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Temperature Variation by Electromagnetic field in Tissue

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Abstract – The Electromagnetic radiation is of increasing importance in the study of biological characteristics variation, When more complex heterogeneous object like skin with nonflat surface are radiated the additional picks in the surface field pattern are possible .In order to have deep understanding about the effect of biological cells the theoretical analysis of heat transfer in the tissue is essential, Now we analyze the single dimensional heat transfer equation. This analysis determines the effect of thermal convocation due to blood flow and transfer of heat from tissue surface into space, for microwave in the 2 GHz to 10GHz range. The increase in tissue surface temperature is 3°C for 10 GHz with 100 mw/ cm^2. The maximum increase in tissue temperature in an animal exposed to the "safe" microwave field of 10 mw/ cm^2 is upto 1°C.

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INTRODUCTION

Electromagnetic Energy is converted into heat when tissue is in electromagnetic field. Due to heat energy tissue temperature increases with time. Without the cooling effects of blood flow & heat loss from the tissue surface, the calculated tissue temperature increases & no steady state solution exists. We observe here that this theoretical model, while approximate, demonstrates several important aspects of the electromagnetic heating of tissue which have not been widely appreciated. Blood flow made large effect on the microwave induced heating pattern. The extent of tissue heat can be experimentally controlled by artificial cooling the skin. In this article we are going to focus on microwave heating in deeper level in the tissue.

2. HEAT INDUCED IN TISSUE:-

The electromagnetic radiation is of increasing importance in the study of the biological characteristic variations, when more complex heterogeneous objects like skin with nonflat surface are radiated the additional picks in the surface filed patterns are possible. In order to have deep understanding about the effects of biological cells the theoretical analysis of heat transfer in the tissue is essential, Now, we analize one dimensional heat transfer equation from fundamental equations.

3. ANALYTICAL TREATMENT

The single-dimensional heat transfer equation in tissue is given by

$$pc\frac{\partial T'}{\partial T} = k\frac{d^2T'}{dx^2} - Vs(T' - T_o) + Q(x,t)$$

Where,

P= the density of tissue in gm/cm3

C= the specific heat of tissue plus blood in cal/gm0C

K= the coefficient of tissue heat conduction in cal/cm/s0C

V_S= the product of flow and heat capacity of blood in cal/cm3/s0C

Q(x,t) = the heat input due to the microwave field in cal/cm3/s

T(x,t) = the tissue temperature in 0C

T_O= the temperature of the arterial blood entering the tissue.

The term Vs (T' - To) represents the contribution of the blood convection to the dissipation of heat deposited by the microwave field.' This energy input is, for a plane electromagnetic wave of intensity Io W/cm2 incident upon the tissue:

$$Q(x,t) = \frac{I_{oT}}{JL} \exp$$

where J is the mechanical equivalent of heat, L is the depth at which the microwave power deposition is reduced by a factor e, u (t) is the unit step function, and r is the fraction of energy transmitted into the tissue (the remaining energy being reflected). For muscle tissue r is near 0.4 at 2.4 GHz.

For convenience, we consider the simplified equation

$$\mu \frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial X^2} - \lambda T + q$$

The simpler expression does, however, produce reasonable temperature profile. We have also neglected a constant source term in above eq. accounting for metabolic heat production, since we are interested in the tissue temperature increase resulting from microwave radiation.

where T= T' - To is the differential temperature increase, and

$$\mu = pc/k, \quad \lambda = Vs/k,$$

Here we made steady-state solution on the above eqn.

In the stedy-state , (dT/dt=0)

$$\frac{d^2T}{dx^2} = \lambda T - q_0 \exp\left(-x/L\right)$$

Where

$$q_0 = I_{0T}/JLk.$$

The solution of above eqn is given by

$$T(x,\infty) = \frac{q_0}{\lambda - 1/L^2}\left[\exp(-x/L) - \frac{1/L + \alpha}{\sqrt{\lambda} + \alpha}\exp\left(-x\sqrt{\lambda}\right)\right] + \frac{\alpha(T_e - T_0)}{\alpha + \sqrt{\lambda}}\exp\left(-x\sqrt{\lambda}\right).$$

The microwave penetration depth L varies in muscle from 1.0 cm to 0.1 cm at 2 GHz and 10 GHz, respectively. The other parameters are approximately:

k=0.001 cal/cm/s0C (thermal conductivity of tissue)

Pc= 1 cal/cm3 0C

Vs=0.0013 cal/cm3/s0C (average blood flow in man)

λ = 1.30 cm-2

μ =1000 cm-1/s

α= 0.25 cm-1 (for resting nude man in a 30C environment).

The Equation suggests that the position of the temperature maximum, The location of the temperature maximum as a function of L and λ can be found by differentiating Eq. Thus, for the tissue surface maintained at temperature Te. The position is express in terms of x.

$$x_{max} = \frac{1}{\sqrt{\lambda} - 1/L} \cdot \left\{ \mathrm{Ln}\left(L\sqrt{\lambda}\right) + \mathrm{Ln}\left(1 + \left(\frac{\lambda - 1/L^2}{q_0}\right)(T_0 - T_e)\right)\right\}$$

4. RESULTS

These three results are analyzed at I_0=100 mw as shown in Fig 1,2 & 3 respectively.

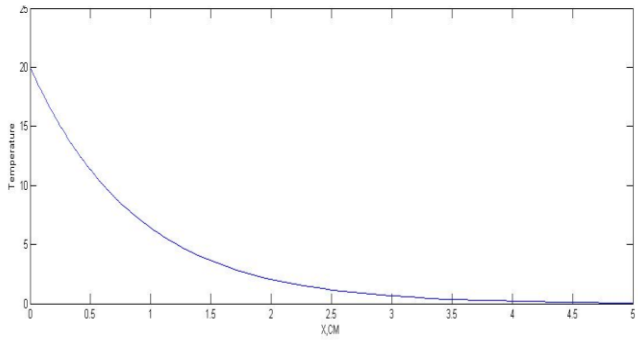

Fig.1 Steady state analysis with L=0.1, f=10GHz

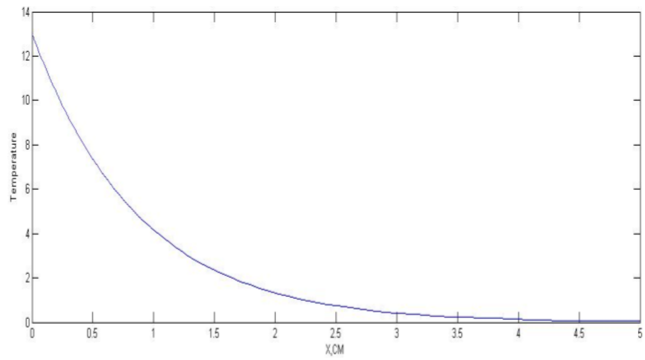

Fig.2 Steady state analysis with L=0.3,f= 8 GHz

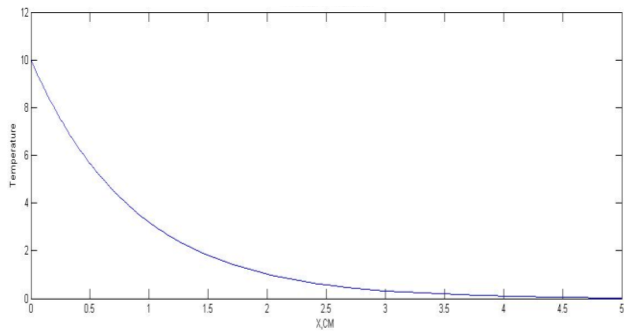

Fig. 3 Steady state analysis with L=1, f= 2 GHz

This result is analyzed at I_0=10 mw as shown in Fig 4

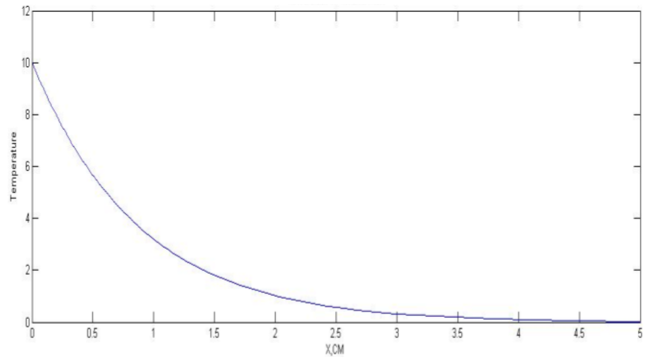

Fig. 4 Steady state analysis with L=0.1, f= 10 GHz

Comparative Chart:-

Sr. no	Frequency in GHz (f)	Penetration Length in Cm (L)	Wave Intensity in mW (I_0)	Rise in tissue Temperature in degree Celsius (Ts)
1	10	0.1	100	3
2	8	0.3	100	2.29
3	2.4	1	100	1.76
4	10	0.1	10	1.76
5	2.4	1	10	0.4

Table 1

5. CONCLUSION:-

Tissue thermal conductivity and blood flow where about equally effective in limiting the temperature rise in the heated area. The increase in tissue surface temperature is 3°C for 10 GHz with 100 mw/ cm^2. The maximum increase in tissue temperature in an animal exposed to the "safe" microwave field of 10 mw/ cm^2 is upto 1°C.

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