Modeling Ex Vivo Microwave Hyperthermia of Different Biological Tissues

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Abstract

This paper presents electromagnetic and thermal simulations using COMSOL Multiphysics® with 2D axisymmetric finite-element method for the design of a percutaneous microwave hyperthermia system and ex-vivo experiments on different biological tissues. It shows the temperature variation and distribution in the biological tissues submitted to an open ended coaxial cable as the microwave applicator.

Three types of heat transfer mechanism within the tissue should be considered for the microwave hyperthermia simulations:

- Thermal conduction which considers the value of the thermal conductivity k of the biological tissue.
- Thermal convection which considers the h parameter, fort transfer of internal energy into or out of tissue by the physical movement of a surrounding fluid along with its mass. The value of h is about 5 W/m^2K for ex vivo experiments [1].
- Thermal radiation which is parameterized through the "surface-to-ambient radiation" for interactions with the environment.

Microwave heating model (Figure1) combining electromagnetic and heat transfer in solids interfaces was used. The simulations approximate that the boundary conditions remain at room temperature (~25°C) during the entire procedure.

There are three parts for the microwave hyperthermia applicator: an open-ended coaxial cable (copper), dielectric part (Teflon) and biological tissue. Dimensions are shown in the Figure 2. Considering the symmetry of the cylinder coaxial cable and samples, 2D axisymmetric modelling is used.

Constant values of relative permittivity and electric conductivity are replaced by measured values of $\epsilon^*(T)$ and $\sigma(T)$ as a function of temperature for different considered biological tissues in order to be as close as possible to the practical experiments (Figure 3).

A constant emitted microwave power (P = 1, 2 or 3W) for a duration of 210 seconds has been applied to attain the stability in simulations and also in the experiments for further comparison. At the following 210 seconds, there is no delivered microwave power.

Spatial distribution of temperature inside the tissue is also obtained by COMSOL. In fact,

the highest temperature (Tmax) appears inside of the tissue. The temperature which is measured by an infrared sensor is lower than Tmax as it measures the back side of the irradiated sample. As an example, for a 3mm thick raw chicken with an applied constant microwave power of P=2W, the measured temperature by the sensor is 44.22°C and Tmax=48.46°C. The difference between two temperatures is 4.24°C (Figure 4-a). The Ts-max for the simulation is 44.50˚C and the Te-max for ex-vivo experiment is 44.22˚C. The difference between simulated and experimental temperature is 0.28˚C (Figure 4-b) which is the same order of magnitude as experimental uncertainty.

In this work electromagnetic and thermal simulations of ex-vivo experimentations for a microwave hyperthermia applicator by using COMSOL Multiphysics software with 2D axisymmetric and finite-element method and microwave heating model have been achieved. In order to reflect the practical experiments, measured values of temperature variations of ϵ*(T) and σ(T) are used in the simulations. The variation of temperature of different tissues measured by an infrared sensor corresponds well with the simulated results.

Reference

[1] [Online]. Available: http://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html. [Accessed: Feb. 05, 2014].
[2] COMSOL Multiphysics, Microwave Cancer Therapy, version 4.2a, 2012, www.comsol.com.

Figures used in the abstract

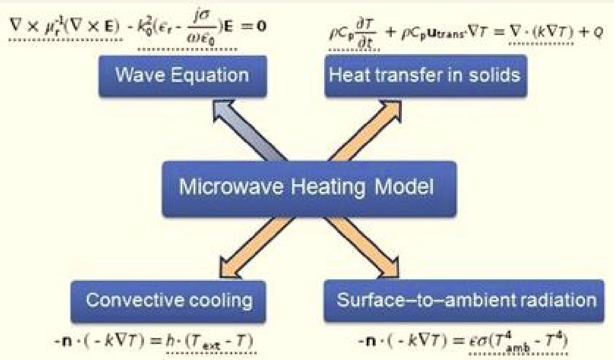

Figure 1: Conditions for microwave heating model for simulation of ex vivo microwave hyperthermia [2].

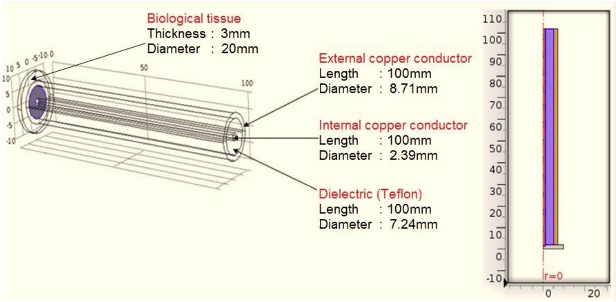

Figure 2: 3D and 2D axisymmetrical views of coaxial cable applicator in contact with biological tissues.

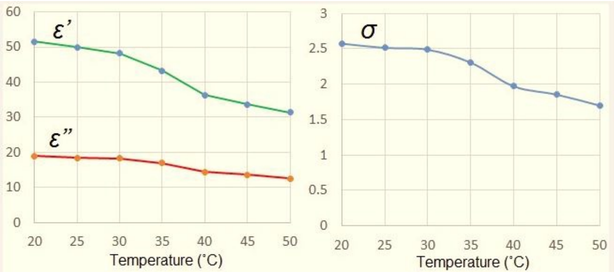

Figure 3: ϵ ' (T) and σ(T) of chicken obtained by dielectric characterzation experiments.

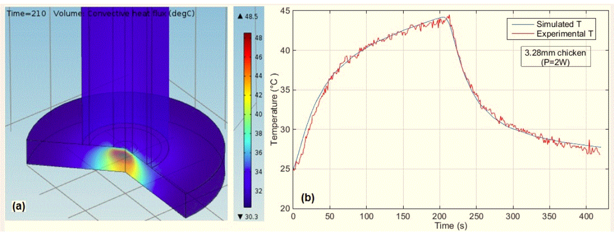

Figure 4: (a) Spatial distribution of temperature inside the 3mm thick chicken tissue. (b) Comparison between experimental and simulated temperature variations of about 3mm thick chicken sample with P=2W.