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Temperature Distribution of Head Tissue Equivalent Liquid Exposed to 900 MHz Mobile Phone Radiation under Varying Conditions

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Abstract **-**There has been a growing public concern on the subject of exposure to electromagnetic field (EMF) radiation. Additionally, the actual discussions have been focused on the radio frequency (RF) area arising from the number of devices in active use. In consequence of the public interest and the increasing number of devices, heating (thermal) effects of EMFs have become a field of study for scientists. In this study, an experimental research, among various methods, is carried out to clarify current challenges to investigate the effect of EMF. The purpose of this paper is to present an effective experimental setup and observe the temperature distribution in the head tissue equivalent liquid (HEL) exposed to EMF. In order to achieve these objectives, a HEL is prepared and the HEL is exposed to EMF with different strengths from different distances. Resulting temperature distribution in the HEL is observed by a sensitive thermal probe at different depths. Thus, one of the most comprehensive studies in the literature is presented in this paper. Through application of high powered EMF, examination of continuous exposure and testing a wide range of experimental variations, this study makes contribution to other studies in the literature.

Keywords**:** Electromagnetic fields, Electromagnetic radiation, Heating effect of electromagnetic fields, Electromagnetic wave absorption

1. Introduction

With recent developments in wireless technology, mobile communication has shown a substantial growth. Due to the increasing use of mobile phones, the current research is mainly focused on the health risks of EMF emitted from the mobile phones (Anemiya, 1995), (MTRC, 1995). According to data obtained from ITU (The International Telecommunication Union), there are nearly 7 billion mobile phone subscribers all over the world. Furthermore, according to this report which was released in May 2014, almost 95.5 percent of the humanity uses a portable communication device (ITU, 2014). There is an increase in mobile phone penetration as well. The highest level of penetration is in Europe (64%) followed by America (59%), and the lowest level is in Africa (19%). These statistics are taken from a report on mobile telephone handsets and associated devices. According to this report there are an increasing number of the devices, used in close proximity of body parts. Accordingly a major part of the studies, investigating the effects of EMF in the literature, are concentrated on the GSM frequency area (Gandhi et al., 1996), (Irmak et al., 2002).

The studies, investigating the effects of EMFs, are divided into two main parts. The first group of studies investigate the thermal effects resulting from energy absorption and the other investigates the biological actions, also known as non-thermal effects. In spite of the number of the researches on non-thermal effects, no conclusive result has been presented in the literature, since non-thermal effects have not been verified on a sufficient number of human subjects. In the presented study, thermal effect of EMF is experimentally investigated.

2. Exposure Mechanism

Human body is in continual interaction with the EMF generated by wireless devices. The interaction between the human body and the EMF depends on the parameters such as the frequency in which the EMF radiates, the distance from which the EMF is applied and the exposure time. In the near field, electric field, which is induced by eddy currents, is more effective than magnetic fields. However within the frequency region below 10 MHz, main exposure is caused by the magnetic fields (Christ et al., 2013). As the frequency increases, due to high dielectric and reflection at boundary transitions between the tissues, the distance covered by EMF decreases (Christ et al., 2006a), (Barber et al., 1979), (Christ et al., 2006b). The same effect may be assumed for all tissue models, especially the dermal tissue. The first dramatic power loss of EMF, interacting with the body, occurs on dermal region, since physiologically the dermal region features a more intense structure compared to other organs, beside its having a layered structure. Due to its layered structure, power losses at boundary transitions and reflections / diffractions both contribute to concentration of local SAR at this region. On the other hand, SAR analyses are interpreted as a mathematical expression of temperature increases occurring at any tissue model. Temperature increases occur in tissue is usually investigated on homogeneous tissue equivalent liquids (TEL) (Balzano, 1995). TELs are not merely used for SAR analyses, but also for compliance testing, hyperthermia and dosimetry studies (IEC, 2005).

3. Method and Requirements for Exposure Assessment

A variety of methods are available for investigation of the effects of EMFs on biological bodies. Some of the studies draw on computer simulations, some utilize numerical and analytical approaches while modeling the thermal effects of EMFs. Another widely applied method is examination of the equivalent liquids. Computer simulations are commonly preferred for they allow researchers to diversify their studies and carry out countless number of experiments (Meier et al., 1997). As for the mathematical approaches, as another examination method, solution of bio-heat equation, introduced by Pennes in 1948, is aimed by use of different methods (Pennes, 1948). In the studies carried out on equivalent liquids, conjugated model of the tissue to be exposed to EMF, is prepared chemically and it is determined whether the relative permittivity and conductivity of related TEL meet the frequency values in which the exposure takes place. Afterwards EMF is employed on the TEL and the temperature changes within the TEL are measured using sensors (Ozen et al., 2004). However, the TEL used should be specified in terms of applied frequency. Since the interaction between EMF and the living tissue varies depending on the working frequencies and tissues' characteristic parameters, relative permittivity and conductivity are accepted as the most important parameters in terms of the interaction with the EMF. Accordingly, in this study, the TEL used is specified for the head region.

As mentioned above, two important data should be known before the preparation of an equivalent liquid. The first one is the frequency applied and the second is the tissue type. In this study, the selected frequency area is 900 MHz as one of the most commonly used frequency band and the selected tissue type is the head tissue. The HEL prepared must provide the relative permittivity and conductivity values specified in (IEEE, 2013). HEL prepared for this study contains the percentage by mass of 40.92% water, 56.50% sucrose, 1.48% salt (NaCl), 1% HEC (Hydroxy Ethyl Cellulose), 0.1% bactericide.

To check whether the HEL prepared according to abovementioned recipe meets the standards, a network analyzer is used with a TEM (Transverse Electric and Magnetic Mode) line. Then, relative permittivity and conductivity of the HEL prepared is measured to determine how accurately the HEL is obtained. Measurement results are shown for 900 MHz in Figure 1.

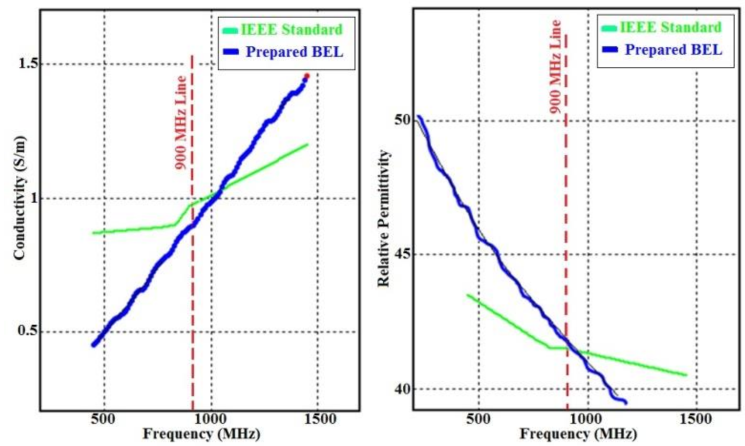

Fig. 1. 900 MHz HEL Performance versus IEEE 1528 Standard

Figure 1 shows the frequency band for which the HEL prepared is suitable. According to figure 1, relative permittivity and conductivity of the HEL complies with IEEE standards for 900 MHz frequency. Relative permittivity and conductivity of the HEL prepared for 900 MHz are found to deviate by 2.7% and 6.2%, respectively.

4. Experimental Setup

An actual SAR measurement can be conducted by measuring the temperature rise in an equivalent liquid exposed to EMF. Therefore, in practice, real time measurements are preferable to numerical analyzes and computer simulations, especially in the near field exposure.

The main target of this study is to experimentally show the temperature alteration in the HEL which is exposed to EMF from different distances at widely used GSM frequency. Thermal effects of EMF were observed at different depths of the HEL. Thus EMF effects are observed based on three different parameters: power, antenna distance and the depth within the HEL. The experimental setup is presented in Figure 2.

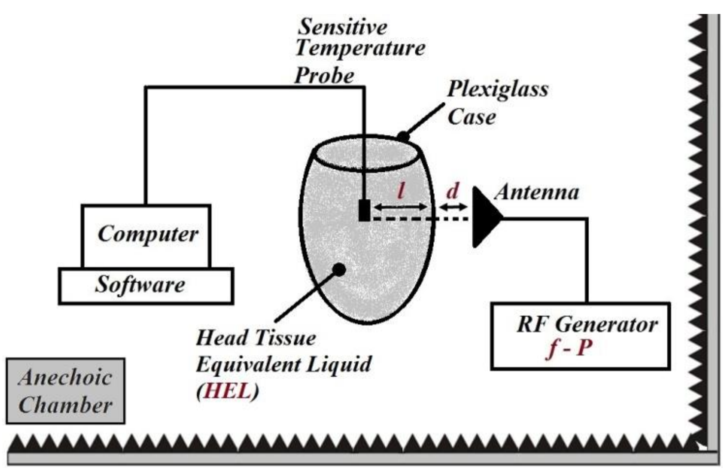

Fig. 2. Measurement Setup.

Measurements were performed with varying *d* and *l* positions for different *P* values. “d” was positioned at 0 mm, 10 mm, 20 mm and 50 mm, “l” was located at 0 mm, 20mm and 50 mm, and “P” was adjusted to 0.5W, 1W, 2W, 4W, 7W and 10W. However, it is highly impractical to show all measurement in this paper. Therefore, some of the measurement results, obtained under varying conditions, are presented in Figure 3.

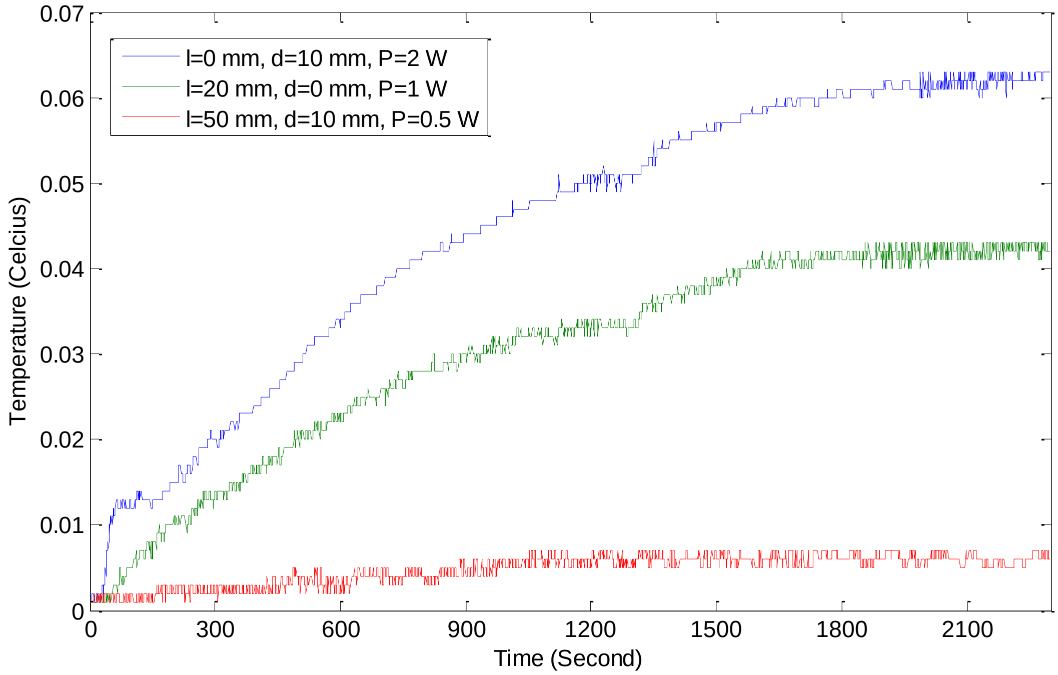

Fig. 3. Some Representative Measurements

According to Figure 3, maximum temperature rise in the HEL is reached in about 1500 seconds for all conditions. After 1500 second, no significant rise in the maximum temperature is observed; this can be attributed to the blood perfusion effect in living systems. Additionally, a major part (about 80%) of the temperature rise is observed within first 900 seconds. Although the temperature change is observed under varying d, l and P conditions, the actual maximum temperature rise within the HEL is the one parameter which really needs to be emphasized. Therefore, the maximum temperature observed is presented in Figure 4 for 900 MHz. As expected, the actual maximum temperature increases with power applied, and the maximum temperature of 0.4 ^{o}C is observed at *d*=*l*=0 and *P*=10 W under exposure with 900 MHz frequency.

5. Conclusion

The following conclusions can be drawn from the present study.

Widely known heating effect of EMF is experimentally proved in order to model the real life exposure. According to the authors’ knowledge, the presented study can be deemed as one of the most comprehensive and detailed studies in the literature, since it includes the application of power options which have never been tested before, as well as a wide range of values for antenna and sensor distances. Additionally application of the most commonly used 900 MHz frequency adds value to the presented study.

The results demonstrate the importance of utilizing the experimental aspects of EMF exposure. Increasing the EMF strength results in a higher temperature whereas removing the sensor or antenna leads to a temperature decrease. On the other hand, our results show that the effect of EMF is strongly in a relation with the distance applied, the strength of EMF and the exposure time.

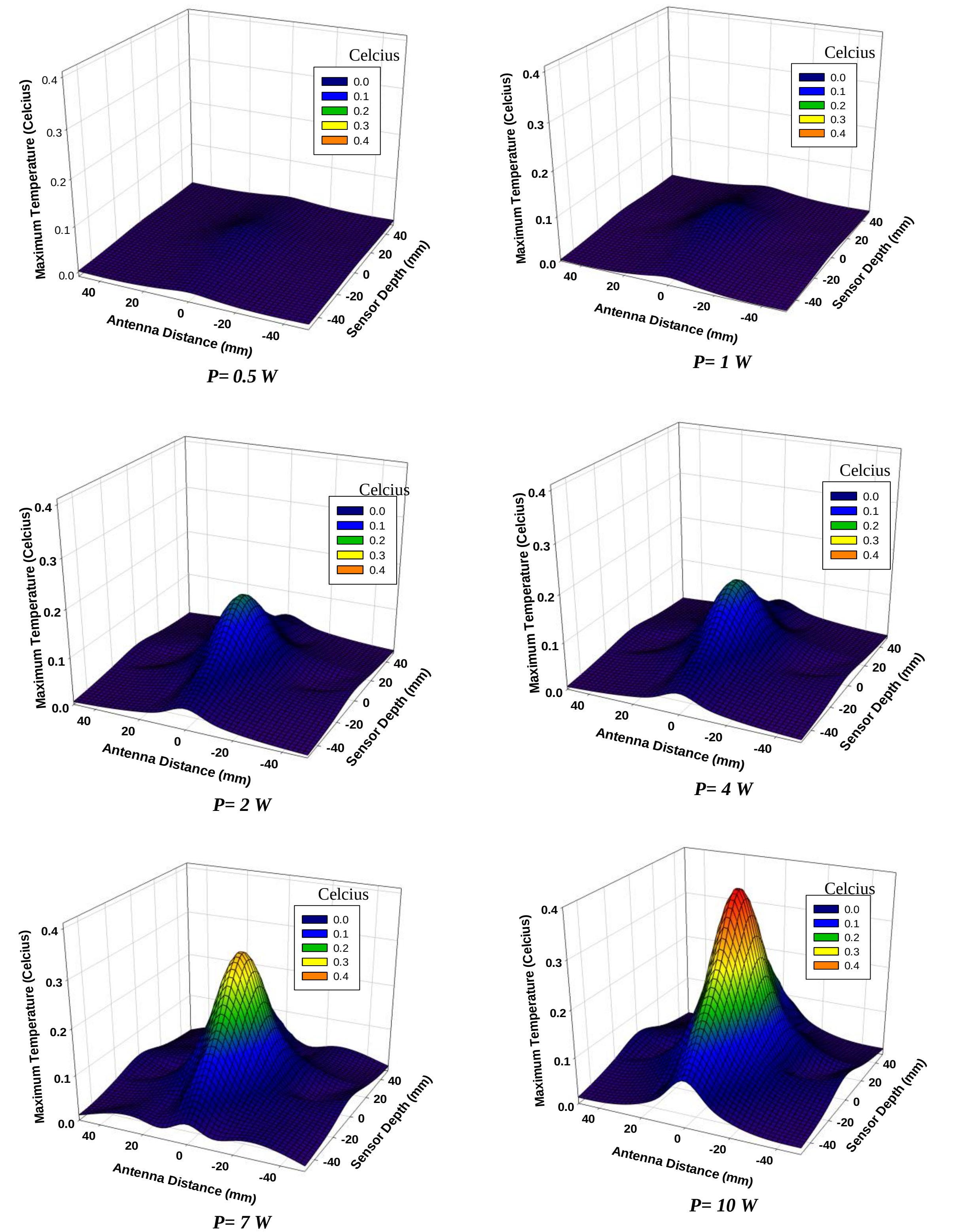

Fig. 4. Maximum temperature observed under varying Conditions

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