

MODEL OF MICROWAVE HYPERTHERMIA TREATMENT

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Abstract: The purpose of this paper is to create the model of microwave hyperthermia treatment using COMSOL Multiphysics 4.1. The model of agar jelly with properties similar to the biological tissue was developed. The waveguide horn applicator with aperture of 100 x 100 mm was used. Results of impedance matching, 3D SAR distribution and 3D thermal changes are presented.

Keywords: Microwave Hyperthermia, Finite Element Method, SAR

1. INTRODUCTION

Microwave hyperthermia is a promising method of cancer treatment utilized increase of temperature in interval of 40 - 45 °C. Two different reactions of healthy and tumorous tissue on artificial temperature increase take place. As blood temperature increases reaching 45 °C, its blood perfusion is rising as well. Healthy tissue is automatically defending against further temperature rise and thermal damage. On the other hand, this defensive mechanism is disappearing for tumors with diameter bigger than two centimeters. With further temperature rise the blood perfusion is even decreasing. The temperature in tumor is growing even faster. The tissue damage of tumorous tissue takes place in a short time [1].

2. MODELS AND METHODS

2.1. MODEL ENVIRONMENT AND PARAMETERS

Comsol Multiphysics 4.1 allows modeling and simulations of physical processes. It is used to solve partial differential equations. These equations are solved by finite element method. This software disposes of an intuitive and comprehensive interface. The program is divided into several modules. Each of them resolves problems from particular physical domain. Radiofrequency and Heat transfer module have been used in this study. Radiofrequency module simplifies designing systems working with electromagnetic waves. Heat transfer module is able to solve the microwave heating taking place in this study. These modules have been the most appropriate for our problem.

Concrete model solution consists of source of electromagnetic waves in form of waveguide horn applicator. It is designed for working frequency of 434 MHz, which is one of the ISM (Industrial, Scientific and Medical) frequencies. The applicator consists of waveguide 60 x 30 x 60 mm and 75 mm long horn with aperture of 100 x 100 mm. The wave is coming in through the 20 mm long coaxial cable with inner radius 1 mm forming a copper wire and outer radius 5 mm representing teflon isolator. The power of coaxial input port boundary condition is set to 100 W. A 20 mm thick water bolus filled with distilled water ($\epsilon_r = 81$) is placed between the aperture of the applicator and the surface of the agar jelly. The agar jelly is used because it has electrical and thermal parameters similar to the biological tissue. All needed parameters are listed in Tables 1 and 2, [1], [2]. The entire model is shown in Fig. 1.

Material type	Electric conductivity σ [S/m]	Relative permittivity ϵ_r [-]	Density [kg/m ³]	Frequency [MHz]	Input power [W]
Agar jelly	0,8	54	1000	434	100
Distilled water	0	81	-		
Teflon	0	22	-		
Copper	$5,99 \cdot 10^7$	1	-		

Table 1: Electrical parameters - RF module

Material type	Thermal conductivity k [W/(m.K)]	Heat capacity C_p [J/(kg.K)]	Density [kg/m ³]	Initial value of temperature [K]
Agar jelly	0,5	3000	1000	293,15

Table 2: Thermal parameters of agar jelly - Heat transfer module

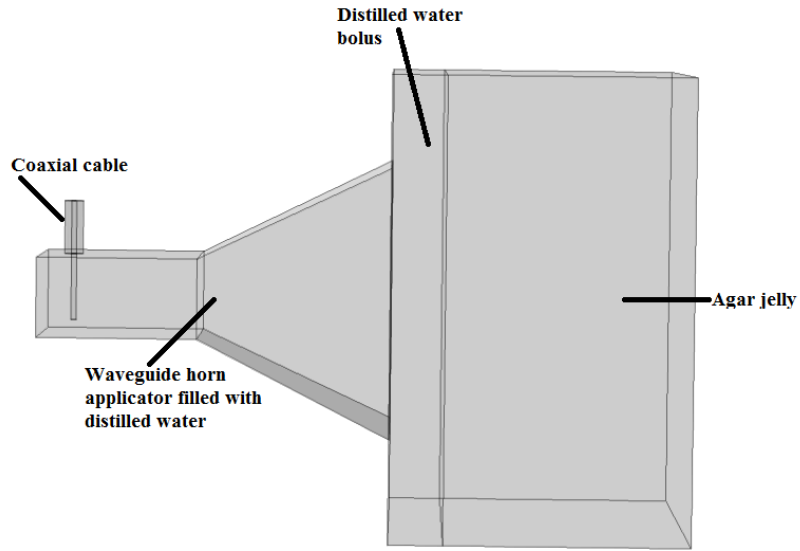


Figure 1: Model of applicator and agar jelly

2.2. SIMULATION RESULTS - ELECTROMAGNETIC FIELD AND SAR DISTRIBUTION

As already noted, the program Comsol Multiphysics resolves the problem using the finite element method. For the issue of electromagnetic waves the following equations are applied in order to determine the values of intensity for each field [3]:

Distribution of the electric field:

$$\nabla \times (\mu_r^{-1} \nabla \times \mathbf{E}) - \left(\epsilon_r - \frac{j\sigma}{\omega \epsilon_0} \right) k_0^2 \mathbf{E} = \mathbf{0} \quad (1)$$

Distribution of the magnetic field:

$$\nabla \times \left(\left(\epsilon_r - \frac{j\sigma}{\omega \epsilon_0} \right)^{-1} \nabla \mathbf{H} \right) - \mu_r k_0^2 \mathbf{H} = \mathbf{0} \quad (2)$$

where ∇ is the Curl operator, μ_r is the relative permeability [-], ϵ_r is the relative permittivity, \mathbf{E} is the electric field intensity [V/m], σ is the electric conductivity [S/m], ω is the angular frequency [rad/s], ϵ_0 is the vacuum permittivity [F/m], k_0 is the wave number [m^{-1}], \mathbf{H} is the magnetic field intensity [A/m].

In order to ensure the convergence, the meshing had to satisfy the Nyquist criteria. The mesh feature uses the expression $c/f/5$ to set the maximum element size to 1/5 of the wavelength associated with the frequency f . The maximum element size of created mesh was set according to formula (3) [3]:

$$\text{MaximumElementSize} = \frac{c}{5f} \quad (3)$$

where c is the speed of light [m/s], f is the frequency of the source of electromagnetic waves [Hz].

The final distribution of electric field intensity is shown in Fig. 2. The slice plot is used. The maximum value in agar jelly is equal to 1343 V/m.

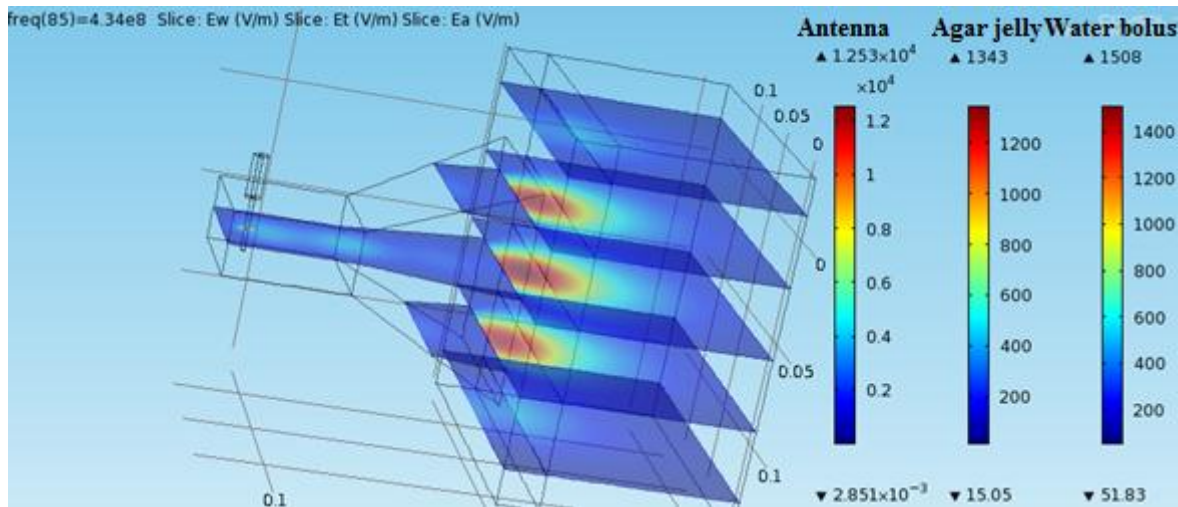


Figure 2: Electric field distribution

Impedance matching of the waveguide horn applicator is show in Fig. 3. At working frequency of 434 MHz is $S_{11} = -16,56$ dB. The applicator frequency bandwidth ($S_{11} < -10$ dB) is 28 MHz (from 424 MHz to 452 MHz).

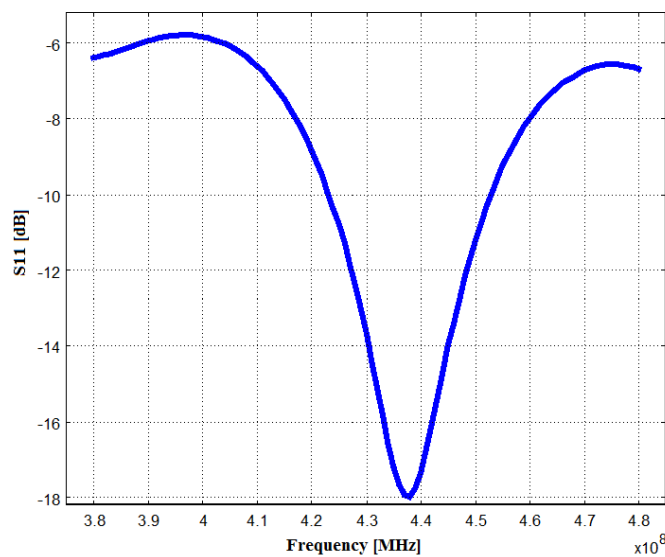


Figure 3: Impedance matching of waveguide horn applicator

The average value of SAR is calculated using a formula (4) [4]:

$$SAR = \frac{\sigma E^2}{2\rho} \quad (4)$$

where σ is the electric conductivity of agar jelly [S/m], ρ is the density of agar jelly, E is intensity of electric field in the agar jelly.

The final distribution of SAR is shown in Fig. 4. The slice plot is shown on the left, while the picture to the right corresponds to the volume plot seen from the front. The maximum value achieved in agar jelly is equal to 738,1 W/kg.

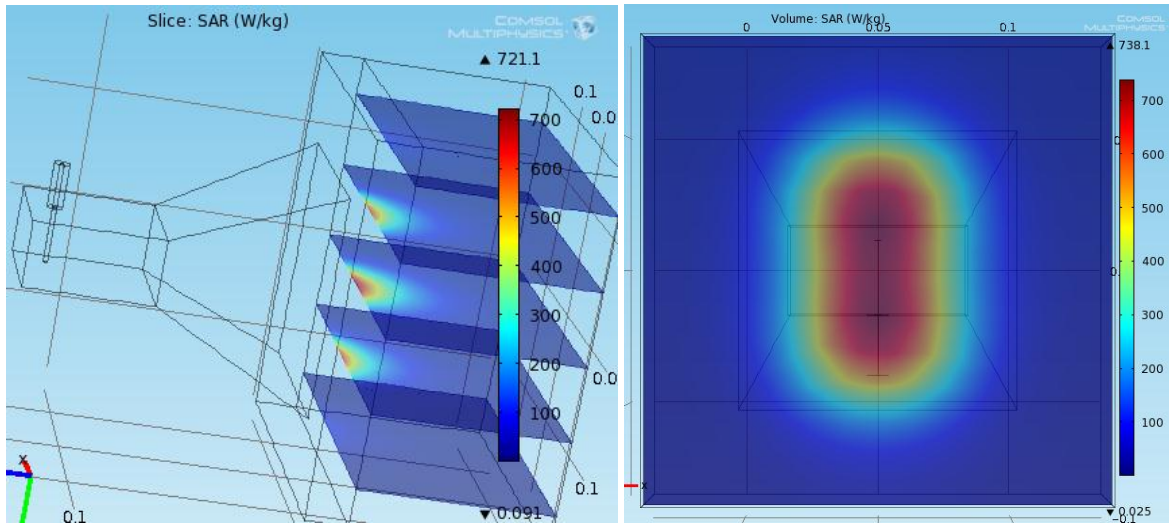


Figure 4: SAR distribution in agar jelly

2.3. SIMULATION RESULTS - THERMAL CHANGES

In order to calculate the temperature change in agar jelly the finite element method is used. In this case the formula in the module called Heat Transfer Module, has the following form listed below [3]:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u}_{trans} \nabla T = \nabla \cdot (k \nabla T) + Q + W_p \quad (4)$$

where ∇ is the Curl operator, ρ is the agar density [kg/m³], T is the temperature [K], C_p is the heat capacity at constant pressure [J/(kg.K)], k is the thermal conductivity [W/(m.K)], Q is the heat source [J], W_p is the source power [W].

The final temperature distribution is shown in Fig. 5. The slice plot which shows the heating depth is on the left. The picture to the right corresponds to the surface plot seen from the front. The microwave heating time is set to 50 seconds. The maximum value of 47,73 °C has been achieved after this time interval. Maximum value of 45 °C applied in microwave hyperthermia has been achieved after 41 seconds as shown in Fig. 6.

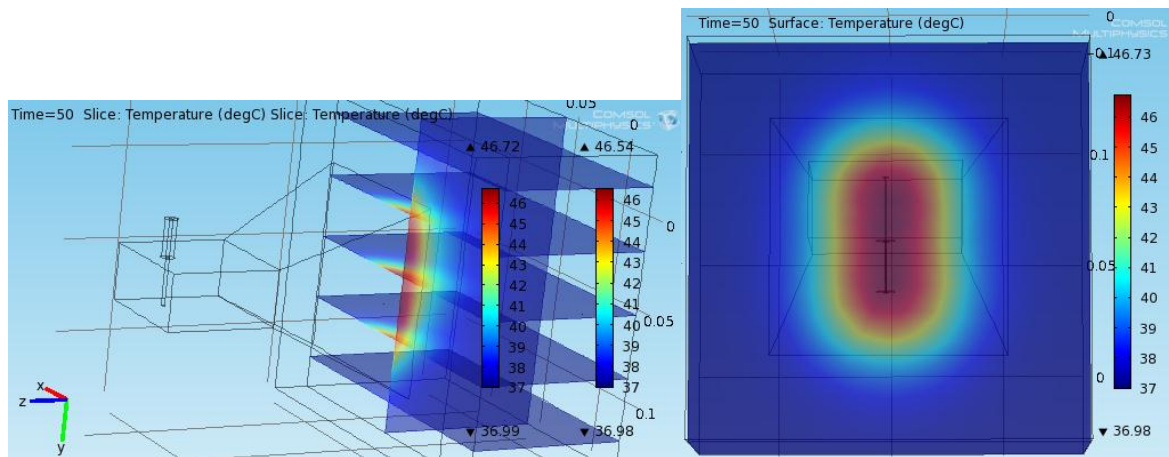


Figure 5: Temperature change in agar jelly

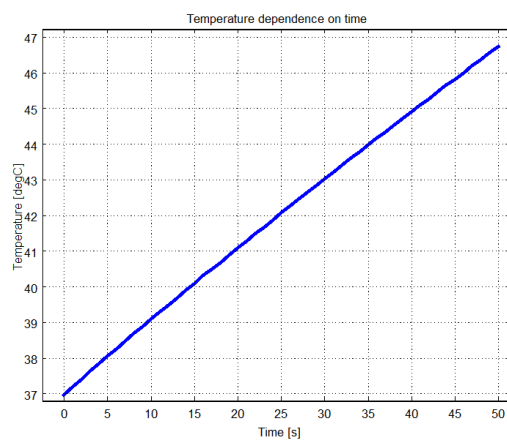


Figure 6: Temperature dependence on time

3. CONCLUSION

The model of microwave hyperthermia treatment has been created. Distribution of electric field along with distribution of SAR has been solved. Temperature dependence on time in the agar jelly has been presented afterwards. In the future this study will be extended about realistic patient model with several tissue types.

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REFERENCES

- [1] Vrba, J., Lapeš M.: Mikrovlnné aplikátory pro lékařské aplikace, Praha, Vydavatelství ČVUT, 1997
- [2] Dřížd'al, T., Vrba, M., Cifra, M., Togni, P., Vrba, J.: Feasibility Study of Superficial Hyperthermia Treatment Planning Using Comsol Multiphysics, 2008. Available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4569914&tag=1
- [3] RF Module & Heat Transfer Module - User's Guide. Available at: www.comsol.com
- [4] Seyfi, L., Yaldiz, E.: Numerical Computing of Reduction of SAR Values in a Homogenous Head Model Using Copper Shield, 2010. Available at http://www.iaeng.org/publication/WCE2010/WCE2010_pp839-843.pdf