Food Cooking Process
Numerical Simulation of the Transport Phenomena

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Introduction

This work presents a theoretical model describing the transport phenomena involved in food cooking.
This work evaluates the dependence of temperature and water content on process time, during cooking of meat pieces of two different geometries (cylinder and parallelepiped) with fixed physical properties and convective boundary conditions. The process is simulated using finite elements software COMSOL Multiphysics.

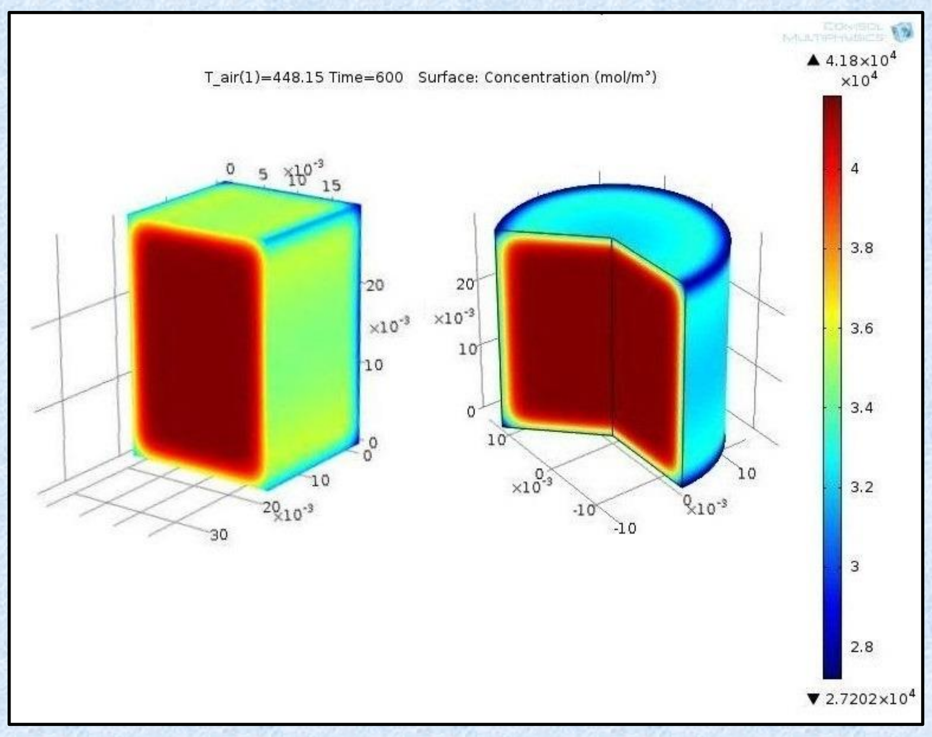

Fig.1: Water content profile at t=600 s and T_{air} =175 ° C

Governing equations

During convection cooking, heat is transferred mainly by convection from air to the product surface and by conduction from the surface toward the product center. Meanwhile, moisture diffuses outward toward the product surface, and is vaporized.

Heat transfer equation	$\rho\, c_p \dfrac{\partial T}{\partial t} = k_T\, \nabla^2 T$
Boundary condition for the heat transfer at the surfaces	$k_T \nabla T = h_T\,(T_{air} - T) + D_m\, \lambda\, \nabla C$
Mass transfer equation	$\dfrac{\partial C}{\partial t} = D\, \nabla^2 C$
Boundary condition for the mass transfer at the surfaces	$D\, \nabla C = k_c\,(C_b - C)$
Initial conditions	$T\big\vert_{t=0} = T_0 \qquad C\big\vert_{c=0} = C_0$

Cooking yield is an important economic factor that measures how much moisture, in percent, remains in the meat after the cooking process.

$$\text{Cooking Yield } (\%) = \frac{C}{C_0} * 100$$

C_0: initial moisture concentration
C: moisture concentration at time t

Conclusions

A first principles based model of heat and mass transfer is developed for a convection meat cooking process. A finite element model, which considered coupled simultaneous heat and mass transfer, was established to describe convection cooking of pork meat. The model was used to predict transient temperature and water content distributions inside the product, as well as transient cooking yield of meat samples during cooking.

References:

1.FDA. (1997). Food Code, Chapter 3, 3-401.11.
2.ASHRAE, (1989). Chapter 30: Thermal properties of foods. In ASHRAE Handbook -Fundamentals, SI Edition. American Society of Heating, Refrigerating and Air Conditioning Engineers, GA: Atlanta.
3.Chen, H., Marks, B.P. and Murphy, R.Y., Modeling coupled heat and mass transfer for convection cooking of chicken patties, J. Food Eng., 42: 139-146, 1999.

Results

From the simulation, the time of 600 s was required to heat the meat center to 75° C to ensure microbiological safety. The fig. 2 shows water content distribution in a section of meat samples at time 0s, 300s and 600s, respectively, for parallelepiped and cylindrical meat sample, under a target air temperature of 175° C. The external surface was more dried than the core, this applies to both geometries. As a result, the water content gradient is developed within the meat. A large water concentration gradient is observed near the surface and the gradient gradually shifts towards the interior of the product.

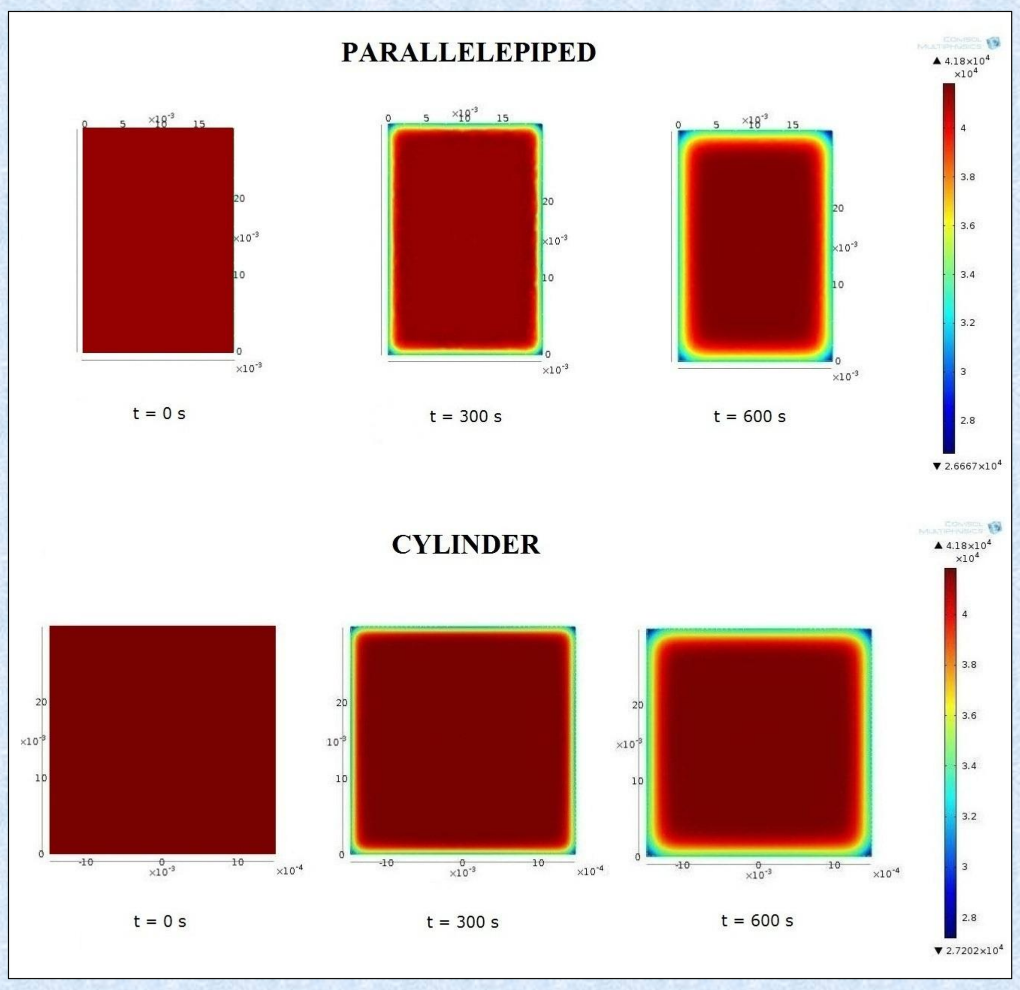

Fig. 2: Water content profile in parallelepiped and cylinder at t=600 s and Tair=175 ° C

Fig. 3 illustrates the temperature distribution during meat cooking at 600s. The surface of the meat is at a higher temperature than the inside part of the meat sample, and a large temperature gradient is developed in the region close to the surface. From the simulation, in the parallelepiped geometry the center temperature of 75 ° C is reached after 500 s at difference of cylindrical geometry in which the temperature at the center of 75 ° C is reached at about 600 s.

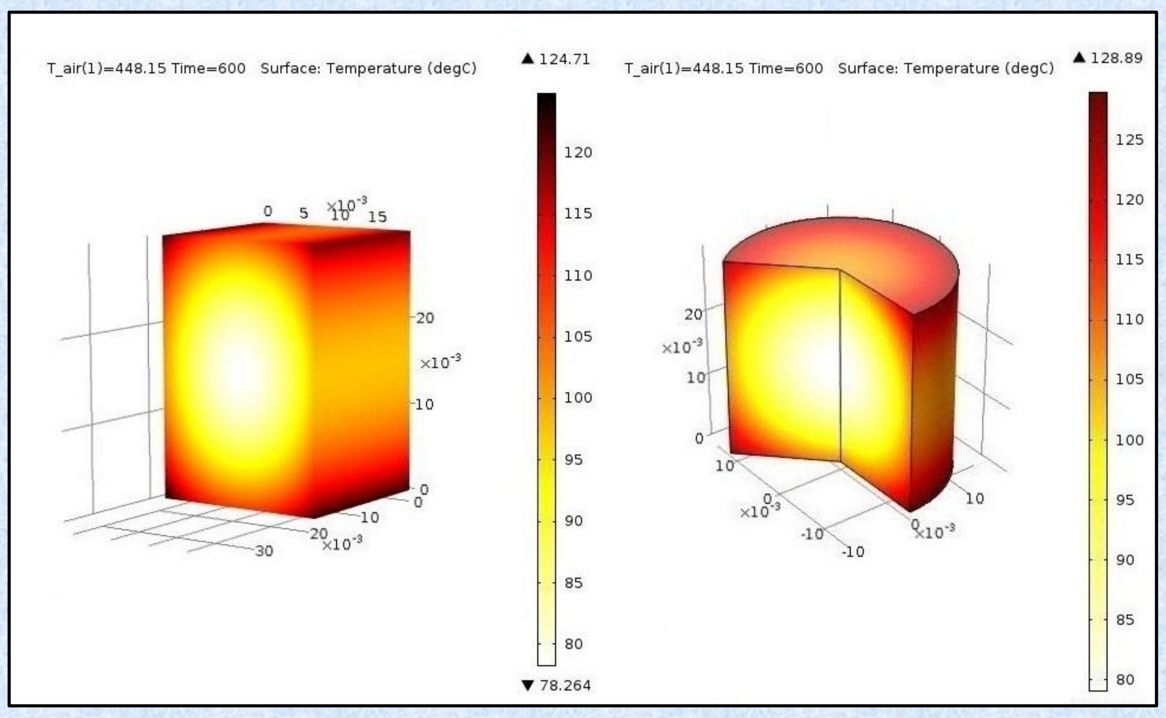

Fig.3: Temperature profile in the two geometries at t=600 s and T_{air} = 175° C

The cooking yield decreases with increasing time in both geometries.
Fig.4. shows that at the same temperature of the air 175° C and cooking time 600s the cooking yield is 94.5% in the parallelepiped geometry, while it is 96.6% in cylindrical geometry.

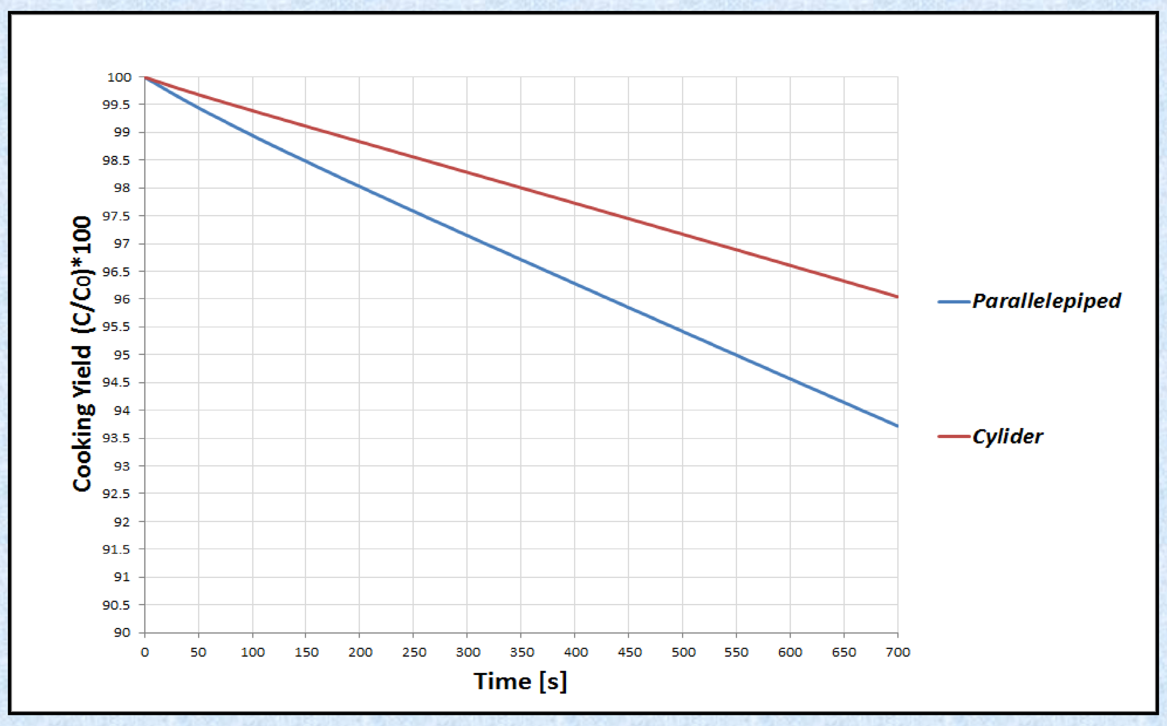

Fig.4: Cooking yield in parallelepiped and cylindrical geometries