Using COMSOL Multiphysics to Model Crust Development at the Surface of Whole Beef Meat Subjected to Hot Air Jet

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Abstract

Introduction

Crust which develops at the surface of foods during grilling and roasting leads to Maillard and oxidation reactions which affect food color, flavor and safety[1][2].

An Experimental Study have been conducted recently to study the mechanisms of crust development at the surface of whole beef meat cylinders subjected to hot air jet [3]. Temperatures, structure (Figure 1) and water content profiles were measured within the crust. A heat-mass transfer model is presented in this paper to predict crust development.

Use of COMSOL Multiphysics

Meat was considered as an association of water and dry matter. Heat transfer in the meat was assumed to be purely conductive, hence meat was modeled as an effective monophasic solid.

During cooking juice is expelled due to the thermal contraction of proteins. This phenomena was simplified using an adapted diffusion equation. When the temperature in the meat approaches the boiling temperature, phase change occurs leading to vapor phase. Energy consumed was integrated as a heat sink.

The modeling approach was validated using a two steps procedure. In the first step the calculated migration of juice was compared to experimental results obtained in water bath where no crust can develop [4]. In the second step simulated results were compared for the hot air jet case [3]. Only the second part of this study is presented from there onwards.

Boundary condition for the transport of water at the top surface subjected to the heat flux depended on the local state of the fluid. For liquid water, juice migration was mainly governed by meat contraction hence a concentration condition depending on temperature was fixed. For vapor water, an external forced convection condition was used with a mass transfer coefficient determined from the properties of the impacting jet [5]. For other surfaces, which were experimentally in contact with isolating material, a no flux condition was selected. Rotational

symmetry was also used to reduce the domain.

This time-dependent study was solved fully coupled using the PARDISO direct solver.

Results

In contrast with the complex internal behavior, surface temperature was mainly affected by the following parameters: heat transfer coefficient, vapor diffusivity in the crust, and equivalent material thermal properties. The heat transfer coefficient was consistent with previous experimental measurements. The water vapor diffusivity in the crust was assumed equal to within air at the same temperature. Thermal properties were varied according to the phases' ratio.

Predicted meat surface temperature profiles were in agreement with the measurements (Figure 2).

Time-temperature variation within the product leads to a color gradient in the meat cut. It is compared to the simulated temperature profile in Figure 3.

Conclusion

This model reliably predict product surface temperatures. Work is in progress to improve the prediction of mass transfer using the water profiles measured by MRI. In the final stage of the project the heat-mass transfer model will be combined with biochemical kinetics to better inactivate the bacteria while minimizing the formation of carcinogenic compounds and preserving meat sensorial qualities.

Reference

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[4] V. Allot, Modélisation des transferts dans un milieu poreux déformable, Institut Supérieur d'Informatique, de Modélisation et de leurs Applications (ISIMA), internship report(2014).

[5] A. Kondjoyan & J.D. Daudin, Determination of transfer coefficients by psychrometry, International Journal of Heat and Mass Transfer, 36(7), 1807-1818(1993).

Figures used in the abstract

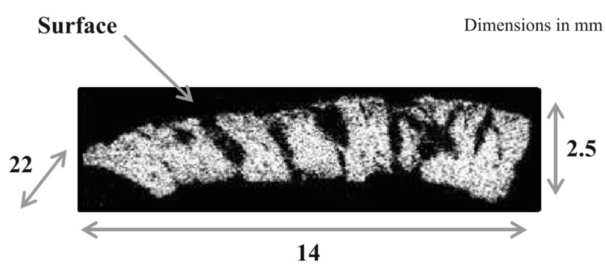

Figure 1: Example of an X-ray microtomography image of meat crust cooked at 260°C for 40 min. Note the heterogeneity in pore and crack distribution

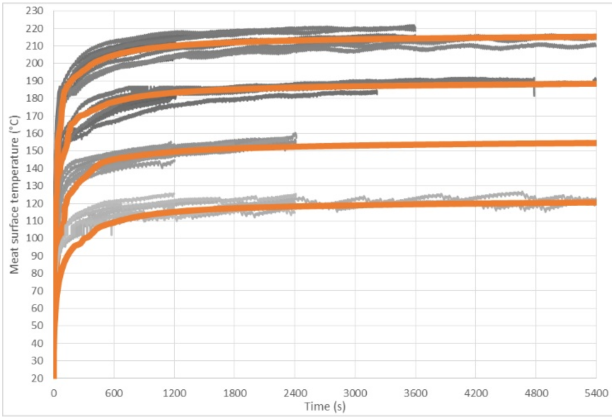

Figure 2: Beef meat subjected to jet of hot air: experimental (grey) and simulated (orange) surface temperature for various jet temperatures (160°C, 190°C, 225°C, 260°C)

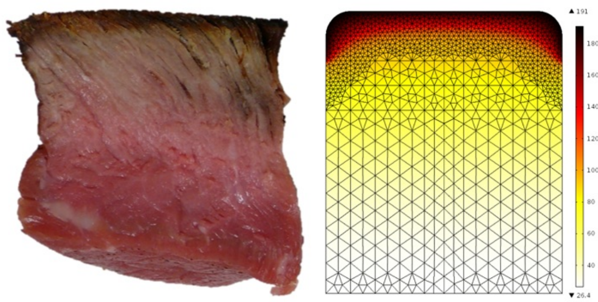

Figure 3: Beef meat cooked at 225°C for 60 min.: experimental picture and simulated temperature