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## Research Article

# Thermal Analysis of head with Exposure to Electromagnetic Mobile Waves

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**Abstract:** The progressive use of cell phones has obliged the researchers to find out proper methods for extraction of radiating pattern and electromagnetic field effects on some part soft he body such as head. The most primitive and outstanding effect of electromagnetic waves on the head is temperature increase. For this reason this paper is looking for advantageous methods for handling the heat transfer problem with special attention to biological characteristics of head. This study was conducted at Department of Biomedical Fluid Mechanics Research Laboratory Biomedical Engineering Faculty, Amir kabir University of Technology(Tehran Polytechnic),Tehran, Iran2014 For this purpose, first by use of a steady finite difference method, the specific absorption rate (SAR) was calculated in a schematic simulated geometry of head and then head thermal contours were derived by using beneficial fluid and thermal equations. In this paper thermal effect to mobile electromagnetic waves was assessed. Maximum temperature increase was determined for 2 different frequencies. For both of them the maximum temperature increase was in the safe region. According to standard communication committee criteria temperature increase of 0.6° K is the ultimate limit for 10 grams SAR. In addition the SAR value scan is regarded. The major point is the application of bio heat equation that considers the biological aspects of the head. In other word, by calculating the SAR, it is possible to derive thermal contours.
**Keywords:** electromagnetic mobile waves, SAR, heat transfer, electromagnetic field.

## INTRODUCTION

In the past decade the developing application of mobile phone has raised this question in the public if the continues use of this kind of device is harmful or not. Also this progressive application has forced the electromagnetic researchers to find out the proper methods for investigating the hazardous side effects of mobile waves. Different organizations in the world have established immune guiding protocol for absorption of electromagnetic waves.

Institute of Electrical and Electronics Engineers [IEEE], International Commission on Non-Ionizing Radiation Protection [ICNIRP] and Federal Communications Commission [FCC] standard have been selected specific absorption rate (SAR) as a criteria of primary limitations for radio frequency (RF) exposure[1-3].

This value is known as the thermal increase of 0.6Centigrade degrees (equal to 2W/kg for10 grams sample tissue).

SAR is the rate of body energy absorption, when body is exposed to electromagnetic field. SAR is calculated as the absorbed power over the mass of tissue and so it has the unit of watts kilogram per (W/kg)[4]. There are different approaches for SAR assessments. In one approach it is calculated and it is averaged over a small volume of a specific tissue (1 g or 10 g of tissue). In another approach it is averaged over the whole body[5]. Frequencies ranged from 100 KHz to 10 GHz are being used for SAR investigations [6]. One of the primary effects of SAR is the temperature increase in head. There are investigations which calculated these thermal alterations For example Kiyungjooet. al [7] by an adaptive finite element method model of the heat transfer in human head, found 0.25 C temperature increase after 10 minutes in special circumstance.

In this paper, we tried to utilize an acceptable model of the head with different tissues concluded. In addition to that, by a low cost finite difference method we tried to obtain accurate results.

## NOMENCLATURE

C [J/kg.°c] Coefficient specific heat
*B* [w/m3.°c] Coefficient of heat transfer by blood circulation
k [W/mK] Thermal conductivity
E [W/m3] volumetric heat generation density

| | | |
|---|---|---|
| SAR | [W/kg] | Specific Absorption Rate |
| T | [K] | Temperature |
| x | [m] | Cartesian axis direction |
| y | [m] | Cartesian axis direction |
| Z | [m] | Cartesian axis direction |

## MATERIAL AND METHOD

### Experimental details/ methodology

### Head model

There are different models that have been used in different researches[8, 9]. In our model, we tried to include different tissues of head and so have a more accurate approach. The head geometry file was entered in GAMBIT software (open-source collection, gambit 14) in IGS format. This geometry was gridded by tetrahedral elements. The grid independency was checked and the total number of 257244 cells was generated in the head volume. This geometry is shown inFigure1.

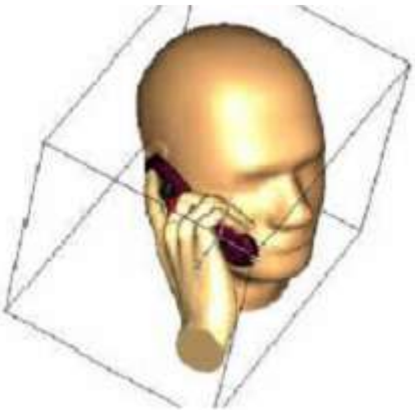

**Fig-1: Head model**

### Numerical Finite Difference Method

For head and mobile phone interaction assessment, CST software was used. This software solved the Maxwell equations for obtaining the electrical magnetic fields by finite difference method. Then by the electric field, the SAR values were calculated. The relation between SAR and electric field is according to equation1.

$$SAR = \frac{\sigma}{2\rho}\left|\hat{E}\right|^2 = \frac{\sigma}{2\rho}\left(E_x^2 + E_y^2 + E_z^2\right) \quad (1)$$

That σ and ρ are the conductivity and density of the tissue respectively. E is the component of electric field in the direction of x, y and z.

### Temperature Increase Calculation in head

The bio heat equation was used for extracting thermal contours of head. This equation contains biological term in addition to heat transfer terms. This biological term shows the heat transfer according to blood circulation in the head. This equation was solved in the head in 2 different conditions. In the first situation, for investigating the effects on skin, the material of the model was considered as skin, and in the second situation by applying bone material on the model, thermal contours were obtained. Bio-heat equation is shown in equation2.

$$K\nabla^2 T + \rho(SAR) - BT = C\rho\frac{\partial T}{\partial t} \quad (2)$$

That C is the specific heat, K is the thermal conductive coefficient, p is the density of the tissue, T is the temperature and B is the biological term that shows heat transfer according to blood circulation in head. In the steady state condition the transient term of the bio-heat equation will be zero and the equation reduces to equation3.

$$K\nabla^2 T + \rho(SAR) - BT = 0 \quad (3)$$

The boundary condition is convection on the surface of the head.

$$H.(T_s - T_\infty) = -K\frac{\partial T}{\partial n} \quad (4)$$

Where $T_S$ is the head surface temperature, $T_\infty$ is the ambient temperature, H is the coefficient of convection and n is the normal direction to surface.

In the initial moment, the temperature of the head was considered 37 centigrade degrees uniformly. Thermal contours of the head were derived by solving Equation3. Time needed to reach steady state condition depends on the frequency, power and impedance of the phone. For a typical phone by the power of 0.5 watt and the frequency between 0.9-2.5 GHz the transient time is about 30 minutes[10]. Thermal parameters were borrowed other researches[11] and presented in chart1.

**Chart1. Thermal parameter of tissue**

| Tissue | C1[J/kg.°c] | K[w/m.°c] | B[w/m3.°c] |
|---|---|---|---|
| Skin | 3500 | 0.42 | 9700 |
| Muscle | 3600 | 0.50 | 2100 |
| Bone | 1300 | 0.40 | 1000 |
| Blood | 3900 | 0.49 | 900 |

It should be noted that the values in chart 1 were obtained by experiments on animals. They were used because of the lack of reliable human values.

## RESULT AND DISCUSSION

### Specific absorption rate

CST software (efficient computational solutions for electromagnetic design, version 4) was used for SAR calculations. By the numerical analysis the SAR values were obtained on the head volume. The antenna was discrete and also it had an impedance of 50 Q. The antenna was located beside the head by the distance of 1cm[12] (this is an acceptable value that has been used in many researches). 2 different thermal and electrical boundary conditions were considered. Model was located in a cubic ambient. It is shown in Figure2.

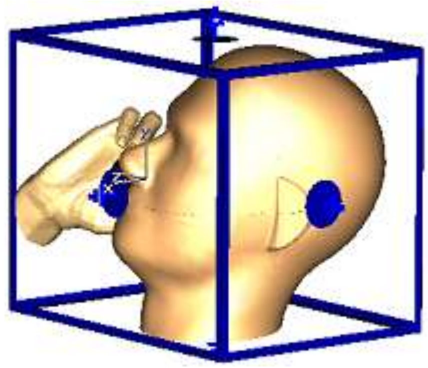

**Fig-2: Boundary condition on walls**

The walls considered as iso-thermal walls with the temperature of 25 centigrade degrees. The zero tangential component of magnetic field is also considered. 10 grams SAR values in 900 MHz frequency are shown in Figure3.

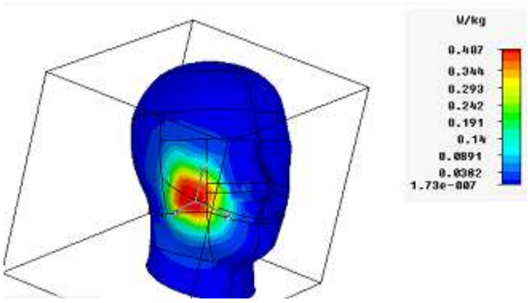


**Fig-3: SAR contour in 900 MHz**

As it has been shown in the Figure 2 the maximum amount of SAR locates on the cheek region and also it has the value of 0.407 W/kg. This contour is derived by the numerical solution of Maxwell equations. It is obvious that the regions near the antenna have the largest SAR values and by keeping away from these regions the SAR Values diminish. SAR contour in 1800 MHz is similar to previous one, except the maximum value increases to 0.611 W/kg. It is shown in Figure4.

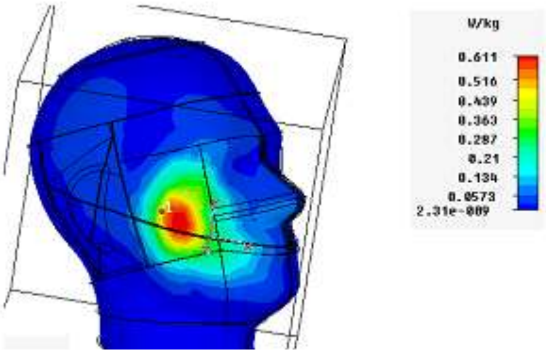


**Fig-4: SAR contour in 1800 MHz**

For investigating the effects of model, a spherical model was generated and the maximum SAR values in the frequency of 900MHZ were compared. For spherical model the maximum SAR value of 0.414W/kg was obtained that is near the original model. It means that the head model has a negligible effect on SAR values. SAR values on spherical model are shown in Figure5.

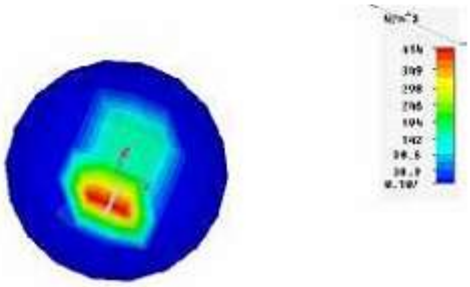

**Fig-5: SAR contour on a spherical head.**

**Thermal Analysis**

GAMBIT software was used for meshing the geometry. For thermal analysis of the electromagnetic waves, 4 hemisphere volumes were generated on the cheek. Uniform SAR values were considered on these volumes. By multiplying SAR and tissue density a new quantity is derived that has a dimension of $W/m^3$. It is stated in equation 5.This quantity is called power lost density and it can be considered as a heat generating source.

$$SAR(W/Kg) \times \rho(Kg/m^3) = E(W/m^3) \qquad (5)$$

Chart 2 shows the dimensions of the misphere Volumes and also it contains the SAR Values on them. These volumes were generated with respect to SAR contours. Chart 3 is same as the previous one and it belongs to the frequency of 1800MHz.

**Chart2.Generatedheatin900MHz**

| R(cm) | 0.02 | 0.03 | 0.04 | 0.05 |
|---|---|---|---|---|
| E(Skin) | 447 | 272 | 154 | 98 |
| E(Bone) | 1140 | 458 | 261 | 166 |

**Chart3.Generatedheatin1800MHZ**

| R(cm) | 0.016 | 0.025 | 0.035 | 0.05 |
|---|---|---|---|---|
| E(Skin) | 672 | 483 | 316 | 147 |
| E(Bone) | 1122 | I806 | 527 | 218 |

Meshed model with considered volumes is shown in Figure6.

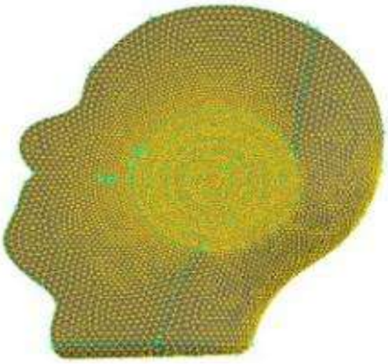

**Fig-6: Meshed Model**

As shown in Figure6, smaller grid cells were generated in the high SAR Value regions. We expect larger temperature gradient in these regions. Fluent soft ware was used for the thermal analysis. Two different materials were considered, bone & skin. Free convection is the boundary condition of the surface $5W/m^2$. K is the approximate convection coefficient for stagnant air [5]. There is dual curve for energy equation is shown in Figure7.

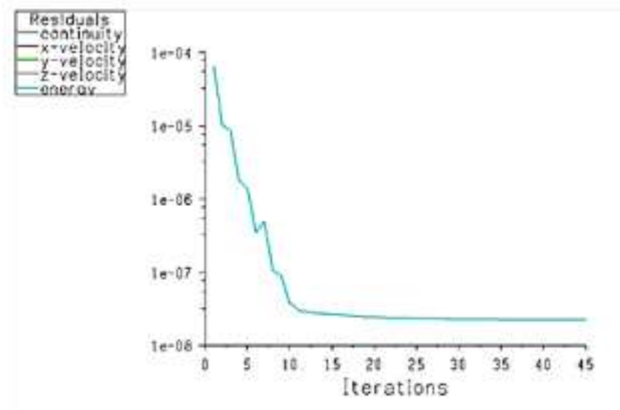


**Fig-7: Residualcurveforenergyequation**

For assessing of grid in dependency, maximum temperature was considered as the substantial criteria. Figure 8 shows the temperature increase Variation by number of the cells.

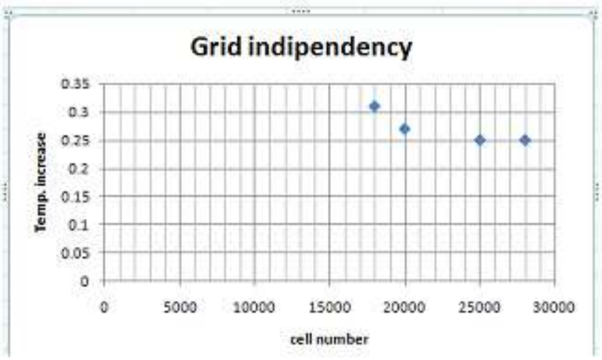


**Fig-8:Temperature increase variation by cells number**

**Thermal Contours**

Figure 9 shows the temperature contribution in 2 perpendicular face sat 900MHz. Material of the model was skin and Maximum temperature was 310.25°K. Figure10 depicts thermal contour for bone material. The maximum temperature increase is a bit smaller. In this case, the maximum temperature increase in head is about0.20°K.

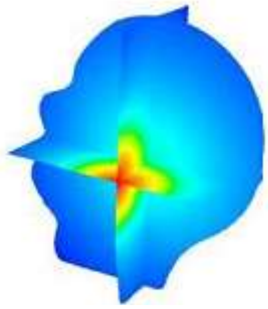

**Fig-9: Thermal contour of skin in 900MHz.The maximum temperature increase is 0.25°K.**

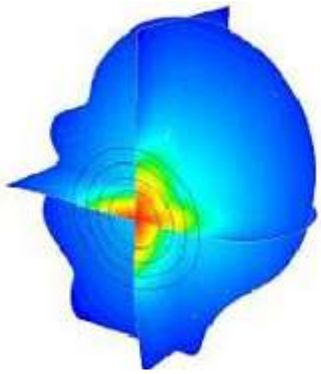

**Fig-10: Thermal contour of bone in 900MHZ.The maximum temperature increase is 0.25°K.**

For comparison of 2 above situations, it is possible to show the temperature variation in one graph. In other hand of the head this comparison is shown in Figure11.

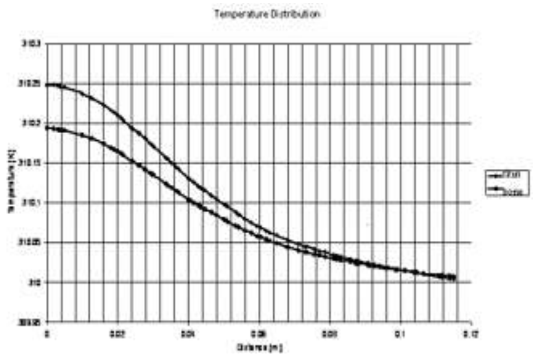


**Fig-11: Comparisonv of two material model in 900MHZ**

The distance between these 2 opposite points is 12cm. Just like SAR distributions, thermal distribution scan be obtained in 2 different frequencies. Figure 12 & 13 show temperature contours for skin and bone in 1800 MHZ. Inthis situation the maximum temperature increase in skin and bone model material is 0.35and0.30K, respectively.

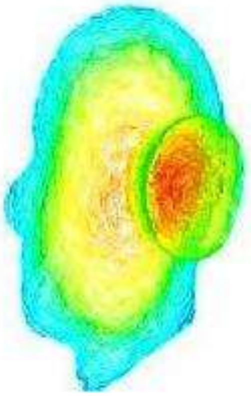

**Fig-12: Thermal contour of skin in1800MHZ.The maximum temperature increase is 0.35°K.**

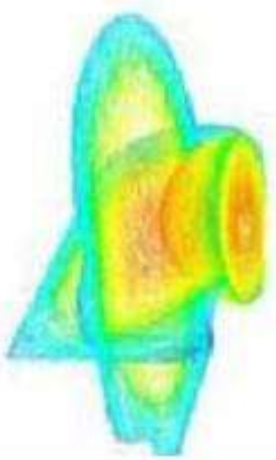

**Fig-13: Thermal contour of bone in 1800MHZ. The maximum temperature increase is 0.30K.**

Similar to previous one for comparison of 2 different materials in this frequency, temperature Variation in one graph is shown in Figure14.

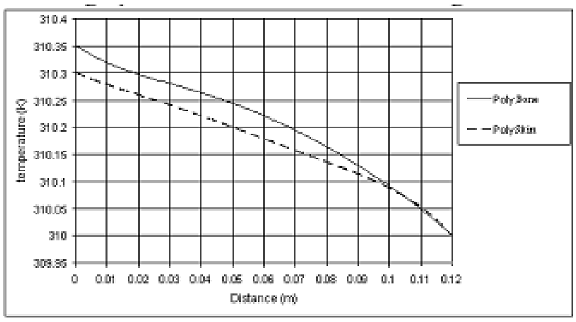


**Fig-14: Comparison of 2 material model in1800MHZ**

**CONCLUSION**

In this paper thermal effect of mobile electromagnetic waves was assessed. Maximum temperature increase was determined for 2 different frequencies. For both of them the maximum temperature increase was in the safe region.

According to standard communication committee criteria temperature increase of 0.6 K is the ultimate limit for 10 grams SAR. In addition the SAR values can be regarded. For 10 grams tissue 2 W/kg is the extreme threshold. Our calculations show that the maximum SAR values are 0.407 and 0.611 W/kg for the frequencies of 900 and1800MHZ. They are both in the safe region. The effect of the head model also has been searched. It was compatible to the previous researches Hirata et, al [13]claims that there is a linear relation between the values of SAR and maximum temperature increase. According to this theory it presents equation6.

$$\hat{T} = a\,.SAR_{ave} \tag{6}$$

According to [13] there is an acceptable correspondence between experimental findings and linear relation between maximum SAR and maximum temperature increase. For 10 grams SAR in 900MHZ this relation is shown in Figure15.

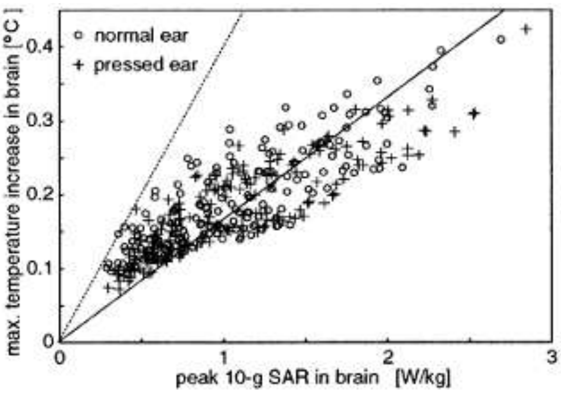


**Fig-15: Linear relations between SAR and maximum temperature increase, borrowed from[13].**

Out simulations show that maximum SAR value for this situation is 0.407W/kg. Base on temperature increase of 0.2K is expectable[13].

As is stated before, one the primary influence of SAR in the increase in temperature. Different researchers have found different temperature increase ranging from 0.1 to 0.7 K [7, 14]. This difference is backed to the different models of the head, boundary conditions and calculation methods. In our research, we have investigated different tissues and different frequencies. Besides that, we tried to assess the thermal variation in different cuts and section of the head. Different regions have been defined and calculations were performed in each part. In addition to that, we tried to apply realistic boundary conditions. Our results are approximately in rage of previous results. Our values are in well correspondence to some other results and it shows that our assumptions and solving methods in spite of its simplicity have an acceptable accuracy with lower computational cost.

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