Numerical analysis of thermal effect of the lossy magnetic materials in the human model by high frequency magnetic field

Dong-Yeol Lee[1], Yu-Ri Lee[1], Young-Jun Ju[1], Yoon-Myoung Gimm[1]
[1] Department of Electronics and Electrical Engineering, Graduate School, Dankook University, 126, Jukjeon-dong, Suji-gu, Yongin-si, Gyeonggi-do, S. Korea, Second Address,
luis7figo@naver.com, myuri2@naver.com, kusa@dku.edu, gimm@dku.edu

Abstract

Electric and magnetic field distributions in the human body model with the magnetic lossy material were calculated between 1 MHz and 1 GHz. Magnetic fields around the numerical human body were generated by a spiral loop around the homogenous body. Distributions of magnetic fields and thermal losses were estimated for local hyperthermal effect in the body.

Keywords : Electric Field Magnetic Field Magnetic Lossy Material Numerical Human Model Hyperthermal Effect

1. Introduction

There arise thermal effects in the complex dielectric materials by E-field or in the complex magnetic materials by H-field. In a lossy dielectric material of biological tissues, it can be observed that temperatures rise in the partial body where coaxial injection syringe is inserted for microwave energy delivery[1]. If lossy magnetic material in a liquid is injected to the dielectric material, it is possible to induce the thermal heat on that specific part of the lossy material by the nearby high frequency magnetic field, which can be developed to hyperthermia for the tumor patients[2].

It is intended to find a proper frequency of magnetic field from 1 MHz to 1 GHz to give the maximum thermal effect to the lossy magnetic material.

2. Material data for field simulation

2.1 Liver

Liver is the target for hyperthermia by magnetic field in this study. The electrical properties of the relative permittivity and loss factor of the liver can be found in the website[3]. Loss factor in the website means ε_r'', which includes both dielectric loss and conductive loss together[4].

The data will be used for field analysis by Maxwell 3D of Ansoft. Because the terminologies in the website for body data and in Maxwell 3D are different, it needs very distinctive understanding for the operation of the tool.

2.2 Lossy magnetic material

Ferrite of NiCuZn was used for lossy magnetic material. It has good absorption characteristics in high frequency bands, so it is widely used in EMI control or EMC applications. A ferrite whose electrical properties are disclosed was used for checking the hyperthermal effect.

Its manufacturing conditions and its electrical parameters are shown in Table 1 and 2[5].

Table 1. Conditions for the NiCuZn ferrite manufacturing.

Composition [mol%]				Calcination temperature [℃]	Calcination time [min.]	Mean particle size [μm]
Fe_2O_3	NiO	CuO	ZnO			
49.0	9.0	8.0	34.0	900	90	1.12

Table 2. Complex relative permeabilities of NiCuZn ferrite of 1.12μm mean particle size.

Frequency [MHz]	Real Permeability (μ_r')	Imaginary Permeability (μ_r'')	Magnetic Loss Tangent ($\tan\delta_m$)
1	1650	720	0.436
2	1150	940	0.817
5	400	780	1.95
10	200	560	2.8
20	40	260	6.5
50	18	180	10
100	5	100	20
200	2	80	40
500	0.92	60	65
1,000	0.40	10	25

3. Electromagnetic field simulation

3.1 Simulation Environment

Liver or ferrite is geometrically modelled in Fig. 1 for numerical EM - field calculation. Each is a cylinder of 100 mm radius and 100 mm height. The current loop is 200 mm radius and the surrounding wire has 4 mm radius and delivers 1 A_{peak} high frequency current.

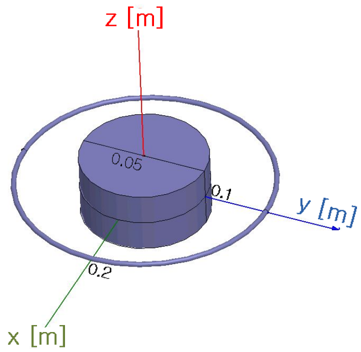

Figure 1. Cylindrical liver or ferrite model surrounded by 1 A_{peak} high frequency current loop.

In the simulation tools of Ansoft HFSS or Ansoft Maxwell, losses by conductivity σ and loss tangent $\varepsilon_r'' / \varepsilon_r'$ should be considered separately. But they affect the fields the same.

3.2 Simulation Result

3.2.1 EM - field and SAR distribution in the lossy magnetic material

If a lossy dielectric material is exposed by E-field, the energy loss per unit mass per unit time is defined as SAR(Specific Absorption Rate), and it is specifically expressed by

$$\mathrm{SAR}(x,y,z) = \sigma(x,y,z)|\overline{E}(x,y,z)|^2/2\rho(x,y,z) \ [\mathrm{W/kg}]$$

$$\sigma(x,y,z) = \text{Conductivity of the medium at } (x,y,z)\ (= \omega\epsilon_0\epsilon_r'')\ [\mathrm{S/m}]$$

$$\overline{E}(x,y,z) = \text{Phasor or amplitude of E-field at } (x,y,z)\ [\mathrm{V/m}]$$

$$\rho(x,y,z) = \text{Mass density of the material at } (x,y,z)\ [\mathrm{kg/m^3}]$$

Because E-field is negligibly small in the liver by a current loop in Fig. 1, SAR(Specific Absorption Rate) values ($SAR_E = \sigma_l |\overline{E}|^2 / 2\rho_l$) in the liver is also very small. H-field has meaningful magnitude in the magnetic material in Fig. 1 and its distribution is shown in Fig. 2 and its corresponding $SAR_H = \sigma_m |\overline{H}|^2 / 2\rho_m$ distribution is shown in Fig. 3. Mass densities of the materials were conveniently decided to be $\rho_l = \rho_m = 1{,}000\, kg/m^3$ in the calculations.

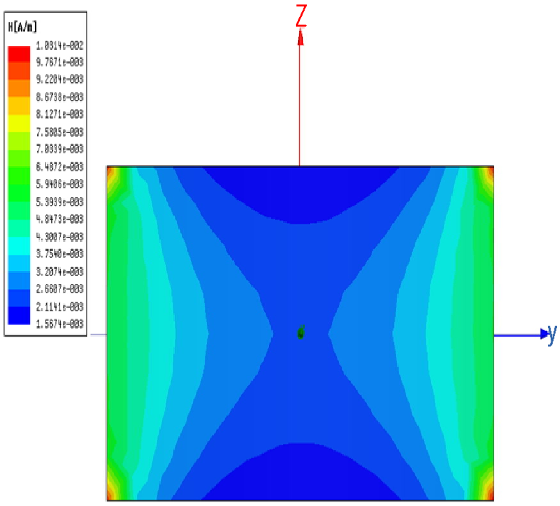

Fig. 2 H-field distribution (1 MHz)
in the lossy magnetic material

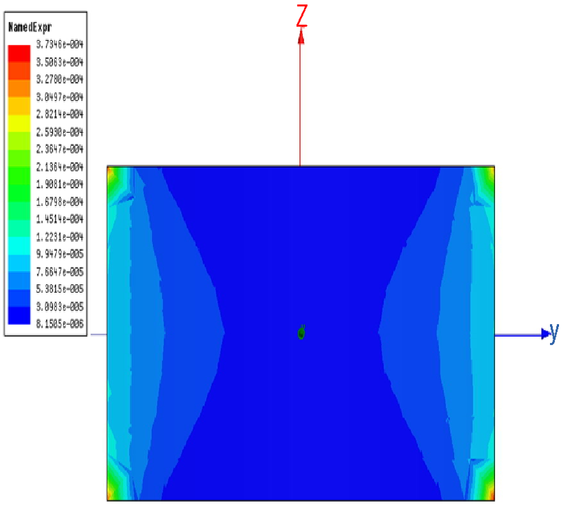

Fig. 3 SAR_H (1 MHz) distribution
in the lossy magnetic material

3.2.2 Embedded lossy magnetic material in the liver

A small lossy magnetic cylinder of 10 mm height and 5 mm radius was dispositioned at the orgin point of the coordinate in Fig. 4. Outside of the magnetic material is the previous liver.

The addition of SAR_E and SAR_H was calculated in the liver with the ferrite as the frequency doubles from 1 MHz to 1 GHz. The peak values in the volume were tabulated in Table 3.

The most efficient thermal effect by 1 A_{peak} current was at 500 MHz in NiCuZn ferrite.

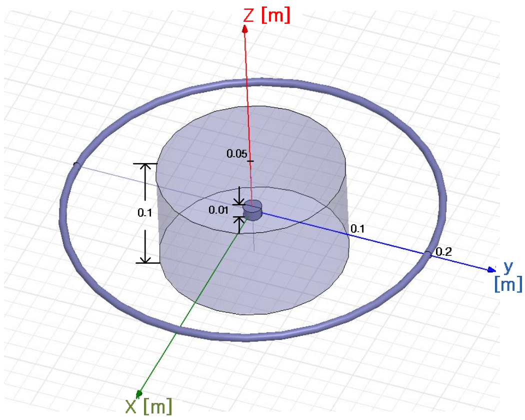

Fig. 4 A small lossy ferrite at the origin point submerged in the cylindrical liver.

Table 3. Peak SAR values in the liver and in the ferrite in 1 MHz ~ 1 GHz band.

Frequency [MHz]	$\|SAR_H\|_{max}$ in the ferrite	$\|SAR_E\|_{max}$ in the liver	$\|SAR_H\|_{max} / \|SAR_E\|_{max}$
1	2.3015 E-04	4.6672 E-28	4.93122 E+23
2	1.5098 E-03	5.2559 E-28	2.87258 E+24
5	5.6672 E-03	1.0360 E-27	5.47027 E+24
10	1.7665 E-02	6.7574 E-29	2.61417 E+26
20	8.3630 E-02	1.5963 E-28	5.23899 E+26

50	3.0319 E-01	6.5599 E-28	4.62187 E+26
100	9.4048 E-01	2.0482 E-28	7.10708 E+27
200	1.9166 E+00	6.4901 E-28	2.95311 E+27
500	6.1714 E+00	3.0584 E-28	2.01785 E+28
1,000	6.0619 E+00	3.0932 E-29	1.95975 E+29

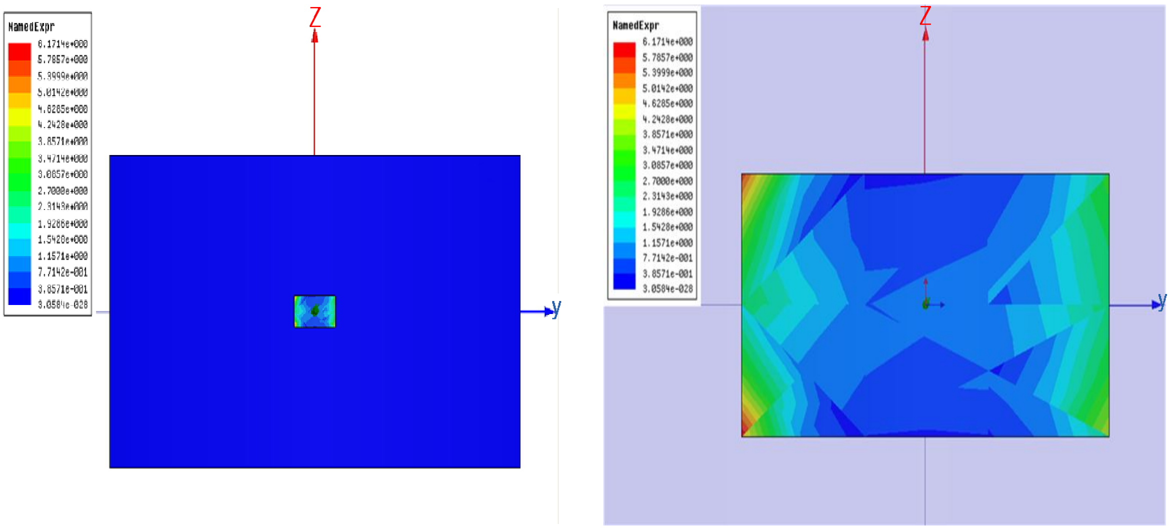

Fig. 5 Distribution of $SAR_E + SAR_H$ at 500 MHz in the liver and in the ferrite.

4. Conclusion

The electromagnetic fields were simulated in a liver and in a small magnetic lossy material embedded inside. It gave the most thermal loss in the ferrite at 500 MHz. This frequency will be changed by the magnetic material types and properties.

The ratio of thermal effect by magnetic field and by electric field is so large that remarkable partial heating is possible.

The frequency region in which the simulation tool of this study is effective should be further investigated.

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