Modelling of Coupled Mass and Heat Transfer and Expansion during Baking of Bread in a Mould

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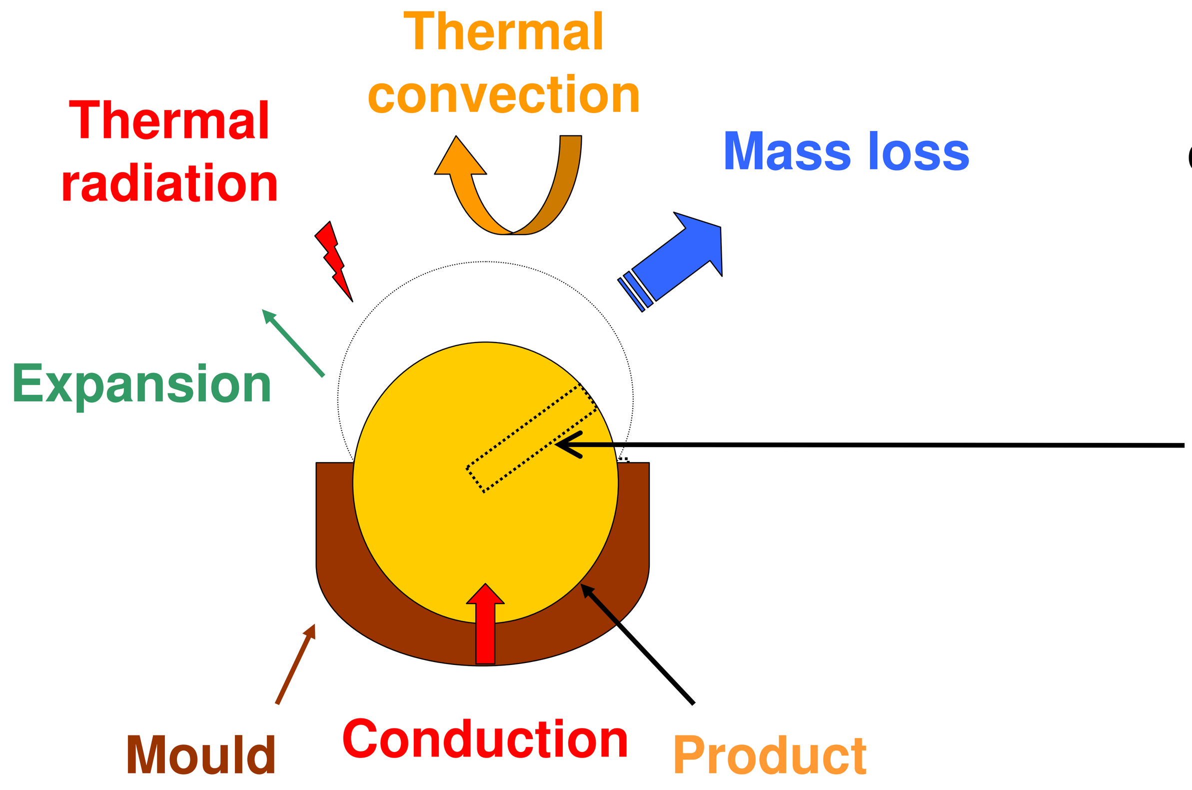
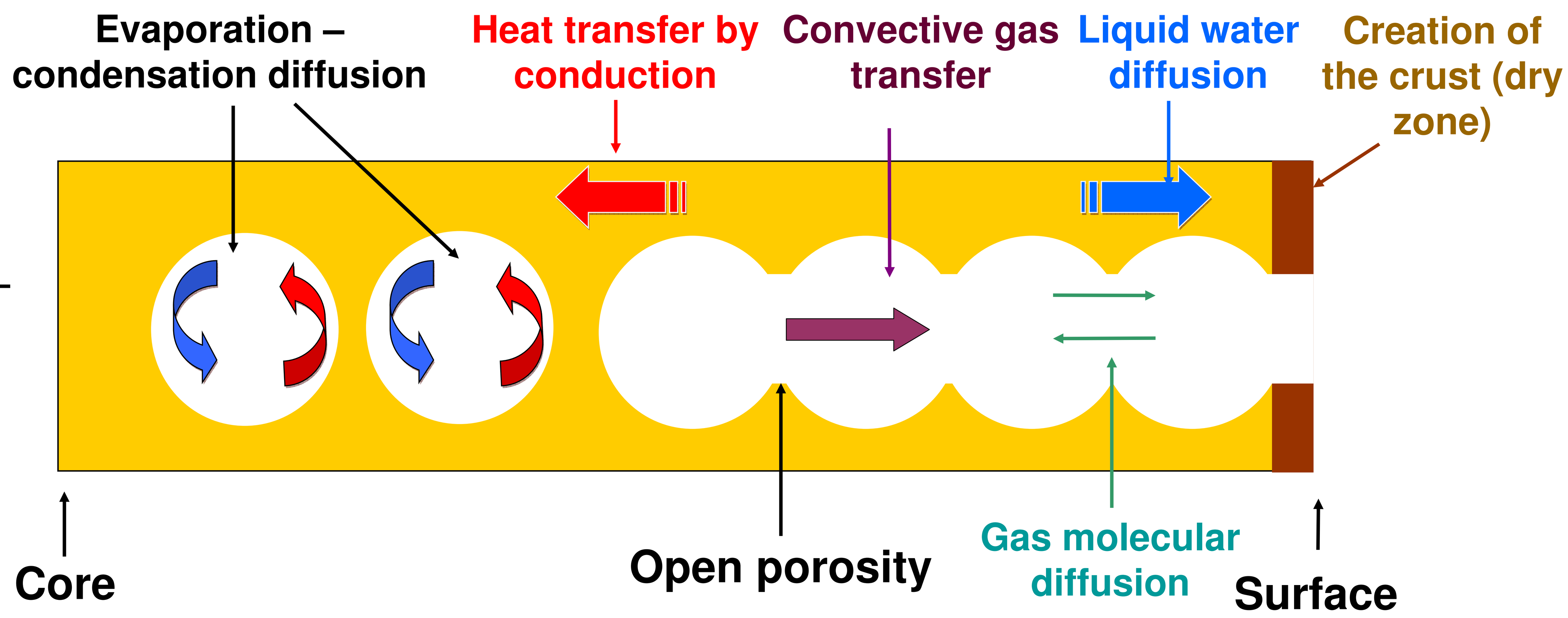
Industrial problematic

High temperatures during bread baking deteriorates the mould. Numerical tools are used to find new processes of baking to preserve mould and bread quality.

Objectives

- have a better knowledge and understanding of the main phenomena and their relative weight occurring during the baking process
- modelling the baking step help to control and optimize the industrial process





Equation system

$$\rho_s^a \frac{\partial X_{wl}}{\partial t} + \vec{\nabla}\cdot\left(\vec{\dot{m}}_{wl} + \vec{\dot{m}}_{wvvc} + \vec{\dot{m}}_{wvd} + \vec{\dot{m}}_{wvdi} + \rho_s^a (X_{wv} + X_{wl})\vec{u}\right) = -\left((X_{wl} + X_{wv})\frac{\partial \rho_s^a}{\partial t} + \rho_s^a \frac{\partial X_{wv}}{\partial t}\right)$$

$$\rho_s^a \frac{\partial X_{cl}}{\partial t} + \vec{\nabla}\cdot\left(\vec{\dot{m}}_{cl} + \vec{\dot{m}}_{cvd} + \vec{\dot{m}}_{cvdi} + \left(\rho_s^a X_{cv} + \rho_s^a X_{cl}\right)\vec{u}\right) = -\left((X_{cv} + X_{cl})\frac{\partial \rho_s^a}{\partial t} + \rho_s^a \frac{\partial X_{cv}}{\partial t}\right)$$

$$\rho_s^a \frac{\partial X_a}{\partial t} + \vec{\nabla}\cdot\left(\vec{\dot{m}}_{ad} + \vec{\dot{m}}_{adi} + \rho_a^a \vec{u}\right) = -X_a \frac{\partial \rho_s^a}{\partial t}$$

$$\rho_s^i \frac{\partial \varepsilon_s}{\partial t} + \vec{\nabla}\cdot\left(\rho_s^a \vec{u}\right) = 0$$

Mass conservation (water, carbon dioxide, air, dry matter)

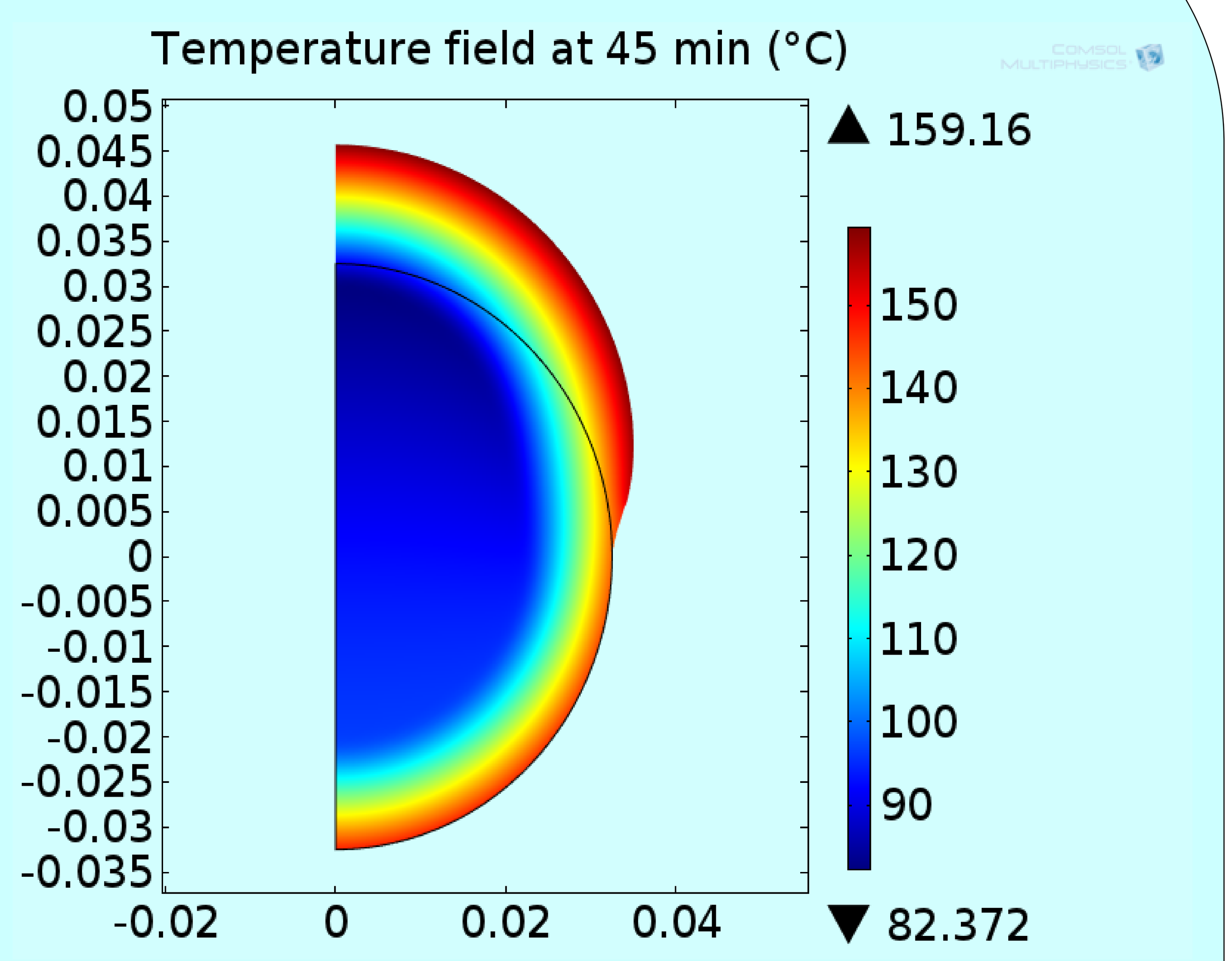
$$\vec{\nabla}\cdot\left(\overline{\overline{\tau}} + (P_{wv} + P_{cv} + P_{av} - P_0)\overline{\overline{I}} + \rho\vec{u}\vec{u}\right) = 0$$

Mechanical equilibrium

$$\frac{\partial \hat{H}}{\partial t} + \vec{\nabla}\cdot\left(\dot{Q} + \dot{H}_{vc} + \dot{H} + \hat{H}\vec{u}\right) = 0$$

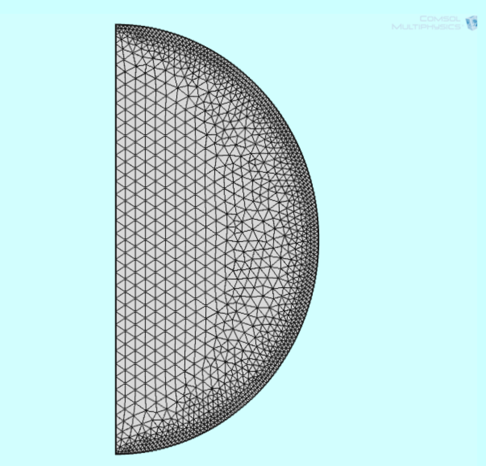
Energy conservation

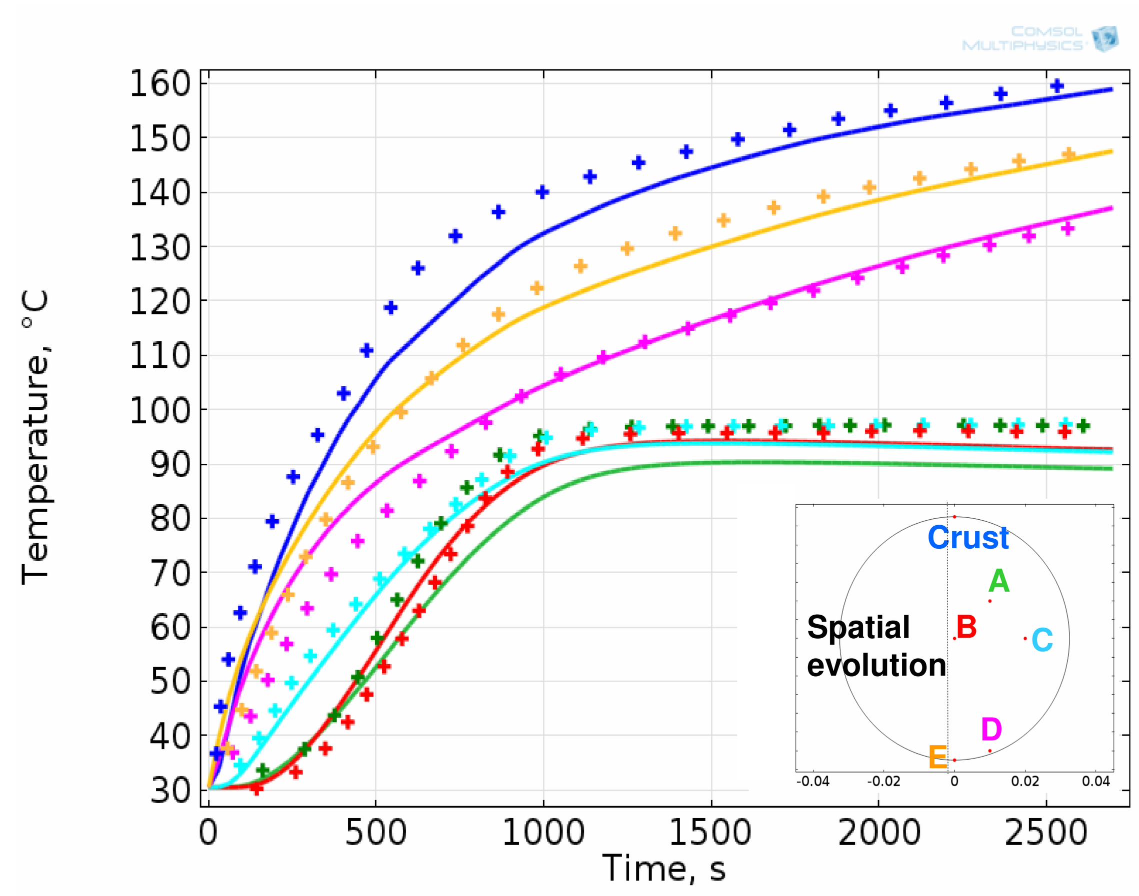
Coupled with thermodynamical equilibrium for water and carbon dioxide between liquid and vapour phase

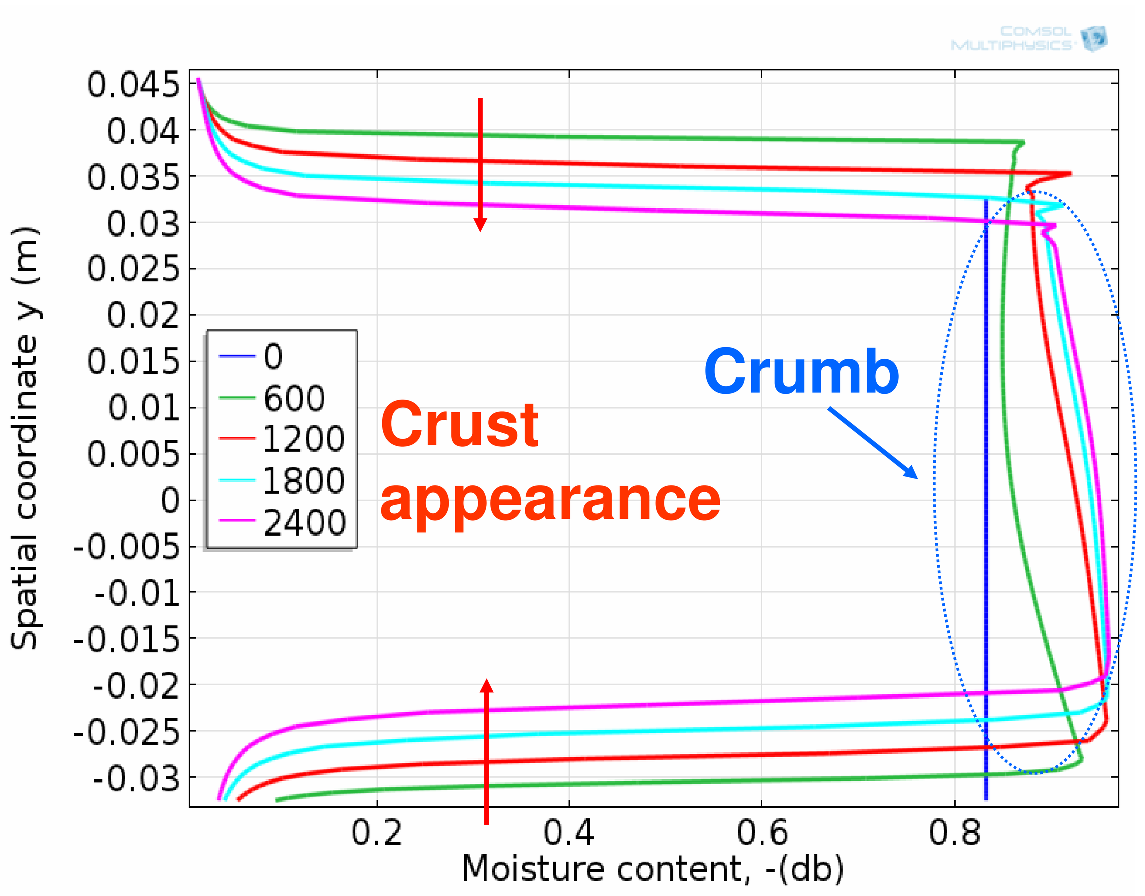


Numerical model

- 2555 triangular elements
- The algebraic differential equations system use an ALE formulation taking into account of the bread expansion







Results

- good agreement with experimental data for temperature, mass loss and deformation
- crust and crumb section are well identified with the model

Conclusion

- the model implemented with COMSOL Multiphysics allows to simulate the baking of bread in a mould
- use the model to explore new heating modes (low temperature baking) in order to increase the mould lifetime

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SATIN Safe Tin Bread 2012-2015 www.satin-baking.fr ANR

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