NUMERIC MODELING IN THERMAL EFFECTS ANALYSIS OF HUMAN BODY EXPOSURE TO RADIOFREQUENCY

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Abstract: *The explosion of mobile users and users of wireless devices from the latest period, specific phenomenon of modern civilization, has led to numerous problems related to exposure to the biological field of environmental impact. The main biological effect, the sample date, the exposure to millimeter wave irradiation is a thermal matter. In this article I determined the temperature induced in a spherical model of human head exposed to 900 MHz mobile phone generic. Although the FEM numerical technique has been used for the electrothermal simulation, FDTD method has recently been very well accepted. Programming environment in which the modeling is SEMCAD produced by Schmid & Partner Engineering AG.*

Keywords: *human head, electromagnetic field, temperature, SEMCAD, FDTD*

1. INTRODUCTION

Human body irradiation with an electromagnetic field produces increasing kinetic energy of molecules, which will turn into heat. Increasing the temperature of a given tissue is directly proportional to the size of incident thermal power and heating degree result is dependent on tissue vascularization. Thermal power dissipated in the target anatomical region is eventually transferred throughout the body by blood circulation, but the irradiation is local. If poorly irrigated blood organs (e. eye), taking excess body heat by the rest is very difficult, making these organs are most sensitive to temperature increase. Another critical event, but more seriously by its generality, is when the whole body is irradiated, and the mechanism of homeostasis cannot stop increasing temperature, resulting in an overall increase in temperature.

The cells generally have an optimal development between 36.8°C and 37°C. Between 38-40°C cell growth is inhibited. At over 40°C, depending on exposure time, cell death occurs due to thermal distortion of cellular components, the irreversible degradation of the spatial conformation of biopolymers and ordered their conformation transition "chaotic ball", as shown in Figure No. 1 (Margineanu, 1980).

Intensification of molecular motion with increasing temperature break the hydrogen bonds and weak forces that maintain the cancellation of other higher order structures of biopolymers. Losing their native spatial structure, its own cellular activities involving, biopolymers lose, obviously, and functions, which involve cell death. This is why the knowledge of local distribution of temperature is so important.

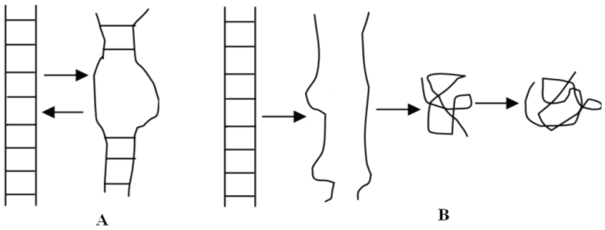

Fig. 1: Reversible thermal distortion (A) and irreversible (B) of a molecule of DNA bicatenare (Margineanu, 1980)

In vitro experiments have shown the following characteristics of microwave hyperthermia caused by:

- 42ºC temperature for one hour train maintained a level almost total cell death;
- State of malnutrition cells are more thermosensitive than cells better nourished;

- Hypoxic cells are more thermosensitive than normal oxygen;
- In the cell cycle, is termosensibility maximum DNA synthesis phase;
- Hyperthermia may increase the action of chemical agents (Margineanu, 1980, Vizitiu, 2001).

2. MATHEMATICAL FORMULATION

The heat transfer equation is:

$$\frac{\partial}{\partial t}(\rho h)+\nabla(\rho\bar{u}h)=\nabla(k\nabla T)+S_h \quad (1)$$

where:

- ρ mass density of the body $\frac{kg}{m^3}$;
- h is specific enthalpy $\left[\frac{J}{kg}\right]$;
- $\bar{u}$ is speed $\left[\frac{m}{s}\right]$;
- k is thermal conductivity $\left[\frac{J}{s\cdot m\cdot{}^\circ C}\right]$;
- T is temperature $\left[{}^\circ C\right]$;
- S_h volumetric rate of heat is generated $\left[\frac{W}{m^3}\right]$

Physical explanation of phenomena is the following:

$\frac{\partial}{\partial t}(\rho h)$ - defines the amount of energy (heat) change per unit time and volume.

$\nabla(\rho\bar{u}h)$ - defines the process of convection within the material.

$\nabla(k\nabla T)$ – defines the heat conduction inside the material, according to Fourier's conduction law, and is related to the diffusion process.

S_h - represented all sources that generate heat

For the ideal gases and liquids:

$$c\nabla T=\nabla h \quad (2)$$

where c is the specific heat at constant pressure.

Enthalpy, if c is constant, is:

$$h=cT \quad (3)$$

The thermal module in SEMCAD implements the solution of the heat transfer equation biological (BHTE – bio – heat transfer Equation), which is a special case of equation (1) and has the form:

$$c\rho\frac{\partial T}{\partial t}+B(T-T_b)=k\nabla^2T+S \quad (4)$$

where:

- $B(T-T_b)$ is the appropriate mechanism to change the infusion of blood heat, proportional to the temperature difference between blood (T_b) and tissue temperature;
- parameter B $\left[\frac{W}{{}^\circ C m^3}\right]$ is proportional to blood perfusion in tissue.
- $S\left[\frac{W}{m^3}\right]$ represents the total effect of volumetric heat generation sources.

For the equation (4) the boundary condition which is used is the convective boundary

$$k\frac{\partial T}{\partial n}+hT_{surface}=hT_{ambient} \quad (5)$$

where:

- h is the coefficient of convection $\left[\frac{W}{(m^2\cdot{}^\circ C)}\right]$
- $T_{surface}$ is considered the body surface temperature $\left[{}^\circ C\right]$;
- $T_{ambient}$ is ambient temperature $\left[{}^\circ C\right]$.

An important boundary condition in heat transfer is the radiating boundary. Radiation of heat is described by:

$$q_{emitted}=\varepsilon\sigma A\left(T^4_{surface}-T^4_{ambient}\right) \quad (6)$$

where:

- $q_{emitted}$ is rate of heat transfer is issued;
- ε is the emission factor of a surface;
- σ is constant Stefan - Boltzmann - $5.669x10^{-8}W/m^2K^4$;
- A is the radiant surface;

Because the emission factor the emission factor calculation is dependent on material, geometry and surface temperature, its calculation not easy to perform, from this reason the border is often replaced by a radiant border linear convection with an equivalent heat transfer coefficient, which is usually determined experimentally, given by:

$$\tilde{h} = \varepsilon\sigma\left(T_{ambient} + T_{surface}\right)\left(T^2_{ambient} + T^2_{surface}\right) \quad (7)$$

3. NUMERICAL FORMULATION

The discretization mesh

The numerical technique used by the thermal solver of SEMCAD is the FDTD method. To derive the discretizing equations of this technique the ‘control-volume formulation’ is chosen. In the of the control-volume formulation the principle is to divide the calculation domain into a number of non-overlapping control-volumes. The value T in Each of these volumes surrounds one grid point (or node), where the value of T is calculated. The differential equation is integrated over each control-volume. To evaluate the integrals a piecewise variation profile of T must be assumed between nodes. The remaining derivatives of the dependent variable can be approximated by the truncated Taylor series expansion in a forward, central or backward finite-differencing scheme (SEMCAD Manual Addendum V1.8, 2003:2-3)

Equations of heat transfer meshing

Derivation of the discretized equation for three-dimensional heat transfer problem following the procedure described above. Discretized equation for an interior point becomes:

$$T^{n+1}_{i,j,k} = T^n_{i,j,k} + \frac{\delta t}{\rho c}\frac{1}{\delta x_i \delta y_j \delta z_k}\left[T\right] \quad (8)$$

where:

$$T = \begin{bmatrix} k'^{x+}_{i,j,k}\delta y_j \delta z_k \dfrac{\left(T^n_{i+1,j,k} - T^n_{i,j,k}\right)}{\delta sx_{i+1}} + k'^{x-}_{i,j,k}\delta y_j \delta z_k \dfrac{\left(T^n_{i-1,j,k} - T^n_{i,j,k}\right)}{\delta sx_{i}} \\ + k'^{y+}_{i,j,k}\delta z_k \delta x_i \dfrac{\left(T^n_{i,j+1,k} - T^n_{i,j,k}\right)}{\delta sy_{j+1}} + k'^{y-}_{i,j,k}\delta z_k \delta x_i \dfrac{\left(T^n_{i,j-1,k} - T^n_{i,j,k}\right)}{\delta sy_{j+1}} \\ + k'^{z+}_{i,j,k}\delta x_i \delta y_j \dfrac{\left(T^n_{i,j,k+1} - T^n_{i,j,k}\right)}{\delta sz_{k+1}} + k'^{z-}_{i,j,k}\delta x_i \delta y_j \dfrac{\left(T^n_{i,j,k-1} - T^n_{i,j,k}\right)}{\delta sz_{k+1}} \\ + \overline{Q}_{i,j,k}\delta x_i \delta y_j \delta z_k - B_{i,j,k}\left(T^n_{i,j,k} - T_b\right)\delta x_i \delta y_j \delta z_k \end{bmatrix}$$

Indices n refers to the distance of time, and indices i, j, k, refers to the position of node temperature in a linear network. The term "heat generated" is represented by a spatial average: inside the given volume element of the product $\delta x_i \delta y_j \delta z_k$ of cell dimensions (three dimensions). Distances between nodes on the three-way temperature are shown in figure no.2. You can see that at the boundary between two materials is necessary for physical consistency reasons, to replace the thermal conductivity weighted thermal conductivity.

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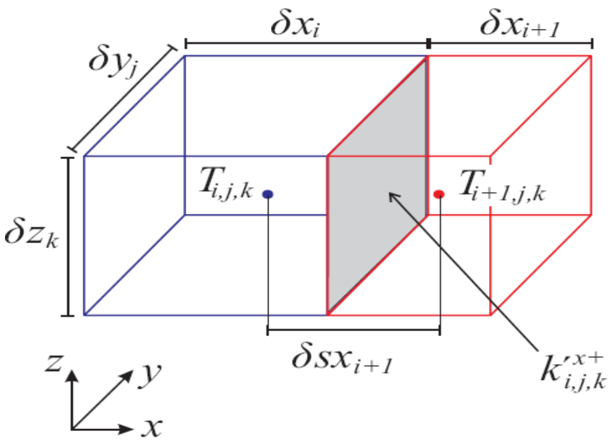


Fig. 2: Grid geometry of the thermal solver (SEMCAD, 2003:2-4)

You can see that at the boundary between two materials is necessary for physical consistency reasons, to replace the thermal conductivity $k_{i,j,k}$ weighted thermal conductivity $k'^{[x,y,z][+,-]}_{i,j,k}$.

Last term, according to one of the six neighboring nodes is given by:

$$k'^{[x,y,z]+}_{i,j,k} = 2\left(\frac{\delta[x_i, y_j, z_k]}{k_{i,j,k}\delta s[x_{i+1}, y_{j+1}, z_{k+1}]} + \frac{\delta[x_{i+1}, y_{j+1}, z_{k+1}]}{k_{i+1,j+1,k+1}\delta s[x_{i+1}, y_{j+1}, z_{k+1}]} \right)^{-1} \quad (9)$$

$k'^{[x,y,z]-}_{i,j,k}$ and can be obtained by substituting the "i-1" by "i" in equation (9). If a uniform network, the distance between nodes in one direction is equal to the volume element size in that direction, and the effective thermal conductivity is the average thermal conductivity of neighboring volume elements. In addition, when the calculation is homogeneous, the effective thermal conductivity is the thermal conductivity of occupying the computing environment. Derivation of the discretized equation for the outer border adjacent nodes is done by introducing fictitious nodes on the sides of the element temperature of volume, not the border. These nodes are assigned null volume elements (SEMCAD, 2003:2-1- 2-4).

4. DETERMINATION OF HEAT INDUCED BY A GENERIC MOBILE PHONE IN A SPHERICAL HEADMODEL

Example of calculation used for thermal modeling is as follows: Determine the heat induced by a generic cell phone antenna at 900 MHz frequency in a sphere equivalent to the human brain.

Choosing the spherical model was made on idea to simplify calculations, according figure no 3.

Fig. 3:The sphere that approximates the human head (http://www.sciencefocus.ro)

Thermal parameters are:

$$\rho = 1030\left[\frac{kg}{m^3}\right], k = 0.528\left[\frac{W}{mK}\right], c = 3710\left[\frac{J}{kgK}\right]$$

Model calculation with apply sensors is presented in Figures no. 3, 4.

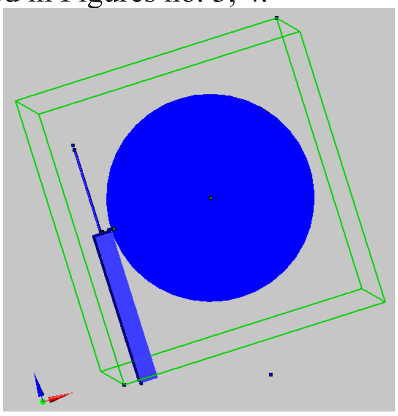


Fig. 3: The spherical model and cell phone use in calculating the induced temperature and grid computing

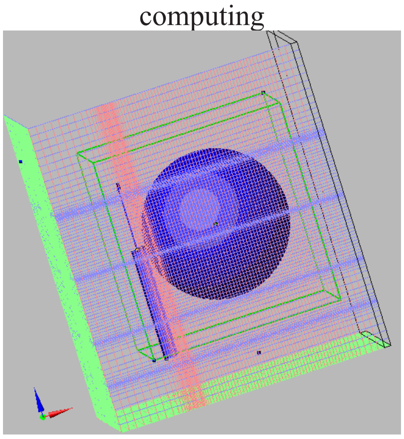
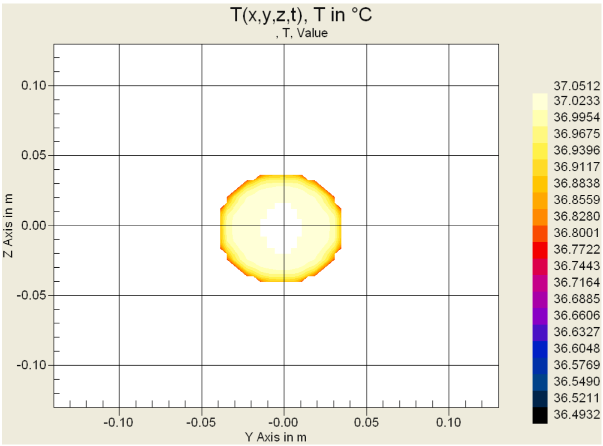


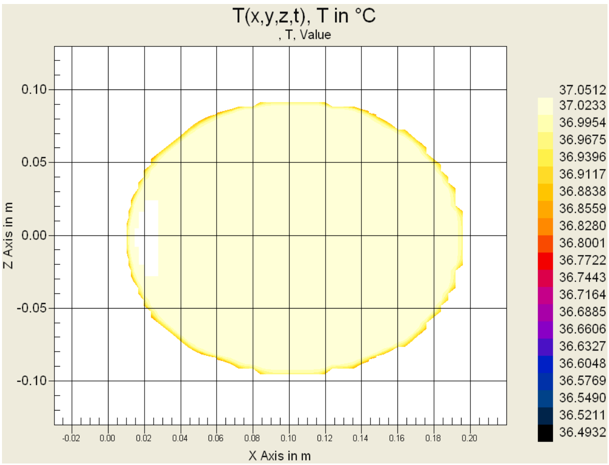
Fig. 4: The spherical model and cell phone use in calculating the induced temperature and applied sensors

The results are shown in Figure no.5, 6. Figure no.5 is the temperature distribution induced by cellular phone in the model human brain generic plans (a)yOz (b) xOz (c) XOY after 3600 sec and output power of 125mW antenna. Figure no. 6 are represented as changes in temperature sensor placed near gathered by phone (red) and collected by the sensor placed in the center of the sphere (blue) (Jeler, 2010).

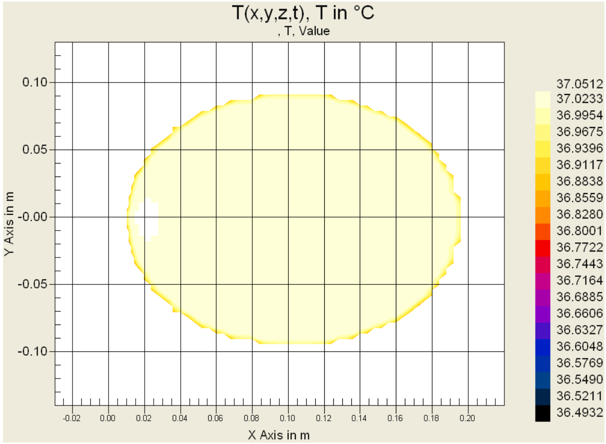
5. RESULTS:



(a)



(b)



(c)

Fig. 5:Temperature distribution induced by cellular phone at a frequency of 900 MHz generic in human brain model approximated by a sphere in plans: (a) yOz (b)xOz (c) xOy after 3600 sec

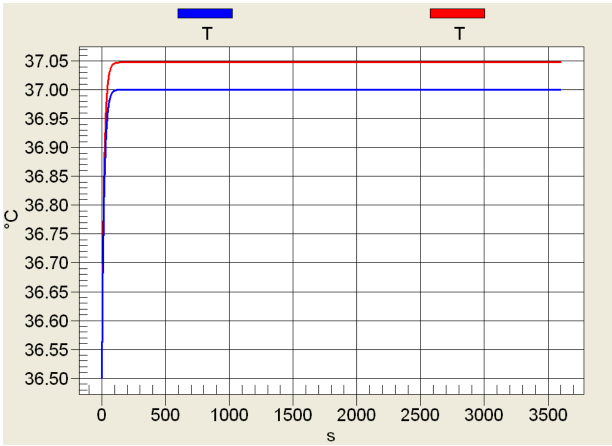


Fig. 6: Graph of temperature variation on the edge spherical model, near the phone, (red) and model center of the spherical model (blue)

5. CONCLUSIONS

Although the model was a simple calculation (a sphere that approximates the human head exposed to a generic mobile phone), the results may be useful in extracting preliminary conclusions and to use more complicated models. The study offers the following conclusions:

-Figure no. 4 we can see the distribution of heat through the model range, there is a sphere that approximates heating the human brain by about 0.5°C after about 100s.

-Values obtained by the local sensors are 37.05ºC at the point in the middle of the sphere, and 37ºC by the phone point to a baseline of 36.5ºC, resulting in an increase in both locations by about 0.5ºC.

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