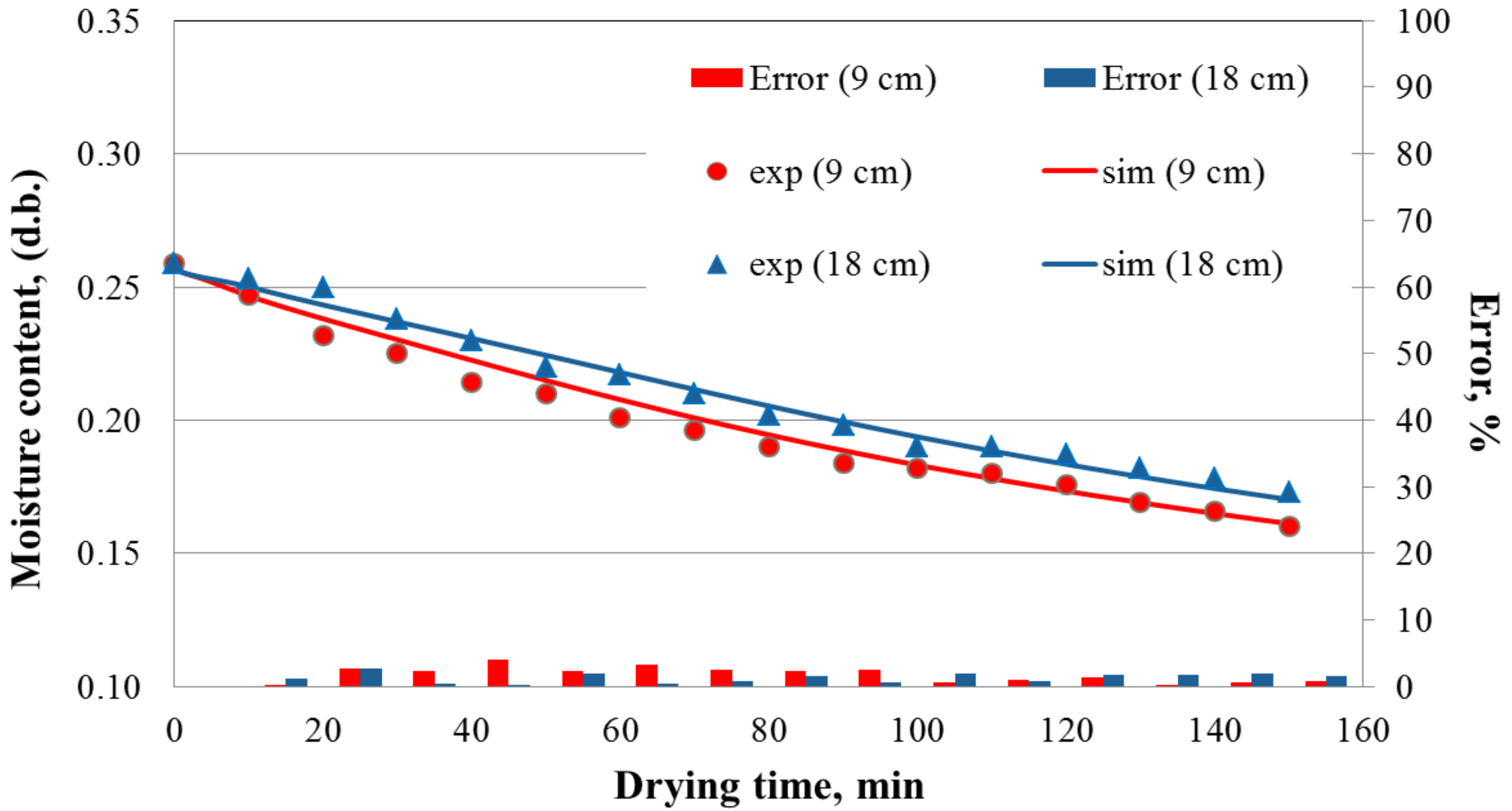
where M_j and $\widehat{M}_j$ indicate the jth experimental and predicted moisture contents of the grain (dry basis), respectively, and n is the number of measurements in each experiment.

Results



Experimental (exp) and predicted (sim) grain moisture content with drying time at different depths at θ = 50 (°C) and G = 0.22 (kg·m^{-2}s^{-1}).

Results



Experimental (exp) and predicted (sim) grain moisture content with drying time at different depths at θ = 45 (°C) and G = 0.22 (kg·m^{-2}s^{-1}).

Results

Table 1. results of validation tests for the predicted moisture content				
Run	Inlet air temperature (°C)	Mass flow of air ($kg \cdot m^{-2} \cdot s^{-1}$)	MRD %	
			Depth, 9 cm	Depth, 18 cm
1	50	0.22	1.15	2.31
2	45	0.22	2.07	1.47
3	50	0.16	1.00	3.13
4	45	0.16	2.04	1.27

Conclusion

- The developed model was used successfully for describing the coupled heat and mass transfer inside a deep-bed of rice during drying.
- The model prediction of the grain moisture content at different locations in the bed was verified using experimental data from literature and was found to be satisfactory.
- Comsol Multiphysics is a useful tool to modeling the heat and mass transfer processes during grain drying.

Thanks for your attention

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