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Introduction

With regard to efficient food processing and cost effective production lines, Radio Frequency (RF) heating is a prime example. Thermal processing of food has gained an ever growing importance as food manufactures strive after increasing the number and quality of value added products on the market. Solid food, such as meat and vegetables, is more difficult to heat efficiently since it cannot be pumped or stirred. This is an area where RF cooking can provide significant benefits due to the volumetric nature of dielectric heating. Since heat is generated internally in the product, by inducing an electric field through the food, which acts as a dielectric material, and does not rely on conduction, convection or radiation, heating takes place evenly in the product without temperature gradients. RF is also superior to micro-wave heating in this respect as the wave can penetrate food items up to several meters in diameter whereas the penetration is limited to a few centimeters at micro-wave frequencies. This means that there are no hot-spots, cold-spots or overcooking of surfaces and the total time is significantly reduced and losses are minimized.

In order to fully take advantage of RF heating there is a need for improved equipment flexibility and design methods. The main reason for this is the high level of investment costs for this equipment. However, this existing RF technology has a well-know limitation: it is generally difficult to modify specialized equipment in order to do something even slightly different with it (Marchand and Meunier, 1990). So, for many new or non-standard applications, because of these design and starting-up difficulties, the investment costs remain too high. Trial and error is not an optimal design method since in RF heating efficiency and process outcomes are highly dependent on the product characteristics rather than just the choice process parameters. Therefore there is an undeniable need to develop new methods and techniques that can be applied rapidly and efficiently in the quest for better optimized industrial systems. According to Marchand and Meunier (1990) to overcome this barrier different compromises between standardization and versatility must be found and the recent developments in measuring and computing techniques must be taken full advantage of. Metaxas (2000) asserts that with the advent of powerful computers many simulation packages have been developed, which pave the way for better technology transfer for RF heating techniques in the medium-term future.

There are also several challenges directly related to the physics of RF heating which need to be overcome, two major ones being arching and thermal run away heating (Zhao et al. 2000). Thermal run away heating or "hot-spots" in a heterogeneous medium is caused by the fact that in some materials dielectric loss factors often exhibit a strong positive correlation to temperature. i.e. the hotter something is the faster it heats (Zhao et al. 2000). Arching (or dielectric breakdown) is caused if the electric field strength across the sample is too high.

This paper describes the modeling work carried out in conjunction with the preliminary design of a lab scale RF-heating apparatus to overcome these problems. The adaptation of 50 Ω technology means that RF applicator can be designed for optimum performance with regard to electrode shape and spacing, since independent of, rather than being a part the tuning system. The higher the resistance the greater the degree of RF heating. The more uniform the current density, the more uniform the heating is.

Material and Methods

The purpose with this simulation is to design a lab scale RF-heating apparatus being able to cook hamburger patties with a dimension of 10 mm thick and 30 mm in diameter. This particular size was chosen in order to be able to compare results with previous work from our department using double sided frying (Oroszvári et al., 2006). This work does not represent a final design, but rather identify which process and design parameters are of greatest importance, i.e. recognizing and quantifying what we need to know in order to make informed decisions while constructing the apparatus.

Results and Discussion

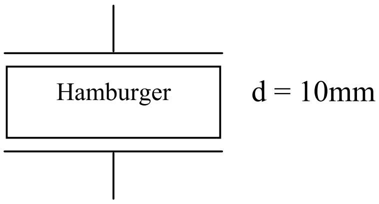
Resistances and Currents are significantly affected by applicator geometry. Conductivity is an intrinsic material property and constant at a given frequency and temperature, but the geometry can be changed to increase the resistance. Dielectric data for beef at 27.12MHz: $\varepsilon' = 70.5$ $\varepsilon'' = 419$, electrical conductivity $\sigma = 2\pi f \varepsilon'' \varepsilon_o = 0.63$ [S/m].

If we consider the simplified 2 dimensional case, the hamburger can be heated in two possible directions. Either by applying the field in the axial direction between 2 plates above and below and shown in Figure 1, Case A (left) or in the radial direction from plates positioned on the sides, shown in case B (right).

Case A

$$R \propto \frac{d}{L\sigma} \propto \frac{1}{3\sigma}$$

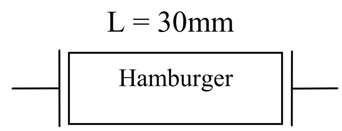
R= 22.5 Ω



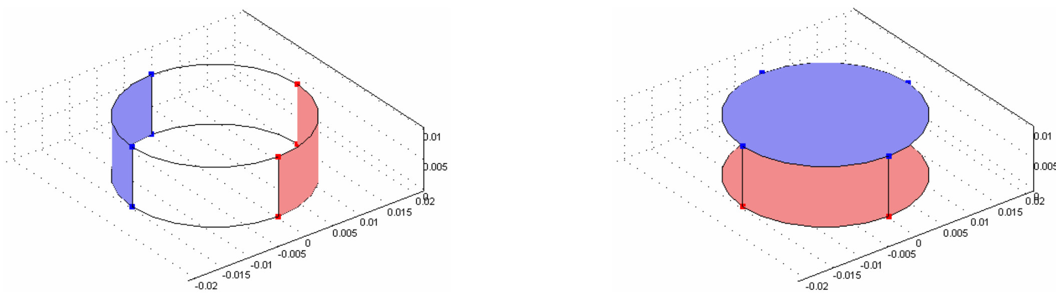
Case B

$$R \propto \frac{L}{d\sigma} \propto \frac{3}{\sigma}$$

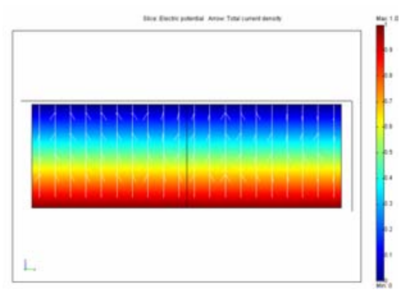
R= 203 Ω



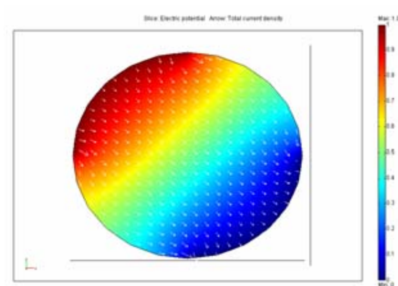
3D FEMLAB model $\sigma \nabla^2 V = 0$, where V is volts, the resistance was calculated from the potential divided by the current. The current, IΩ was found by integrating the current density over the V=0 boundary (Blue)



Model geometry and electric field boundary set-up used in FEMLAB.



R = 22.5 Ω, same as analytical



R=176 Ω, smaller than analytical because current will take the shortest path. This caused the current density vary through the material and can cause uneven heating.

Conclusions

By using FEMLAB, a computers simulation package, the 3D resistance in hamburger patties with a dimension of 10mm thick and 30mm in diameter, using Radio Frequency (RF) heating was simulated. By applying the RF field in the axial direction between 2 plates above and below or in the radial direction from plates positioned on the sides it was shown that the latter configuration gave rise to about 8 times higher resistance in the hamburger patty compared to the former and thereby a more efficient heating.

References:

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