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THE THERMAL EFFECTS OF 900 MHz CELL PHONES ON THE BRAIN PHANTOM

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Abstract

Investigation of the effect of mobile phones in the terms of human health is getting more important position in the literature due to the increased public concern. An experimentally efficient setup was established to determine the thermal effects caused by mobile phones in the brain. Temperature increasing in the brain during exposing the mobile phone is investigated in a brain equivalent liquid (phantom). In the proposed experimental setup, mobile phone which operates at 900 MHz frequency was represented with a radio frequency (RF) generator which has a half-dipole antenna and this system is applied to phantom at different distances. Thermal absorptions were observed by sensitive temperature sensors at different depths. Effects of electromagnetic fields are usually investigated via numerical methods and simulations in the literature. In this study, an experimental analysis of temperature distributions in the human brain phantom exposed to mobile phone radiation at 900 MHz is presented. All experiments were conducted in an anechoic chamber where temperature variation is about 0.009°C. Additionally, high-power electromagnetic fields are used such as 4W, 7W and 10W which are not implemented till now in the literature for GSM frequencies. Different temperature distribution in the phantoms was observed by systematically changed distances and power options. In this last case, maximum temperature elevation was observed as 0.403°C. While the temperature elevation increases with increasing applied power, removing the mobile phone from the phantom reduce the temperature elevation in the phantom.

Key Words: Electromagnetic Thermal Effect, Brain Phantom, 900 MHz Electromagnetic Field

1. Introduction

The use of mobile phone is becoming common all over the world, in recent years. Estimates suggest there are about 6.915 million mobile phone subscribers throughout the world and the numbers are increasing each passing day (URL-1, 2014). The latest report was published by International Telecommunication Union (ITU) on May, 2014. According to the report that was published by ITU, while the number of mobile phones for per capita was 120.8 in developed countries, number of the mobile phone user is lower in Africa; it is about 69 for every one hundred people. In the report, mobile broadband growth rate is presented as %11.5, %26, and % 43 for developed countries, developing countries and Africa respectively.

Interest is nowadays focusing on the electromagnetic wave that produced by the mobile phone, due to the increased number of user using the mobile phone. Increasing public concern about the use of mobile phones attract the attention of researchers due to the possible negative effects on the human health. Although the safety standards are regulated in terms of the peak Specific Absorption Rate (SAR) value of tissue, the maximum temperature increase in the human brain caused by electromagnetic heat effect induce adverse physiological effects. Ignored small temperature increases on human body can create unexpected bad effects on sensitive organs such as the brain and eyes. That is why, investigation of thermal effect of electromagnetic fields is so important.

There are many studies investigating the heating effect of electromagnetic fields around the frequencies that are used by mobile phones such as 900 MHz, 1800 MHz (Bei & Cao, 2007; Aly et al., 2008; King & Wong, 1977; Bernardi et al., 2003; Jianqing & Fujiwara, 2003). Human who exposes to the electromagnetic fields for experimental purposes is limited, due to the ethical consideration. For this reason, researchers have tried to find the most convenient research methods to develop a realistic human model. Some of researchers use computer simulating programs, some use mathematical models and the others use tissue equivalent liquids (phantoms).

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Studies using mathematical models like bio-heat equation and thermal wave model of bio-heat transfer (TWMBT) have a common point (Jianqing & Fujiwara, 1999; Özen et al., 2011; Liu et al., 1995). Almost all mathematical models are based on the numerical approaches. Most of the mathematical models use the Finite Element Methods (FEM) and some of them use the method of Finite Differences Time Domain (FDTD) and Moment Methods (MOM). Many mathematical models produce fairly successful results (Bernardi et al., 2000; Citkaya & Seker, 2012; Riu & Foster, 1999; Kuster & Balzano, 1992). In (Bernardi et al., 2000), effect of various mobile phones which are accessible at markets was investigated by FDTD method. Temperature increases caused by different mobile phones are compared with each other and finally 0.10 ºC temperature increases were obtained in the external part of brain. In (Citkaya & Seker, 2012), SAR and temperature increase in the human brain and head is investigated in a numerical way. Researchers who used FEM to solve bio-heat equation have noticed the safety standards are exceed. In (Riu & Foster, 1999), temperature effects of electromagnetic calculations were performed at 900 and 1900 MHz at various distances. The resulting temperature rises were estimated by FDTD of the bio-heat equation. The correlation of calculated SAR values is compared with the (Kuster & Balzano, 1992) and consistent results are obtained.

In addition to the mathematical approaches, some computer programs such as FEKO, SEMCAD X, HFSS, CST and XFDTD can be used to investigate the thermal effects of electromagnetic fields (Shamsad & Amin, 2012; Li et al., 2012a; Li et al., 2012b). Each computer program that used different mathematical techniques in background presents a solution about electromagnetic heating effect. For instance, HFSS uses FEM; CST uses FDTD, FEKO-IE3D/FIDELITY use MOM techniques. There are many advantages of doing research with computer programs. First, the researchers can be executed their works in a healthier manner, since they are not exposed to radiation. In addition, researches can easily and quickly see the effects of all distances, all strength and all frequencies because there is no need to establish a separate experimental setup for each experiment. This enables researchers to be flexible in their works.

In the other investigation methods, phantoms are used to determine the heating effect of electromagnetic fields (Kuster & Balzano, 1992, Koichi et al., 2001; Özen et al., 2006; Özen et al., 2004). In fact, actual usage of phantoms is for Specific Absorption Rate (SAR) calculations. However, SAR calculations and electromagnetic heating effect is not different phenomenon. Thus, heating effect of electromagnetic fields is affected by electromagnetic field strength, tissue conductivity, permittivity and density. In the SAR calculation, same constants are also utilized. The SAR Equation is presented below.

$$SAR = \sigma \frac{|E|^2}{\rho} \quad (1)$$

In this equation, "σ" shows electrical conductivity (S/m), |E| shows RMS (Root Mean Square) value of electric fields strength (V/m) and "ρ" shows density of tissue (kg/m3). SAR value is accepted as the key parameter to explain the influence of electromagnetic field source on the biomass. Therefore, international organizations describe the SAR measurement methods) (IEEE1528, 2003, IEC 6209, 2005). While both of international standards' measurement methods are compatible with each other, the determined limit values are different from each other. The standard of "IEEE Std 1528" determines 1.6 W/kg for 1 gram average mass as limit value and the standard of "IEC 62209" accepts 2 W/kg, for 10 gram average mass.

As can be understood from the above, parallel with the wider use of mobile phones, public concern and scientific interest about these devices' safety grow. Health effects of electromagnetic fields are handled in two different perspectives. The one is non-thermal effect and the other is thermal effects.

1.1. Non-Thermal Effects

Certain biological consequences of the electromagnetic field can be explained by non-thermal effects. These effects involve all the interactions of electromagnetic fields with tissues without heat producing which is not worth to take into consideration. Particularly, magnetic fields carry more potential risk than the electrical fields for living organism. Since, penetration ability of magnetic fields is stronger than electrical fields (Cleveland et al., 1997). Non-thermal effects involve non-specific symptoms, which are caused by electromagnetic field radiation such as headache, dizziness and insomnia (Nakamura et al., 2003; Hermann & Hossmann, 1997**).** For instance in (Chia et al., 2000), the relationship between headache and mobile phones usage is shown. In (Mann & Roschke, 1996), the influence of pulsed high-frequency electromagnetic fields of digital mobile radio telephones on sleep is investigated and reduction of sleep duration and percentage of REM sleep was found. Moreover, spectral analysis revealed qualitative alterations of the EEG signal during REM sleep with an increased spectral power density. In the study of (Diem et al., 2005), thermal effects of electromagnetic fields are eliminated and non-thermal effect of electromagnetic fields on DNA breakage is investigated. Under conditions of several different mobile-phone modulations RF-electromagnetic fields induces DNA single-strand and double-strand breaks in human diploid fibroblasts and in the rat granulose cells.

1.2. Thermal Effects

Radio frequency electromagnetic fields can penetrate through semi-solid substances such as living tissues. Penetration depth is related with the power density of electromagnetic field source, used frequency range and material properties. Electromagnetic fields' penetration ability induces dielectric heating to living tissues. Dielectric heating is also known as thermal effect and a big majority of the sustained cell phone's electromagnetic field associated with biological results can be explained by thermal effects. The main reason of thermal effects in the living tissue is energy absorption from oscillating electric fields. Temperature rising is principally associated with the absorption of high frequency electromagnetic fields radiation, due to the increase in the conductivity of the tissue in the high frequency. Temperature increments in a tissue are associated with instability between heat generation and heat dissipation. Although heat dissipation can occur in three different ways, temperature increase in the tissues often is not prevented. As a first way, tissues transmit their own energy to other tissues, the second way is that tissues can radiate their own energy to surround and lastly, tissues can also convent their energy through blood perfusion. Generally, the most sensitive organs that are exposed to thermal effects more than others are the eyes and brain because of limited capacity of heat dissipation. At same time these organs are often exposed to radiation from mobile phones (Mushtaq & Vijay, 2013).

Different concepts and mechanism have been established to characterize the propagation and absorption of electromagnetic energy in biological systems. Because, electromagnetic fields' impact is not very clear for public. There are a lot of studies that discuss the thermal effects of electromagnetic fields (Riu & Foster, 1999; Pšenáková & Benová, 2008; (Kassimi et al., 2012; Rusnani & Norsuzila, 2008; Taurisano & Vorst, 2000). It is pointed out in (Riu & Foster, 1999). that, low-powered sources can produce significant thermal increments in case of antenna located sufficiently close to the tissue. In (Pšenáková & Benová, 2008), it is asserted that, heating effect of electromagnetic fields is negligible. However, majority of the studies that have been investigating the heating affect of electromagnetic fields claim that heating effect of electromagnetic fields is harmful enough (Kassimi et al., 2012). In particular, in (Rusnani & Norsuzila, 2008), different commercially available handheld mobile phones are investigated in the terms of thermal effects. The research group has found that different thermal effects have been obtained under identical experimental conditions. In another study, thermal effect of electromagnetic fields is investigated on a realistic human head (Taurisano & Vorst, 2000). In consequence of (ibid), researchers have reported that; the most significant surface temperature increment has found on the ear lobe at the end of talking phase for higher duration then 20 min and at lower signal conditions (50% of the maximum, in a basement).

As can be seen above, effect of electromagnetic fields strongly depend on the spreading frequency, applied power and the antenna distance. In our work, thermal effects of electromagnetic fields were employed. 900 MHz frequency was selected as operating frequency. Electromagnetic fields at different strength and different antenna distance were applied to brain phantom which is prepared for this paper and temperature distribution was recorded depending on depth in phantom.

Rest of this paper is planned as follows. Preparation of phantom and electrical prospect of international organizations will be described in detail in the Section 1.3. Section 1.4 will explain the experimental setup. Experiments that were carried out under variable conditions will be brought to attention in this section. The results of different conditions will be presented in Section 1.5. Section 1.5 will be expressed in three main section, the main sections are organized in the terms of brain depth.

1.3. Preparation and Testing of Brain Phantom

Electrical properties of tissues have been investigated for a long time (Schwan & Piersol, 1954, Stuchly & Stuchly, 1990). Preparing the phantoms of human biological tissues is necessary for electromagnetic dosimetry and hyperthermia research, due to the impossibility of experimental studies on humans. When the phantom is created, the physical structure of an average man is taken into account so that it has electrically equivalent feature of the tissue in the brain. The relative permittivity and conductivity is defined in the related standards of IEEE and FCC which are shown in Table 1 and Table 2. Dielectric constant and conductivity are different for each frequency point. Because the electrical feature of the tissue is depending on the frequency (Kanda et al., 2004).

Table 1 - IEEE Frequency Dependent Changing of the Permittivity and Conductivity (IEEE 1528, 2003)

Frequency (MHz)	Relative Dielectric	Conductivity (S/m)
300	45.3	0.87
450	43.5	0.87
835	41.5	0.90
900	41.5	0.97
1450	40.0	1.20
1800	40.0	1.40
1900	40.0	1.40
2000	40.0	1.40
2450	39.2	1.80
3000	38.5	2.40

Table 2 - FCC Frequency Dependent Changing of the Permittivity and Conductivity (Fields, 1997)

Frequency (MHz)	Permittivity	Conductivity (S/m)
150	52.3	0.76
915	41.5	0.98
5800	35.3	5.27

Table 3. Phantom examples in the literature for 900 Mhz Brain Model

	Water (%)	Sugar (%)	NaCl (%)	HEC (%)	Bactericide (%)	TX 150 (%)	Polyethelene Powder (%)	Agar (%)	Glycerol (%)
Prepared in (Hartsgrove et al., 1997)	62.61		0.5282			7.01	29.80		
Prepared in (Okano et al., 2000)	36.31		1.12				3.74	5.35	53.48
Prepared in (Kaori et al., 2004)	40.30	57.90	1.38	0.24	0.18				
Prepared in (Özen et al., 2003)	43.55	54.66	0.72	0.9	0.17				

Different chemicals can be used in order to create a brain phantom for 900 MHz. There are many works in the literature which use different chemicals to prepare brain phantom (Durney et al., 1986; Gabriel, 1996; Hartsgrove et al., 1997; Gandhi et al., 1999; Hakim, 2006). There is no just one recipe to prepare phantoms; phantoms can be prepared by using different amounts of the chemicals. Some phantom examples in the literature are given in Table 3.

As can be seen in Table 3 there can be found a lot of ways to prepare brain phantom. However, in this study, bactericide (% 0.10), HEC (hydroxyl ethyl cellulose) (% 1.00), NaCl (sodium chloride) (%1.48), sugar (sucrose) (% 56.50) and distilled water (% 40.92) are used to prepare a brain phantom for 900 MHz. There is no particular reason for choosing this formulation. The main aim is that the electrical parameters of the prepared phantom and the electrical values specified in ieee1528 are the same.

Several measurements were conducted on the electrical parameters of prepared phantoms by using vector network analyzer at 23.1 ^{o}C temperature and results were compared to the IEEE 1528 standards.

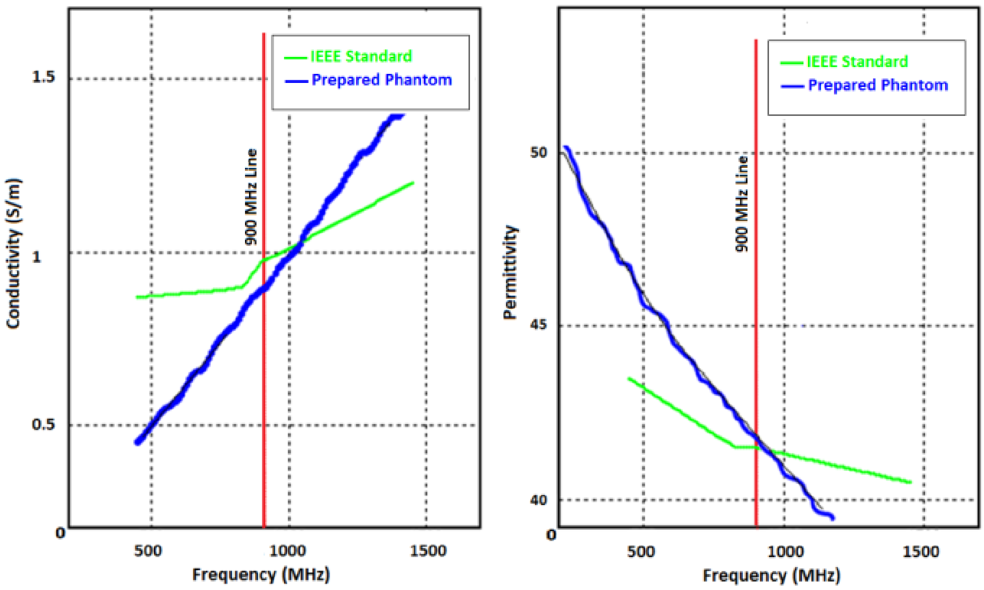


Fig. 1. Relationship of IEEE Standards and Experimental Results

As can be seen in the Figure 1, permittivity and conductivity of prepared brain phantom does not meet the requirements of IEEE 1528 standard for all frequencies. However, at the 900 MHz frequency band, permittivity and conductivity of the prepared phantom are in well agreement with the IEEE 1528 standards. Thus, the closest point of prepared phantom and IEEE 1528 standard must have been compatible about 900 MHz because of the applied working frequency. Green line shows the IEEE standards, blue line shows the prepared brain phantom's characterization and the red line shows the 900 MHz at frequency band. As shown in the Figure 1, conductivity has about %6.2 deviations and permittivity has about %2.7 deviations. Researchers, who are expert on measuring the electrical characteristics of phantoms, have accepted 5% deviation from the IEEE standard (Okano et al., 2000; Gimm, 2004). Moreover (Okano et al., 2000; Gimm, 2004), the commonly accepted accuracy of the open-ended probe measurement is 5% for relative permittivity and 10% for conductivity (Özen et al., 2003; Suzana & Suzana, 2009). Depending on the Figure 1, it can be easily said that, prepared brain phantom can be used for brain investigations at the frequency of 900 MHz frequency.

1.4. Experimental Setup

Several measurement devices and different types of equipments have been utilized to investigate the electromagnetic exposure in the literature (Kuster et al., 1997; Schmid et al., 1996; Onishi et al., 2008). For example in (Kuster et al., 1997), a scanner is designed to investigate the human exposure to cellular phones. In (Schmid et al., 1996), performances of different probes are examined and SAR distribution is investigated. In (Onishi et al., 2008), Electro-Optic (EO) probe and the SAR estimation method are advised as different SAR measurement methods. Mentioned methods does not produce consistent results quantitatively and these methods usually does not explain the technique used in.

This inadequacy of knowledge about electromagnetic absorption mechanism and determination methods motivated this study. Another aim of this work is to explain the relationship between the electromagnetic strength, applied distance and the temperature changes in the brain at different depths, in a simple way.

In this study, the experimental setup which is shown in Figure 2 is designed in order to investigate the thermal effect of electromagnetic fields. All experiments conducted for this study are carried out in an anechoic chamber in order to achieve a satisfactory measurement precision. The realizations of experiments in anechoic chamber provide some important advantages. First of all, if experiments were not carried out in anechoic chamber, all researchers could have exposed to more electromagnetic fields than they exposed. In addition to the contribution of researchers' health, temperature changing of anechoic chamber can be kept under control. Temperature control is so important such studies which focused on determining the temperature alteration. With the help of anechoic chamber temperature alteration of the experimental environment is kept about 0.009 ^{o}C. The last and most important advantage of anechoic chamber is that, there is no reflection, refraction and scattering effect of electromagnetic fields.

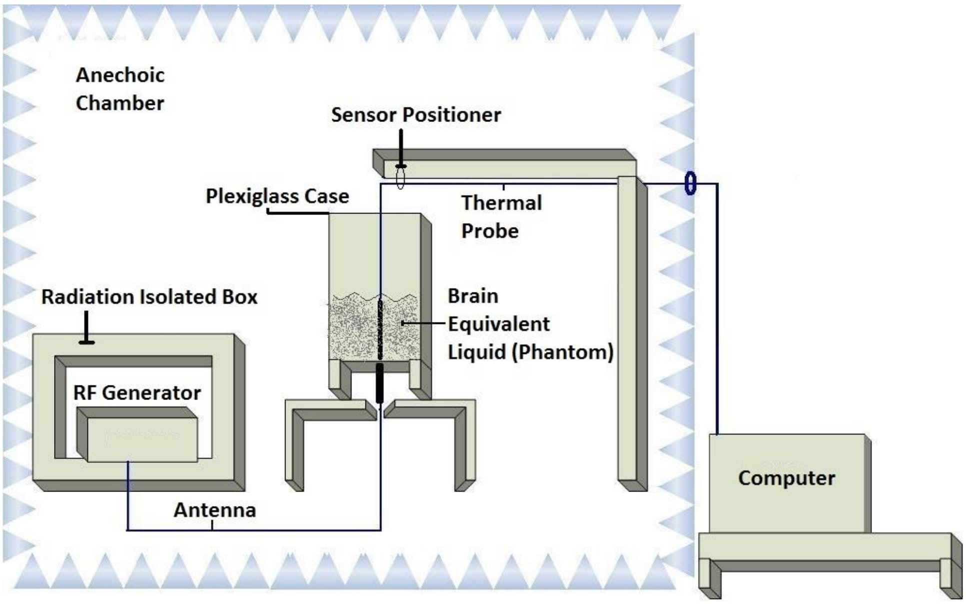


Fig. 2.Experimental Setup

In order to simulate the effect of mobile phone, a Radio Frequency (RF) generator is used. The RF generator was positioned in a radiation and temperature isolated box and its frequency was adjusted 900 MHz frequency. Pulsed mode was activated and different power options were examined during the experiment. 0.5 W, 1W, 2W, 4W, 7W and 10W power options are applied relatively to the brain phantom. Used antenna is a kind of half dipole antenna. In order to replicate the mobile phone, half dipole antennas are used in similar studies (Zhang & Alden, 2011; Virtanen et al., 2007). Generally a half-wave dipole antenna produces higher SAR values than a generic mobile phone with λ/4 monopole antenna (IEEE 1528, 2003)

Phantom is filled into Plexiglas case before electromagnetic exposure. In this study, plexiglas case is preferred to glass case. Because light transmission of Plexiglas is higher and its impact-resistant is better than glass. However, the main reason for the use of plexiglas is that thermal conductivity of plexiglas is 20% less than the same thickness glass. Hence, all thermal variances which may occur in the brain phantom are isolated from the environment factors.

1.5. Experimental Results

All temperature measurements were recorded by using the software of the thermal probe on the computer simultaneously. Recorded temperature changes have 0.001ºC sensitivity and 0.01 ºC accuracy. RF generator's antenna was applied to center of the bottom of the Plexiglas box and antenna distance which is marked as "d" was changed for 0mm, 10 mm, 20 mm and 50 mm distances during the experiments. d represent the distance between ear and mobile phone. Expected temperature changes were recorded at different depth which is marked as "l" for 0 mm, 20 mm and 50 mm. l also expresses the depth of brain. Obtained temperature changes are organized as graphs which are presented in Figure 3-4-5 for different exposure conditions. Some results are not clear schematically in the figures. Therefore, graphs are zoomed down and added to top of the figures. Figure 3 shows the temperature effect of electromagnetic fields under different power options, for different d distances for l=0 mm depth. The authors of this work are focused on the temperature increases in the brain. Because, while temperature value increases in the brain, thermal effects which can be cause different types of diseases can be seen more frequently.

There can be obtained many results from Figure 3 that, while applied power increases, occurred maximum temperature increases. The second important result is that, while d increases observed maximum temperature decreases. In addition, maximum temperature increase occurs at d=0 mm for all applied power options. While d is changed from 0 mm to10 mm obtained maximum temperature increase is decreased about %30 for almost all power options. While d is changed from 0 mm to 20 mm obtained maximum temperature increase is decreased about % 60. While d is changed from 0 mm to 50 mm obtained maximum temperature increase is decreased about % 75. Because, thermal effects of electromagnetic field has a power-dependent and distance-depended characterization. Increasing the applied electromagnetic power causes temperature increase in the brain phantom. In addition to this, antenna distance is inversely proportional to the temperature increase in the brain. According to results seen in Figure 3, while choosing the personal mobile devices, if there is a possibility to buy a mobile phone which is low-powered, this alternative should be assessed.

As can be seen in Figure 3-a, when the RF Generator's power level is adjusted 0.5W (27dBm), the obtained maximum temperature increase is about 0.040 ºC for d=0mm. In Figure 3-b, while the brain phantom has been exposed to 1W (30dBm) electromagnetic power, 0.071 ºC temperature increase has been obtained for d=0mm. It can be clearly seen in figure 3-a and 3-b that, although there is just 3 dBm difference between 0.5W and 1W exposures, in case of exposure to 1W electromagnetic power there can be occurred 1.5 times increase in temperature was observed. In Figure 3-c, RF generator has been fixed to 2W (33 dBm) and the most temperature increase was occurred in brain phantom as 0.01 ºC. The relationship of 0.5 w and 1 w electromagnetic exposure is very similar to 1W and 2W electromagnetic exposure for other d options too.

Figure 3-d shows that, when the RF generator has been adjusted to 4W (40 dBm), 0.180 ºC temperature increase was occurred for d=0 mm. 4W electromagnetic exposure shows different characterization from 0.5, 1 and 2 watt. As can be seen in figure 3-d, temperature increase shows a faster increase in brain phantom. Also, reached maximum temperature increase is about 2.5 times of 2 watt.

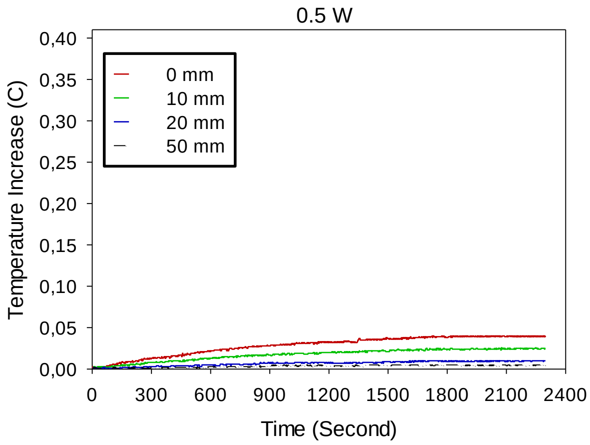
Figure 3-e imply that, when the RF generator has been fixed to 7W (38.45 dBm), 0.315 ºC temperature increase was occurred at d=0mm. The maximum temperature was obtained in approximately 32th minutes. After 32. minutes, the phantom's temperature was reached stability and measurements for the next six minutes did not show any temperature increase.
It can be seen in Figure 3-f that, when the RF generator has been fixed 10W (38.45 dBm), 0.403 ºC temperature increase was occurred. As a result of exposure to 10W electromagnetic field, 0.403 ºC temperature increase is observed. Although reached maximum temperature increase take about 30 minutes, %75 to 80 of maximum temperature increase is occurred in the first 10 minutes. Temperature increase rate in the phantom is slowed down after 10th minutes.

The other test was employed to understand how changes occurs in the brain at the depth of 20 mm. Therefore, l is adjusted 20 mm level, different power options and different d options were applied to brain phantom for 2300 second just like the previous test set which is shown in figure 3. Same test sets were used in order to compare results with each other.

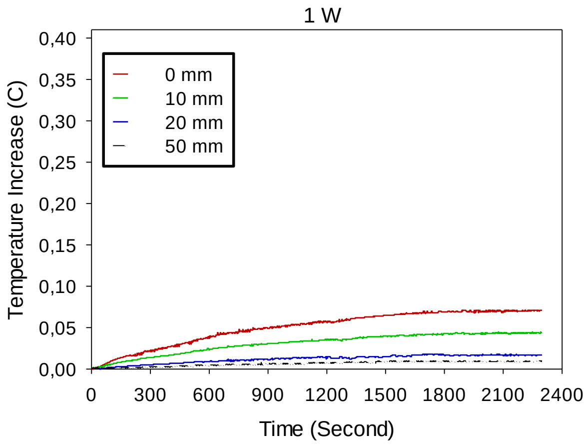
As can be seen in Figure 4, occurred maximum temperature increase is decreased at the depth of 20 mm of the brain for all power options and for all d options. This means that, thermal effect of electromagnetic fields is come down. Although, the maximum temperature increase was about 0.403 ºC for the first test set, occurred maximum temperature increase was found as 0.266 ºC at the 20 mm depth of brain.

The last experiment set was carried out to examine how changes occur in the brain at the deeper. Therefore, l is adjusted 50 mm level and different power options and different d options were executed to brain phantom for 2300 second where the steady-state behaviour is obtained. Same experiment sets were used in order to compare results with each other.

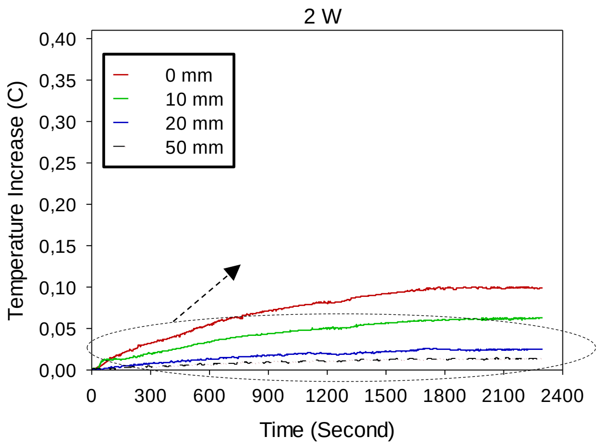
It can be clearly seen in Figure 5 that, temperature increase was occurred in the phantom, although measurements were taken 50 mm depth. 50 mm is approximately corresponded to center of the brain. Maximum temperature increase is obtained about 0.100 ºC, when power is adjusted 10W and d=0. While the applied electromagnetic strength increases, occurred temperature also increases just as seen in Figure 3 and Figure 4. The main consequence of Figure 5 is that, no matter how far electromagnetic fields sources away from your brain, it can create heat in the deeper level of the brain.



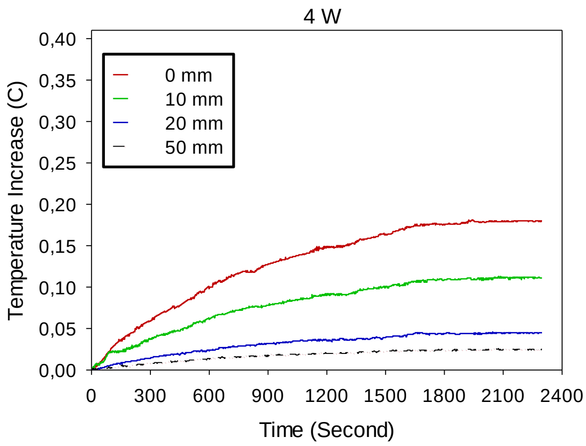
a) Power=0.5W, *l*=0mm; *d*=0, 10, 20, 50mm



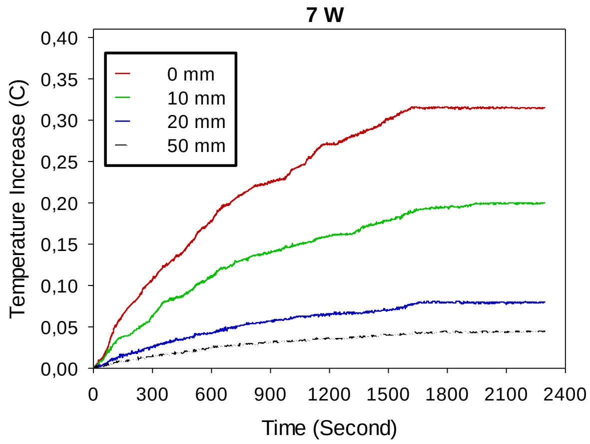
b) Power=1W, *l*=0mm; *d*=0, 10, 20, 50mm



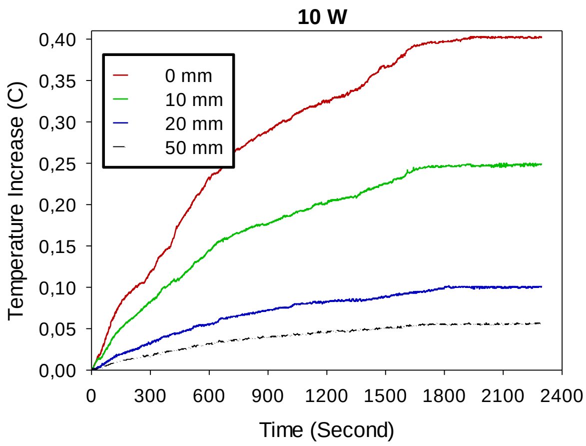
c) Power=2W, *l*=0mm; *d*=0, 10, 20, 50mm



d) Power=4W, *l*=0mm; *d*=0, 10, 20, 50mm

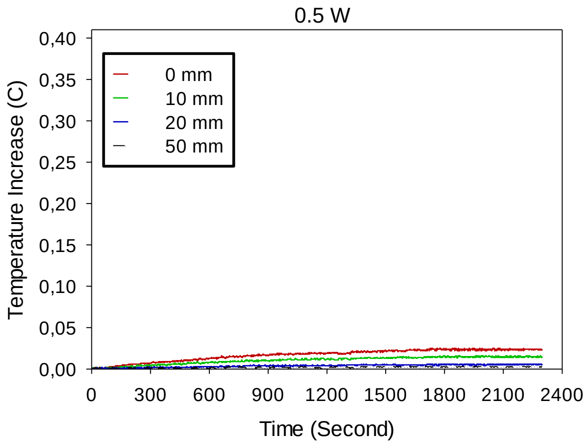


e) Power=7W, *l*=0mm; *d*=0, 10, 20, 50mm

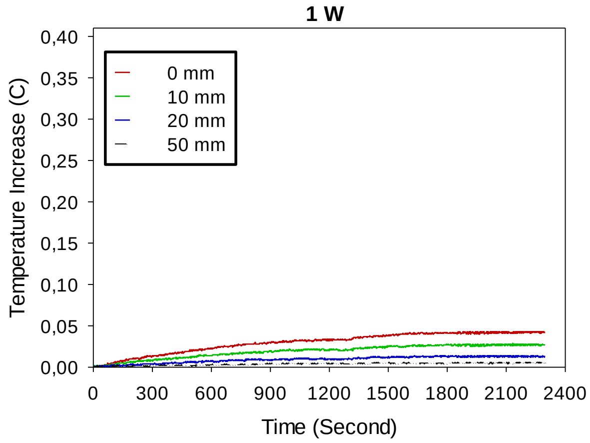


f) Power=10W, *l*=0mm; *d*=0, 10, 20, 50mm

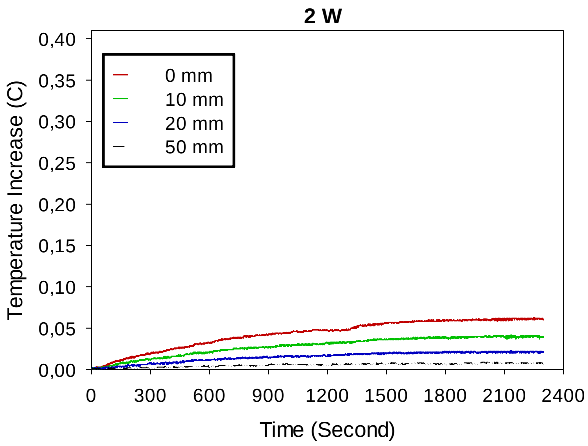
Fig. 3. Temperature effect of Electromagnetic Fields at Different Power, Different Antenna Distance for l=0 mm



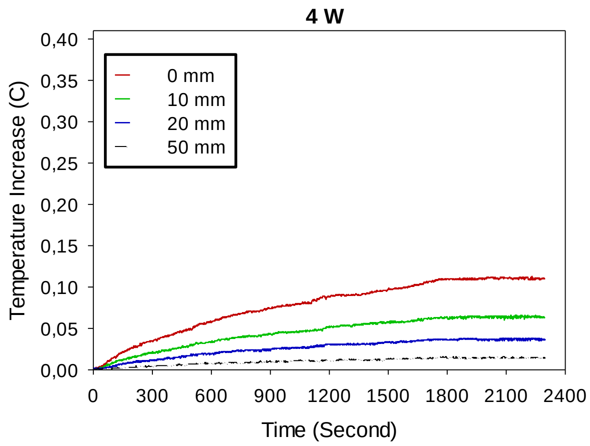
a) Power=0.5W, *l*=20mm, d=0,10,20,50mm



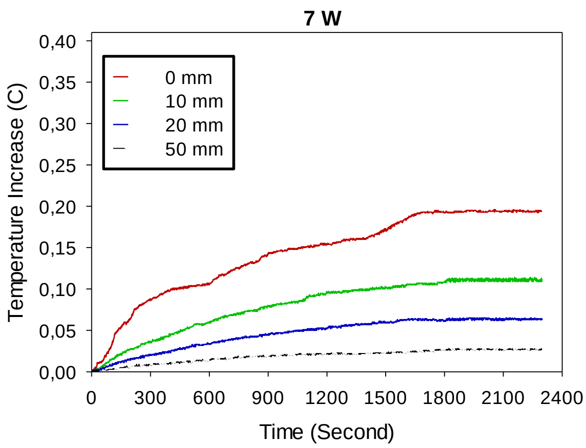
b) Power=1W, *l*=20mm; *d*=0, 10, 20, 50mm



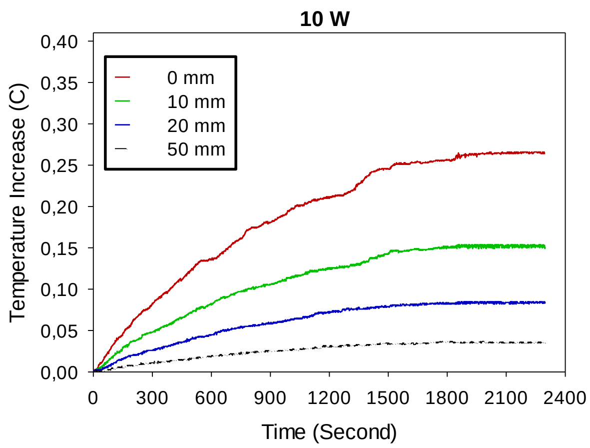
c) Power=2W, *l*=20mm; *d*=0, 10, 20, 50mm



d) Power=4W, *l*=20mm; *d*=0, 10, 20, 50mm

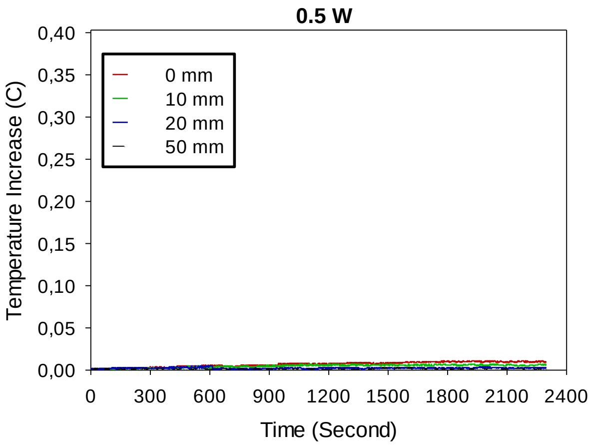


e) Power=7W, *l*=20mm; *d*=0, 10, 20, 50mm

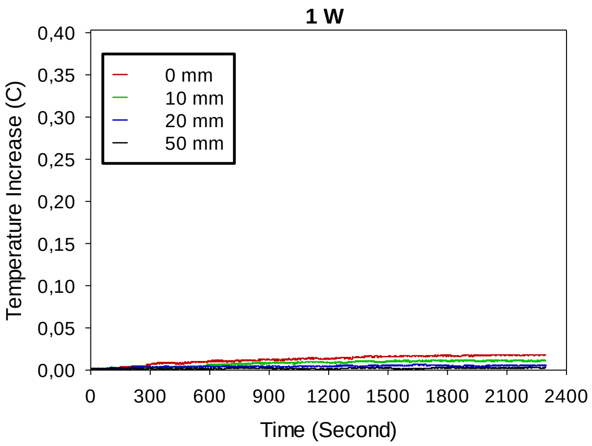


f) Power=7W, *l*=20mm; *d*=0, 10, 20, 50mm

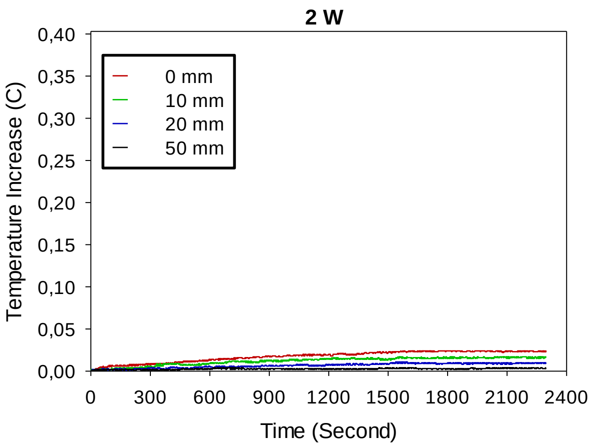
Fig. 4. Temperature effect of Electromagnetic Fields at Different Power, Different Antenna Distance for l=20 mm



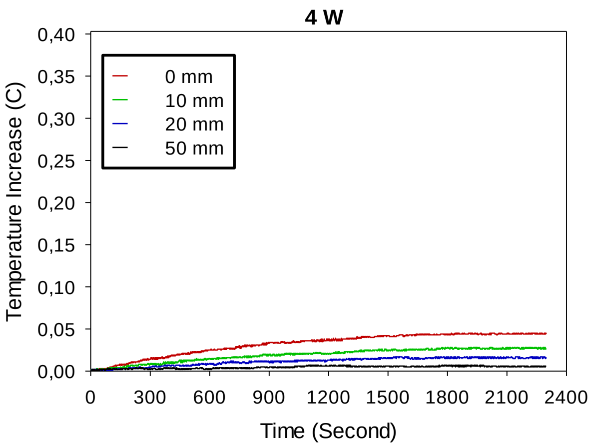
Power=0.5W, *l*=50mm; *d*=0, 10, 20, 50mm



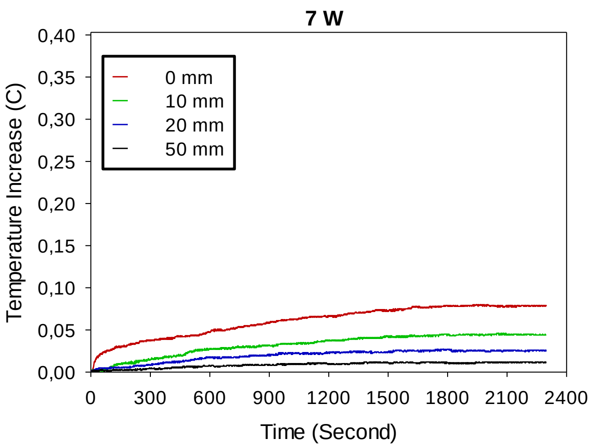
Power=1W, *l*=50mm; *d*=0, 10, 20, 50mm



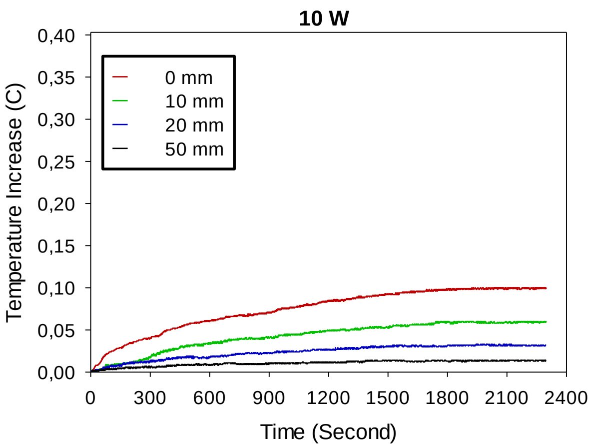
Power=2W, *l*=50mm; *d*=0, 10, 20, 50mm



Power=4W, *l*=50mm; *d*=0, 10, 20, 50mm



Power=7W, *l*=50mm; *d*=0, 10, 20, 50mm



Power=10W, *l*=50mm; *d*=0, 10, 20, 50mm

Fig. 5. Temperature effect of Electromagnetic Fields at Different Power, Different Antenna Distance for l=50 mm

2. Conclusion

This study presents the experimental results for the temperature distribution in the brain phantom exposed to electromagnetic field radiation at the frequency of 900 MHz with various power densities. Several important features of the energy absorption in the human brain are obtained in this study. These experiments show that, the radiation from the electromagnetic fields at the range of 900 MHz can be easily absorbed by human brain which causes thermal effects. In case of exposure to electromagnetic fields, heating effect shows a high rate of increase until about 15-20 minutes. After 20 about minutes, the rate of increase slows down. After 30-35 minutes, maximum increase in the temperature is obtained for all power options, and temperature elevation reaches stable.

Consequently, one of the most comprehensive experimental research projects is presented in this paper and it was observed that the temperature increase occurs in the brain while strength of the electromagnetic field emitter increases. It was presented in Figure 3-4-5 that an important part of the temperature increase (about 80%) took place in the first 20 minutes. The maximum temperature rise on the surface of the brain caused by radio waves is about 0.403 ^{o}C. It should be investigated whether such a temperature rise has biological significance in terms of human health. The temperature of the brain normally internally fluctuates about one degree. However, an external increase of 0.403 ^{o}C may be harmful for human health, especially for the long terms. The investigation of the relationship between the temperature rise and human brain will be our future work with an interdisciplinary group of researchers

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