CAVITY RESONATOR FOR STUDYING THERMAL AND NON-THERMAL EFFECTS OF RADIO WAVES ON BIOLOGICAL TISSUES

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Abstract

In this article a design and simulation of a circular cavity resonator is presented. The resonator will later on be used to conduct a study on thermal and non-thermal effects of radio waves on cancer cells. The cells will be irradiated with different intensities and modulation schemes and later on the samples will be examined by medical scientists to determine if cancer treatment could benefit from the non-thermal effects of RF radiation.

Keywords *– Microwaves, Cancer treatment, Cavity resonator, non-thermal effects, thermal effects*.

1. INTRODUCTION

The research of the effects of Electromagnetic Field on biological systems is of growing interest. In recent years one of the main directions of research on this topic is the application of RF fields in medicine [1] [2] [4]. Our work is concentrated on cancer treatment using radio waves. There are multiple studies conducted on microwave heating and very few on non-thermal effects of radio waves on malignant cell. Microwave heating, or microwave hyperthermia, is a procedure where high frequency electromagnetic field is applied on parts of the human body and is used to elevate their temperature [1]. Non-thermal effects occur at low power of the applied field, which is not enough to heat the tissue.

This paper describes a device that will be used to conduct a study on how low power FR radiation affects cancer cells. On this early stage of our research however we will study the ability of radio waves at 434 MHz to penetrate and heat different types of tissues. The experiment itself will be performed in collaboration with medical scientists who will study the samples and will analyze all the possible effects of RF radiation on the cancer cells, if any.

2. DESCRIPTION OF THE RESONATOR

To conduct the experiment described above we will have to put the samples containing the cancer cells in controlled environment and radiate them with electromagnetic radiation. In order to have reliable results the samples must be radiated by constant EM field which has well known spatial distribution. We should also ensure that the samples won't be subjected to the influence of sources of FR radiation other than our own. This is important because all unwanted and uncontrolled influence can compromise the results.

Such a device that can meet both conditions is a cavity resonator. The electromagnetic field inside the cavity resonator is incased within the boundaries of the cavity. Its structure can be calculated using software model and later on it can be experimentally measured. This means that we will have full knowledge of the EM field inside the cavity and can guarantee that it will be the same during the whole experiment. On the other hand no outside EM energy can penetrate within the cavity. This makes the cavity resonator very convenient for conducting our study.

We have chosen to utilize cylindrical cavity resonator with resonant frequency 443 MHz for mode TM_{010}. One of the walls of the cavity will be removable and the sample will be put inside of it.

The resonant frequency of the cavity is calculated using[3]:

$$f_r = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{(\frac{x_{np}}{a})^2 + (\frac{q\pi}{d})^2} \quad (1)$$

For mode TM_{010} n=0, p=1, q=0, and for the resonant frequency we have:

$$f_r = \frac{3.10^{10}}{2}\sqrt{\left(\frac{2.405}{2}\right)^2} \quad (2)$$

The calculated dimensions of the cavity are as follows – height d=0.25 m; radius a= 0.259m. The size of the cavity is big enough to contain the sample with the cancer cells.

Slots will be cut out on the walls of the resonator so that we can experimentally measure the EM field inside of it and to compare it to the simulation results.

The cavity will be fed by coaxial line from RF generator.

3. SIMULATION AND RESULTS

The properties of the resonator are simulated using COMSOL Multiphysics software. COMSOL calculates the electric and magnetic field inside the cavity resonator, surface losses and surface currents density. We are also able to calculate the microwaves induced heating in the biological tissues.

To calculate the temperature of the tissues Pennes bioheat equations is used [1]:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ext} \quad (3)$$

where $\boldsymbol{k}$ is the corresponding tissue's thermal conductivity (W/(m·K)), $\boldsymbol{\rho_b}$ represents the blood density (kg/m3), $\boldsymbol{C_b}$ is the blood's specific heat capacity (J/(kg·K)), $\boldsymbol{\omega_b}$ denotes the blood perfusion rate (1/s), and $\boldsymbol{T_b}$ is the arterial blood temperature (K). Further, $\boldsymbol{Q_{met}}$ is the heat source from metabolism, and $\boldsymbol{Q_{ext}}$ is an external heat source, both measured in W/m3. The initial temperature equals $\boldsymbol{Tb}$ in all domains. This model neglects the heat source from metabolism.

The model assumes that the blood perfusion rate is $\boldsymbol{\omega_b}$=0.0036 s-1, and that the blood enters the corresponding tissue at the body temperature $\boldsymbol{T_b}$ = 37 °C and is heated to a temperature, $\boldsymbol{T}$. The blood's specific heat capacity is $\boldsymbol{C_b}$=3639 J/(kg·K).

We use simple models of three types of tissues- liver, fat, muscle. The electromagnetic properties of these tissues at the frequency of interest 443 MHz are given in Table 1 [5].

Tissue	Permittivity	Electrical Conductivity [S]
Liver	50.5	0.672
Muscle	56.8	0.807
Fat	11.6	0.0826

On Figure 1 and Figure 2 the mesh and the geometry of the model is shown. The biological tissue is modelled as a sphere with radius of 5 centimeters and is placed along the vertical axis of the resonator.

On Figure 3 you can see the distribution of the Electric and magnetic fields inside the cavity. The EM field is stronger near the axis of the cavity and drops to zero at the side walls which is in compliance with the air- conductor boundary conditions.

The configuration of the EM field inside the resonator points out that the best location to place the cancer cells is at the center of the cavity as far as possible from its walls.

On Figure 4 the surface losses and surface current density of the resonator is displayed.

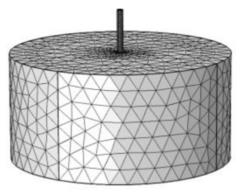

Figure 1. Mesh used for the calculation

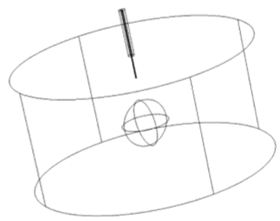

Figure 2. The geometry of the model. The sphere inside the resonator represents the biological tissue.

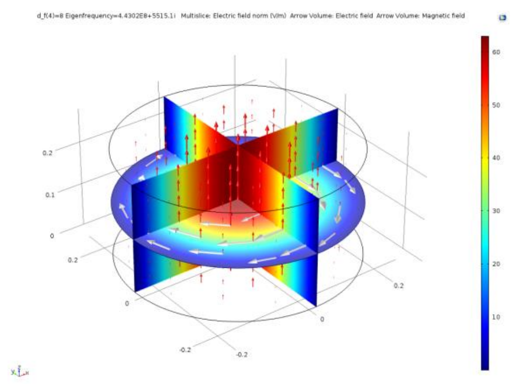

Figure 3. Electromagnetic field distribution inside the resonant cavity

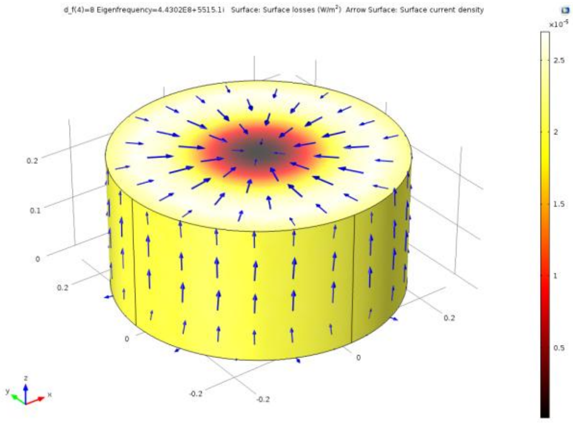

Figure 4. Surface losses and surface current density

In the model we simulate electromagnetic radiation with constant power for 10 minutes. The initial temperature of the tissue is 37 ℃. On figure 5 the temperature distribution after 6 minutes of heating of a liver tissue is displayed. Because of the symmetry of the model we only represent the results in a single plane that goes along the central axis of the tissue.

The temperature distribution after 10 minutes of heating is presented on Figure 6. It's visible that the heating is concentrated in the center of the sample and that the longer we heat the temperature rises and the heating becomes more uniform.

On the next two set of figures Figure 7 and Figure 8 the temperature distributions for muscle tissue after heating for 6 and 10 minutes are displayed.

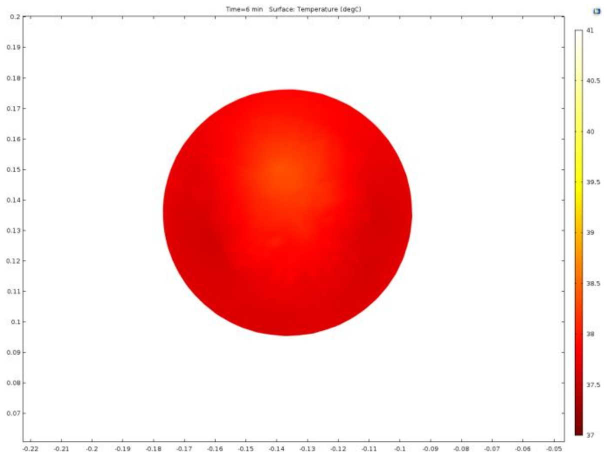

Figure 5. Temperature distribution in liver tissue after 6 minutes of heating

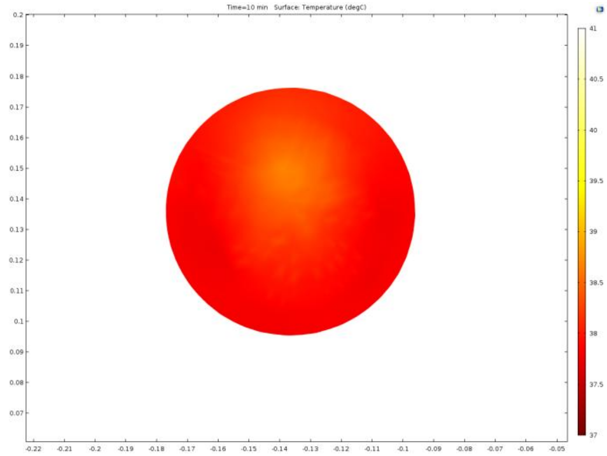

Figure 6. Temperature distribution in liver tissue after 10 minutes of heating

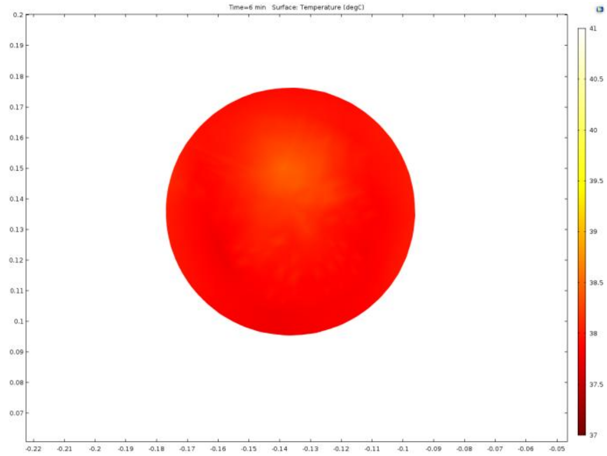

Figure 7. Temperature distribution in muscle tissue after 6 minutes of heating

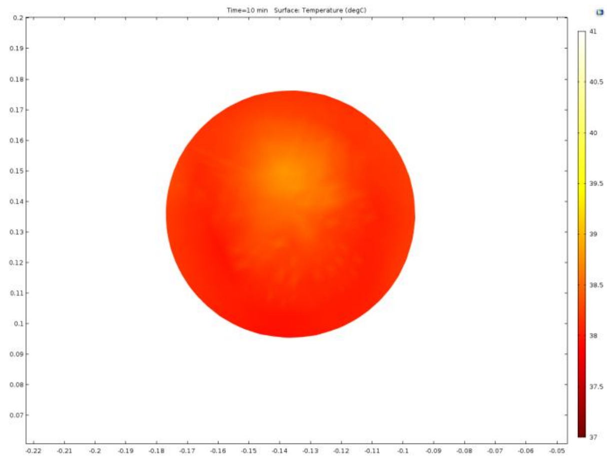

Figure 8. Temperature distribution in muscle tissue after 10 minutes of heating

On Figure 9 Figure 10 the temperature distributions for fat tissue after heating for 6 and 10 minutes are displayed.

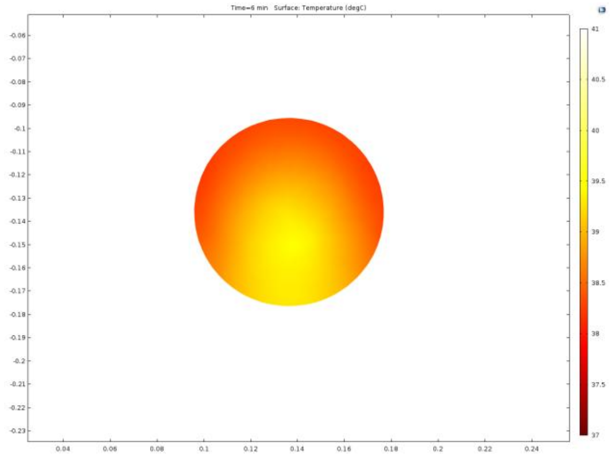

Figure 9. Temperature distribution in fat tissue after 6 minutes of heating

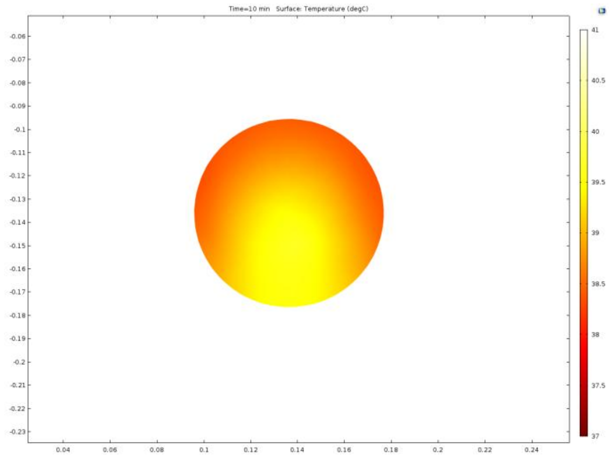

Figure 10. Temperature distribution in fat tissue after 10 minutes of heating

It's easily seen that different kinds of tissues react to the heating in different way. The degree of heating of a certain tissue greatly depends on the blood perfusion for this tissue.

From the results of the simulation we can conclude that using radio waves with frequency of 443 MHz we can achieve significant penetration in the tissue of interest.

The results of the simulation include only the thermal effects of the irradiation, because non-thermal ones can't be simulated using software model. They will be studied later on when we fabricate the resonator using real tissue samples.

4. FUTURE CHALLENGES

After the software simulation next step is to produce the resonator and to measure its properties. If they agree with the simulation results and we can guarantee constant field distribution, we can proceed with the actual study of the effects of the EM field on the cancer cells.

The samples will be irradiated with different types of electromagnetic waves:

- Different intensities of the field
- Time modulation of the wave – periods of irradiation will be followed by periods of silence.
- The high frequency (443MHz) wave will be modulated with modulated with low frequency (several kilohertz) one

The influence of radio waves on the samples will be examined also in combination of drugs to test whether or not the RF radiation can improve the effect of the drugs.

References

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