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UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI INGEGNERIA INFORMATICA, MODELLISTICA, ELETTRONICA E SISTEMISTICA
DIMES

COMSOL MULTIPHYSICS®

MODELING AND SIMULATING THE PASTA DRYING PROCESS VIA COMSOL MULTIPHYSICS

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COMSOL Conference, Firenze, October 2024

Research Team

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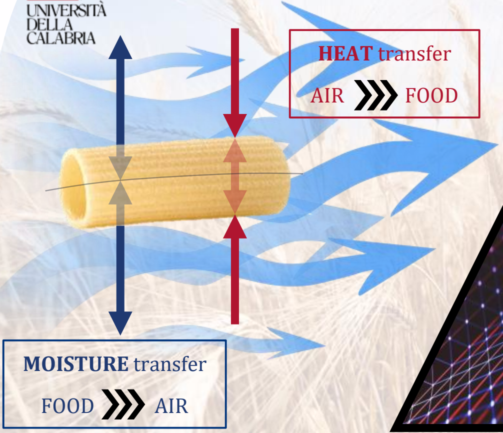
1. Problem Outline



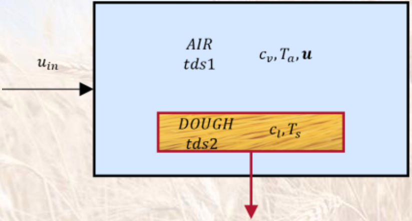
4. Simulation software
- COMSOL Multiphysics 6.2

3. Numeric-Engineering approach
- **F**inite **E**lement **M**ethod

2. Problem to be solved
- System of unsteady, non-linear **PDEs**

1. Physical-Mathematical model
- **Heat** Transfer Balance
- **Mass** Transfer Balance
- **Momentum** Transfer Balance

2. Model Structure



$$c_{v,int} = \frac{P_s(T_{s,int}) \cdot a_w(X_{int}, T_{s,int})}{R \cdot T_{a,int}}$$

- **2 species**, each for each domain ($\boldsymbol{c_v}, \boldsymbol{c_l}$)
- **2 -Transport of Diluted Species-** modules, each for each domain (***AIR***, ***DOUGH***)
- Obtaining **vapour concentration** at the interface by applying **thermodynamic equilibrium condition**

$$y_v \cdot p = P_s \cdot a_w$$

- **"Transport phenomena in pasta drying: a dough-air double domain advanced modeling",** *G. Adduci, F. Petrosino, E. Manoli, E. Cardaropoli, G. Coppola, S. Curcio*, Journal of Food Engineering 2024, https://doi.org/10.1016/j.jfoodeng.2024.112052

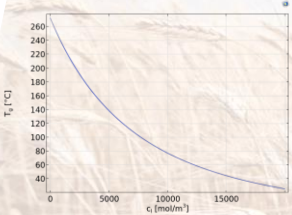
3. Heat / Mass Transfer

	Heat	Mass
Solid Domain 	$\rho_d\, C_{pd}\, \frac{\partial T_s}{\partial t} = \boldsymbol{\nabla} \cdot (k_d\, \boldsymbol{\nabla} T_s)$ ▪ By **conduction** exclusively ▪ **Fourier's Law** ▪ **Evaporation** only occurs at **food surface**	$\frac{\partial c_l}{\partial t} = \boldsymbol{\nabla} \cdot (D_d\, \boldsymbol{\nabla} c_l)$ ▪ By **diffusion** exclusively ▪ **Fick's Law** ▪ **Liquid** species only ▪ **Evaporation** only occurs at **food surface**
Fluid Domain 	$\frac{\rho_a\, C_{pa}\, \partial T_a}{\partial t} - \boldsymbol{\nabla} \cdot (k_a\, \boldsymbol{\nabla} T_a) + \rho_a\, C_{pa}\, \boldsymbol{u}\, \boldsymbol{\nabla} T_a = 0$ ▪ By both **convection and conduction**	$\frac{\partial c_v}{\partial t} + \boldsymbol{\nabla} \cdot (-D_a\, \boldsymbol{\nabla} c_v) + \boldsymbol{u}\, \boldsymbol{\nabla} c_v = 0$ ▪ By both **convection and diffusion** ▪ **Vapour** species only

- **"Transport phenomena in pasta drying: a dough-air double domain advanced modeling",** *G. Adduci, F. Petrosino, E. Manoli, E. Cardaropoli, G. Coppola, S. Curcio*, Journal of Food Engineering 2024, https://doi.org/10.1016/j.jfoodeng.2024.112052

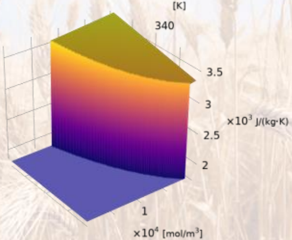
4. Glass Transition Phenomena

T_g from Kwei's Model



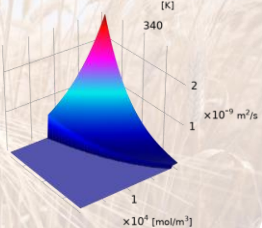
- $T_g = f(c_l)$
- **Rubbery** state above, **glassy** state below
- T_g **increases** as c_l **decreases**

Adjusted $C_{pd} = f(c_l, T)$



- $3400 < C_{pd}|_{T_{g,RUB}} < 3500 \quad \left[\frac{J}{kg \cdot K}\right]$
- $C_{pd}|_{T_{g,GLA}} = 1841 \; \frac{J}{kg \cdot K}$
- $MaxVar \cong -49\ \%$

Adjusted $D_d = f(c_l, T)$



- $0.1 \cdot 10^{-9} < D_d|_{T_{g,RUB}} < 2.5 \cdot 10^{-9} \quad \left[\frac{m^2}{s}\right]$
- $D_d|_{T_{g,GLA}} = 1.55 \cdot 10^{-12} \; \frac{m^2}{s}$
- $MaxVar \cong -99\ \%$

5. Structural Analysis

$$\sigma = \sigma_{el} + \sigma_{inel}$$

Elastic Stress (σ_{el})

- *Linear Elasticity*
- *Isotropic Material*

$$\sigma_{el} = \sigma_{el,dev} + \sigma_{el,vol} = \|C\| : \epsilon_{el}$$

Inelastic Stress (σ_{inel})

- *Linear Viscoelasticity*
- *Generalized Maxwell Model*

$$\sigma_{inel} = \cancel{\sigma_0} + \cancel{\sigma_{ext}} + \sigma_{ve} = \sigma_{ve,dev}$$

0 0

Hygroscopic Swelling (ϵ_{hs})

$$\epsilon_{hs} = \beta \cdot M_l \cdot \left(c_l - c_{l,ref}\right)$$

$$\{d\epsilon\} = \{d\epsilon_{el}\} + \{d\epsilon_{ve}\} + \{d\epsilon_{hs}\}$$

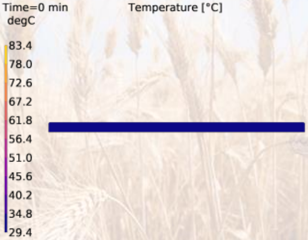
6. System Geometry

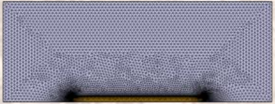
3D 2D

$$\frac{V}{S_{exp}} \Leftrightarrow \frac{S}{L_{exp}}$$

- Basic geometry equivalent to a **"Tortiglione" pasta**
- Better understanding of **transport phenomena** propagating close to **the interface**
- **Facilitated structural analysis**

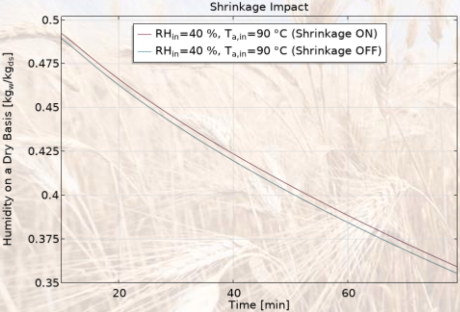
7. Results (I)

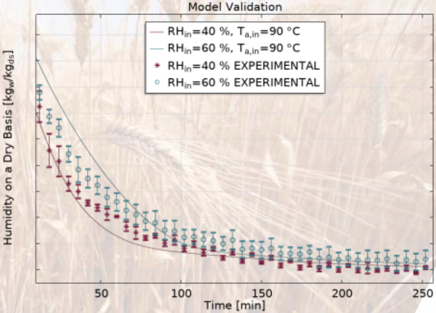




- Number of Elements 12063
- Mesh Vertices 6599
- Mesh Area 9600 mm^2
- Average Element Quality 0.8663

8. Results (II) and Model Validation





Conclusions

- **Transport phenomena** within a drying chamber were first **modelled** and then **simulated** via COMSOL Multiphysics.
- COMSOL implementation of **2 tds interfaces**, each for each domain.
- The proposed model totally **disregards** the use of the **transport coefficients** of mass and heat at the interface between the samples to be dried and the drying air.
- **Glass transition phenomena** were taken into account.
- A **structural analysis** was conducted.
- Simulations **reflect** the physics governing the process by **closely mirroring** the **validated tests**.

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