Numerical Model for Predicting Heat and Mass Transfer Phenomena During Cake Baking

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Abstract

This communication deals with the implementation of a numerical model for predicting heat and mass transfers phenomena as well as the swelling encountered during the baking of cake contained in mold. The aim of this study is to provide an effective numerical tool for a well understanding of the mechanisms leading to the desired end product.
A transient two-dimensional axisymmetric model is implemented in COMSOL Multiphysics® software to simulate temperatures, moisture contents distributions and cake swelling caused by the leavening agent (Figure 1). In this approach, the medium is assumed to be a deformable porous medium containing three phases: solid (dough), liquid (water) and gas [1-3]. Gas phase includes two species, water and CO2 (released by the leavening agent). Based on the governing equations for heat and mass transport and under few assumptions (homogenous medium, local thermodynamic equilibrium, gas phase assumed to be an ideal gas mixture…), the problem consists in solving a system of five coupled partial derivative equations. The state variables are the temperature, the moisture content, the total gas pressure, the porosity and the displacement [4-5]. The swelling of dough caused by the increase of total gas pressure is predicted by a viscoelastic model included in the Structural Mechanics Module. A moving mapped mesh (ALE) with 2500 elements is used (Figure 2).
For model validation, experimental tests are carried out on a laboratory set up. A specific instrumentation continuously provides information about boundaries conditions, thermal and moisture content inside the dough. The swelling is tracked by camera. These measurements are next exploited.
First numerical results are presented in Figure 3. Temperatures and moisture distributions are plotted for three instants: initial state, halfway through cooking and final state. The swelling can be also visualized. The analyze of moisture content distributions for the three instants shows an increase of water content in the cake core (crumb) caused by evaporation-condensation phenomenon whereas water content continually decreases at the cake surface (crust). This physical phenomenon, already observed for other baking processes [1-3], participates in the formation of large moisture contents gradients which induces large heterogeneity of porosity and properties (thermal, hydric, mechanical properties). Moreover, heating mode generates large temperature gradients, which also participates in the heterogeneity generation.
The model implemented in COMSOL predicts temperatures, moisture contents, pressures and porosities distribution during the baking of cake.

Reference

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Figures used in the abstract

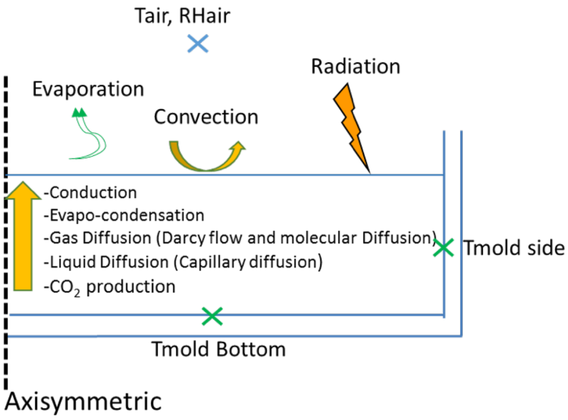

Figure 1: Transport mechanisms.

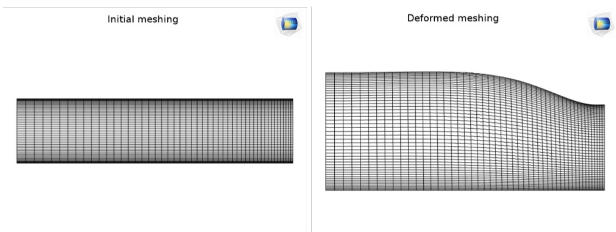

Figure 2: Geometry and mesh.

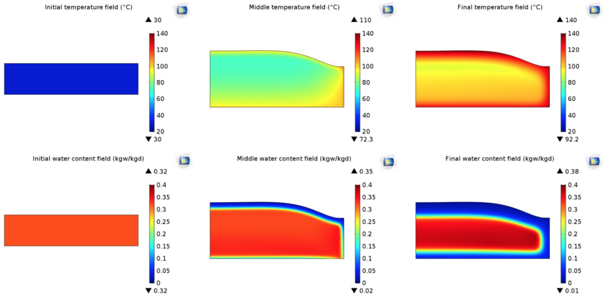

Figure 3: Simulated distributions (temperatures and moisture contents) during baking process.