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EiT-project - Group FUTHARK

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Introduction

Numerical simulations and experiments with bacon preparation in a microwave oven were performed. The numerical simulations were performed using the Crank-Nicolson numerical scheme on various heat equations for the different media in bacon.

This gives us the discretization scheme

$$u_m^{n+1} - \mu k\left(\frac{1}{h^2}\delta_x^2 u_m^{n+1} - \frac{1}{f^2}\delta_y^2 u_m^{n+1} - \frac{1}{g^2}\delta_z^2 u_m^{n+1}\right) = u_m^n + \mu k\left(\frac{1}{h^2}\delta_x^2 u_m^n + \frac{1}{f^2}\delta_y^2 u_m^n + \frac{1}{g^2}\delta_z^2 u_m^n\right)$$

with truncation error of order

$$\frac{\tau_m^n}{k} = \mathcal{O}(k^2 + h^2 + g^2 + f^2)$$

The truncation error $\frac{\tau_m^n}{k} \Rightarrow 0$ as $h, f, g, k \Rightarrow 0$, and the Crank-Nicolson method is consistent for the heat equation. By performing a von Neumann analysis of the numerical scheme, one can show that the method is unconditionally stable, thus the scheme converges.

As boundary condition we used a constant temperature of 20 °C, which represent the room temperature. A source term, J^{MW}, was also added to the heat equation, to represent the microwave effect.

$$J^{MW}(r) = 0.5 + 2.55008r - 0.588013r^2 + 0.032445r^3 + 0.00124411r^4 - 9.73516 \cdot 10^{-4} r^5$$

The experiments were performed with regular and with thick bacon in an ordinary household microwave oven, for single slices, and preparation times in the range 30-70 seconds. The results of the experiments are in good agreement both with expected behaviour and with the results of the numerical work.

Result

A program was written in C++, implementing equations given in the previous section. The program produced an animation of heat distribution in the bacon, yielding the following plot at $t = 50$s:

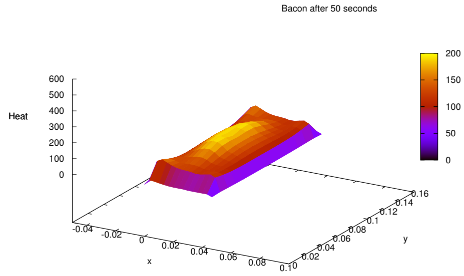

Figure: The bacon is divided into fat at the right and meat at the left (x-dir.).

By observing the plot in the figure above we notice that the temperature in the bacon slice is fairly close to 150°C. This is the required temperature for initiation of Maillard reactions, thus the bacon is (according to theory) cooked. This means that our numerical model predicts bacon completion at about 50 seconds, give or take.

The experiments yielded cooked bacon between $40 - 60$ seconds, depending on desired degree of crispness. Bacon completion was predicted to coincide with a critical temperature, as well as a limiting fat loss.

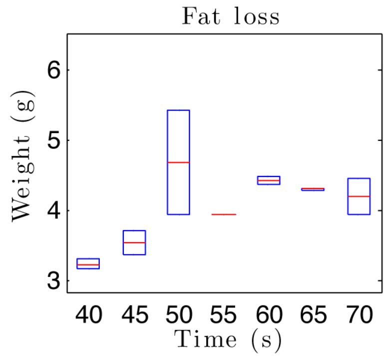

Figure: Experimental data regarding fat loss

As we can see in the figure above, there is clearly a limiting fat loss at about 50 seconds. This implies that our numerical model is accurate.

Conclusion

The performed numerical simulations and experiments with bacon preparation in a microwave oven gave satisfactory results so far as they were implemented. The numerical simulations of the heat equations gave reasonable results in agreement with experiments. A complete implementation of the transport equation would have been more satisfactory, and is suggested as a possibility for future work in this direction. As microwave preparation of bacon is shown elsewhere to be the healthiest option, expanding on the work here with more simulations and experiments, and introducing a more complicated model of bacon fat at high temperatures, one should be able to attain a complete understanding of the preparation process and thus produce guidelines for the optimal preparation of bacon.