STUDY ON SOME EFFECTS OF RADIOFREQUENCY ON HUMAN BRAIN

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Abstract: *The study is based on determining the impact of the radiofrequency on the human by taking into account the SAR (Specific Absorption Rate) value and the temperature elevation through the brain. SAR represents a parameter given by each phone manufacturer regarding the amount of radiation emitted and absorbed by the brain. Was used the FlexPDE software to solve the Pennes' bioheat equation and to determine the temperature elevation in the brain due to radiofrequency. In the graphical output, it was observed a sudden temperature rise above the normal brain one, of 37 ^{0}C, but stabilization after a short period. This study targets to make people aware both of the advantages and disadvantages of GSM usage.*

Keywords: *electromagnetic compatibility, radiofrequency, bioheating.*

1. Introduction

Exposure to radiofrequency radiations (RFR), such as those emitted by mobile communication devices, has sparked increased worry about the potential for negative health impacts. This form of radiation is known as non-ionizing radiation and its health effects are still being debated. Over millions of years, living creatures have adapted to exposure to electromagnetic radiation from natural sources and its consequences. Humans are exposed to the natural environment when they are outside. We must begin to recognize that we have drifted too far from the natural conditions to which humans and all other living organisms have adapted in the twenty-first century.

Nowadays, many people start to pay attention to the effects of using cell phones and health issues related. Electromagnetic waves are passed to the body when using a mobile phone, causing health difficulties, particularly in the ear skull area, where they are known to harm neurons. Being silent on the dangers that GSM might pose to the brain from them manufacturers, we must investigate the radiation emitted by GSM to see if it has any negative effects on the brain [10].

The underlying issue in this debate over the dangers of EMF exposure is a lack of understanding of the fact that certain particular fields interacting with the human body

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might have negative health consequences. Due to physical and physiological variances, these effects vary from person to person, with some people being far more impacted than others. The World Health Organization (WHO) and the International Agency for Research on Cancer (IARC) released a press paper in 2011 [12] classifying radiofrequency electromagnetic fields as possibly carcinogenic to humans, citing an increased risk of glioma, a malignant type of brain cancer, linked to wireless phone use.

The World Health Organization (WHO) suggested that biological, biomedical and epidemiological investigations be carried out to ensure that no health impacts are created at levels below those that induce thermal impacts. Because public opinion is now concerned about the impacts of radiation, particularly in relation to cellular systems (mobile phones and transmitting antennas), it is critical to establish and strengthen scientific research that can confirm or deny the existence of evident harm. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Mobile Manufacturer Forum (MMF) organizations claim that the radiofrequency emitted worldwide has no noticeable effects. Due to this fact, there have been multiple reports published suggesting that both biological systems, in vivo (performed on living organisms) and in vitro (carried out outside the living organism, usually in a test tube), are harmed by the exposure to field intensities.

Electromagnetic radiation may pass through several popular construction materials. There are compounds that can be used to dampen electromagnetic waves and their reflections. Aluminum foil-based insulation products are efficient. If the building has critical systems, steel barriers can be used to safeguard them. As a result, several manufacturers use covers made of metallic and other specific materials to prevent electromagnetic radiation from propagating within. Metal-containing paints and drapes can also help to reduce radiation, although their effectiveness is limited due to the thin protective layer. Radio and television equipment, along with radar transmission towers at higher frequencies, generate electromagnetic radiation. These and other sources, such as electric power lines, are constantly triggered in many urban and rural locations. Towers allow the radiation to spread out across a large area. Radiation beams, on the other hand, are directed. If the beams are directed to the horizon, the radiation exposure in the immediate vicinity of a tower may be reduced. If negative health impacts are discovered in the vicinity of radiation producing towers, they might be the result of concurrent substantial environmental exposures, such as chemical exposures. [2]. As a result, it is critical that we study the potential dangers associated with the use of a phone, which is a device that receives and transmits signals (information) through antenna by creating and receiving radio frequency waves. It is also well known that radio waves are a type of electromagnetic wave, which poses some risk to the human body.

The most sensitive organ that faces electromagnetic radiation is the human head. One issue that is brought up rather often is that the antenna of a cell phone radiates close to one's head. Changes in intracellular ionic concentrations, the synthesis rate of different biomolecules, cell proliferation rates, animal reproductive capability and other biological impacts of radio frequency (RF) electromagnetic radiation have been observed on biomolecules, cells and complete organisms. As an outcome, the GSM must be analyzed in order to determine its impact on the brain [6].

During exposures to simulated or genuine GSM phone fields, as well as FM (analog) phone fields, changes in human cognitive function have been recorded. There was an increase in decision reaction time with simulated GSM and FM fields, with FM exposures being faster than GSM. Low amounts of RF radiation generated by mobile phones have been linked to health issues such as migraines and brain tumors [1].

Program involving finite elements FlexPDE is a tool for numerical analysis of partial derivate equations. It is not focused toward engineering design like most recent products. This software's language's flexibility allows users to quickly specify the system of differential equations, boundary conditions, and form of the region, as well as set up the essential numbers to be calculated. Unlike most modern FEM software, it focuses primarily on equations that describe physical processes, allowing a deeper understanding of the underlying mathematics, easy switching to new models, and conducting numerical experiments to test materials, as well as the functional characteristics of these models. FlexPDE is used in a wide range of applications, including physics, biology, and chemistry.

2. Bioheat Transfer

Bioheat transfer research is difficult because it involves a complex set of mechanisms to consider, including thermal conduction in tissues, convection and blood perfusion, metabolic heat generation, vascular structure, and changes in tissue properties as a function of physiological state, among others. It is crucial to understand how heat is transferred in live tissue, and this study focuses on heat transmission in the brain.

A thermoregulatory system maintains the body and brain temperature at 37 ^{0}C, although exposed to external stress, for example RFR from cell phones [7].

The amount of blood that runs through a body portion varies depending on the function that area performs. The thermal energy balance is influenced by blood in two ways. It can act as a heat source or a heat cooler. In case of cold weather, blood transfers the heat from the heart so that it can warm the body. In warmer times, it is a heat sink. Each particular tissue needs an exactly amount on nutrient. This term is called Blood Perfusion Rate and it is defined as the quantity of blood given to a specific tissue in time (minutes) by 100 grams tissue weight [3].

The heat transfer process can only be understood if the thermal properties of the tissue are known. In this study, we will determine the distribution of temperature in the brain through exposure to RFR by using the equation on bioheat transfer. It is necessary to have the values for blood perfusion, external heating and heat conduction, along with the SAR value determined previously. After replacing all of them in Pennes' equation, we will find our wanted results. In order to compute the differential equation in the script program FlexPDE, the variables used, including the dependent one, the boundaries and the equations are mandatory. In our study it is used the Pennes'equation with it's variables and the boundaries established by the model that have been used.

2.1. Pennes' Equation

Pennes' bioheat transfer equation is built around the concept of Fourier law, which states that a temperature change in any portion of the materials causes an immediate change in all points. This indicates that even when the intervening distance is infinite; the transmission speed of thermal perturbation is limitless, which raises some issues and controversies. Pennes wrote a book based on the interaction of a tissue in this case, the brain, with perfuse blood. Then he devised a model that he utilized to characterize the impact of metabolism and blood perfusion on tissue energy balance.

Different continuum approaches in the form of a customized heat diffusion equation in which the impacts of microvascular blood flow are addressed for by one or more extra variables have been developed to quantify microvascular heat transfer in biological tissues. The equation proposed by Pennes for bioheat transfer equation is dependent on time and given below:

$$\rho C_p \frac{\partial T}{\partial t} - div(Kgrad(T)) + W \rho_b C_b (T - T_a) = \rho \, SAR. \tag{1}$$

Where: ρ - Brain density; ρ_b - Blood density; C_p - Brain's specific heat; C_b - Blood's specific heat; K - Thermal conductivity constant; W - Volumetric perfusion rate; Q - Power deposit within the tissue (per unit volume); T_a - Arterial blood temperature; SAR - Specific Absorption Rate.

Thermal properties of tissue   Table 1

Tissue	ρ (kg/ m^{-3})	K (Wm^{-1}K^{-1})	C (WsKg^{-1}K^{-1})	W 10^{-3} (m^{3}s*kg)
Skeletal Muscle	1050	0.50	3465	0.9
Kidney	1050	0.54	3700	61
Liver	1060	0.52	3600	15
Adipose Tissue	950	0.27	3100	0.5
Cortical Bone	1920	0.79	1300	1.3
Blood	1060	0.51	3720	-
Brain	1040	0.54	3640	7.3

This study is based on the analogy of the brain situated inside a box, so it is convenient to use a two dimensional box and a circle to represent the brain. The circle can be define by considering an ARC with centre at zero and having a radius R with the angle 360^0 , we have centre(0,0), circle(R,0). Angle = 360^0, our radius previously calculated to be 9 cm. The region is like, making the temperature between line (-10,-10) to (10,-10) and and from(-10,10) to (-10,-10) be zero. Also, between (10,-10) to (10,10) and from (10,10) to (-10,10) be the temperature elevation calculated for each frequency on a 4-minute call. This is an approximation approach that we may use to analyze temperature elevation in relation to coordinate distances, not an actual situation of RFR to the brain. Each parameter has a specific value, already determined by the researcher (Table 1) [4], [8].

Using FlexPDE on the Relation (1) was determined the temperature change in the brain. To obtain a simple and analytical solution, was restricted the analysis to a tissue

model that is homogeneous, by taking most of the terms as constants from the table. Throughout the body, the arterial blood temperature is unchanged, being equal to the core temperature of it, usually T_a = 37 ^{0}C. Thus, we need to have a boundary condition of the model [5]. This means that the crucial part of this simulation is to model the brain inside this box. The easiest way to do this is by comparing the brain with a circle in a 2D box. Because was determined the radius of the brain, was defined this circle as an Arc with center in zero and radius R. This implies an angle of 360 degrees. The box should have some boundaries that require the temperature elevation previously calculated in Table 2 [11]. Finally, there are two regions, number one for the box and number two for the brain [9].

Temperature elevation values Table 2

Frequency (MHz)	1800	1900	2100	2400
ΔT	0.0850	0.1021	0.1057	0.1339

From the software point of view, it recognizes a few plots. In our study, was studied he graphical output for the temperature elevation around brain and the one along its enclosure, the box. Moreover, was also plotted the temperature elevation through the box, meaning through the brain and on the ,'surface' of the circle. Due to the fact that we have taken into account a 4 minute call, the time for graphical plotting will be from 0 to 4 with 0.5 steps.

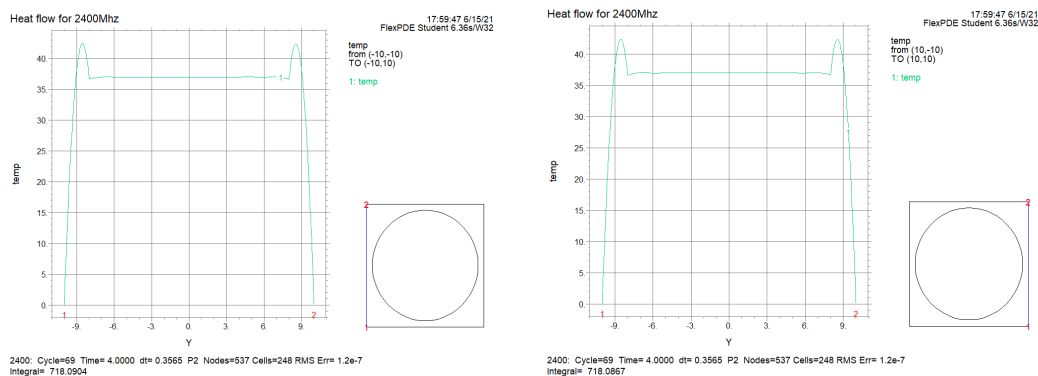## 2.2. Temperature Elevation along Sides of the Box

Fig. 1. Graphics for 2.4 GHz

The graphical outputs obtained by the simulation in FlexPDE of Equation (1) for the frequencies 1800 MHz, 1900 MHz, 2100 MHz, 2400 MHz show that the temperature is not constant or linear, it rises and falls.

In some cases, it is seen that the temperature can reach even 44 ^{0}C, above the normal 37 ^{0}C. After this sudden rise, it comes back to normal 37 ^{0}C and stabilizes (Figure 1), but then it increases once again and then comes to zero. Within the circle/brain, it remains normal, but in the surroundings it is abnormal.

2.3. Temperature Elevation between the Box and the Brain and Contour Temperature

One of the most important results is the temperature elevation through brain (Figure 2). From the obtained graphics, was remarked that the temperature ascends abruptly and decreases to a constant value of 37 ^{0}C, stabilizing at the blood temperature.

Effects of this sudden rise cannot be felt by the user during a usual call due to the fact that it will elevate, but sink back at the normal body temperature. It is observed to be the steady at 37 ^{0}C.

By analyzing the maximum temperature reached in the brain for the analyzed frequencies, it can be seen that this temperature is of 39 ^{0}C, plus minus small errors of solving in all of the cases. An increase of temperature will advance to the center of the brain and represents dangerous effects on our brain.
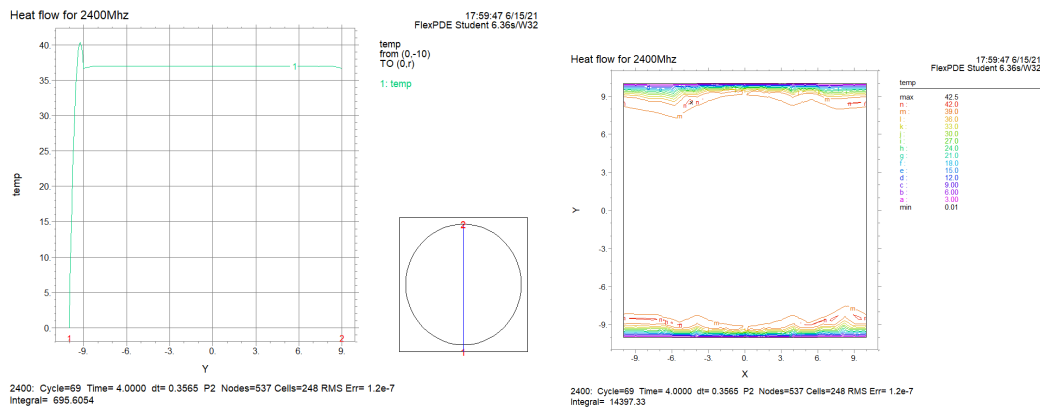

Fig. 2. a) Temperature elevation between box-brain; b) contour temperature for 2.4 GHz
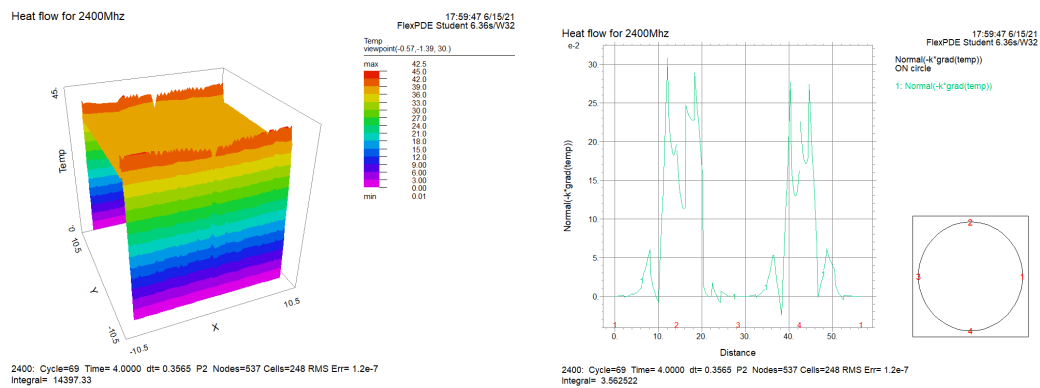
2.4. Surface Temperature

Fig. 3. a) Surface temperature; b) temperature elevation on the circle (2.4 GHz)

Was studied also the elevation of temperature around the brain's surface (Figure 3). It can be observed the rising of temperature across its surface. For most of the

frequencies, the maximum temperature is 42.5 ^{0}C, but there are also some peak values of 45 ^{0}C. The difference is between 5.5 - 8 ^{0}C more than normal temperature.

3. Conclusions

By studying the graphics in detail, it can be observed that the person making the call will not feel the effect of this temperature elevation at the moment of the call, but with time. Talking from the point of view of the skull, in our case, the box, the temperature is 44 ^{0}C at 1800 MHz. Then, it increases by half of degree, being 44.5 ^{0}C for 1900 MHz, 45 ^{0}C for 2.1 GHz, 45.5 ^{0}C for 2.4 GHz. After this rising, the temperature goes back to 37 ^{0}C, normal one. This means, that for each of these frequencies, it is an elevation starting from 7 ^{0}C to 9 ^{0}C. Once again, this oscillation will not damage the brain massively at once, but step by step. For all of the frequencies, the maximum contour temperature, the brain contour, oscillates around 39 ^{0}C, only 2 ^{0}C above the body temperature. This is not a harmful difference, but is important to not neglect it.

Another plot that is interpreted is the one showing the temperature through the brain. Starting with a frequency of 1800 MHz, the value is also 40.5 ^{0}C. With an increase of frequency, the temperature will get to 41 ^{0}C at 1900, 2100 and 2400 MHz. The fifth generation of network determines the temperature around 41 ^{0}C and 41.5 ^{0}C. Although our brain is protected by Blood Brain Barrier (BBB), these extra degrees are not an advantage. BBB may cool down the brain, but this constant heating may weaken the barrier and years later it will not be able to reduce the temperature any more.

The last output is the one for surface temperature. This means the temperature of the surface of human brain. In most of the cases, the maximum temperature reached over the surface is between 39 ^{0}C and 42.5 ^{0}C. The difference is made by some peak values that appear in every graphic. From 900 MHz to 28 GHz, these peaks start to multiplicate. If at 900 MHz, they can hardly be seen, at 2400 MHz, it is easy to observe them. The value of these peaks is of 45 ^{0}C, meaning that BBB will heat suddenly and exceed the normal temperature with 8 ^{0}C.

In this study, was observed that the difference between every frequency that was simulated is not clearly noticeable. This means that probably Pennes' equation is more dependent on the SAR value or, for our simulation, on the dielectric parameters of the tissue. In this case, the problem is represented by the fact that these characteristics of the human head are not properly documented and there is a lack of certainty regarding the known values. As a plus, this equation may not be sufficient for simulating and determining the elevation at such high frequencies.

All in all, this temperature rise is not big, but little by little it affects the thermo-regulator of the brain and damages the tissue along. Harming the brain is not something that happens at once, but over a period of time.

To sum up, this study has shown that the effects cannot be seen or felt at the moment, but they are dangerous in time. The most important thing is trying to limit this exposure to radiation and paying attention to the phone we are buying. It is important to take into consideration the SAR value given by their manufacturers. Because poor

mobile phone design results in high radiation levels, it is important to build an ideal phone with a low SAR value.

As for the further research, a study based on 2D axi-symmetric application will be considered with a sphere model for the brain taking into account also the three dimensional analysis of the corner effect.

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