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Equivalent Permittivity Based on Debye Model of Blood and Its SAR

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Abstract: Dielectric parameters vary with frequencies are important properties of biological systems, which determine the absorption rates of electromagnetic radiation in human body. Two phase dielectric model is considered to investigate the dielectric properties of human blood in this paper. This paper systematically calculates the body's specific absorption rate of electromagnetic fields at low frequencies based on the dielectric properties obtained from the Debye model. This study could lay foundation not only for the theoretical basis for further study on electrical properties of biological tissue, but also for the exposure limits of health standard on electromagnetic radiation.

Keywords: Equivalent Permittivity, Debye Model, Specific Absorption Rate

1. Introduction

Blood, as a fundamental part of the immune system and one of the functional tissues, can deliver oxygen and nutrition to the vital parts in body. The precise knowledge of the dielectric properties of blood is prerequisite for fixing limiting values for electromagnetic pollution [1]. But according to the *Assessment conclusions and suggestions of WHO's international EMF project*, research on the association between extremely-low frequency (ELF) fields and the risk of blood disease is not clear. Blood cells are unevenly distributed in the blood plasma, and the polarization direction will change when the external electrical field changes. Therefore the dielectric parameters of blood are of great importance for exploring protection of electromagnetic pollution. The equivalent permittivity is related to the structure of the composite medium and the nature of the material. Many scholars put forward some classical formula for calculating equivalent permittivity of the two-phase, three-phase or even multi-phase composite based on the experimental data. These classic methods are subject to many restrictions, each theory can only be successfully applied to a certain type of composite media. In this paper, the physical model of blood tissue is established from the point of theoretical view. Particle suspension of blood cells is considered to the constitutive characteristics of whole blood along with some other typical phase. We ultimately find a more appropriate calculation model. Finally, the applicability and potential application value of the model are discussed with Specific Absorption Rate (SAR) of blood tissue as an example.

2. Model and Calculation Method of Dielectric Property in Blood

Uneven distribution of blood cells in plasma makes the whole blood having a representative dielectric property. One model of pellet cell in blood is established to meet the characteristics of blood composition, selecting some typical dispersed unevenly distributed in the continuum model (Figure 1). Here we know that the Debye equation describes the frequency characteristics of dielectric constant [2]. We build multi-phase models of biological tissue with biological tissue structure based on its identical function as a composite part of the dielectric material is processed in the same phase and each phase as a unified system. Establishment of biological architecture model can help us to simplify complex biological constitution, so the bio-material characteristic can meet the appropriate theory formula [3-4]. Since each model is calculated using the physiological model, and in the following models the calculating dielectric models of biological systems also using these formulas. Biological system will actually be the equivalent of such a physical model [5]. Blood plasma contains large dielectric because its conductivity is much larger than pure blood cells. Because of the effect from the proteins in cell membrane, the fatty acids, other macromolecules, and the intracellular, blood can be mixed as a suspension system, here we consider without the interaction between different cells.

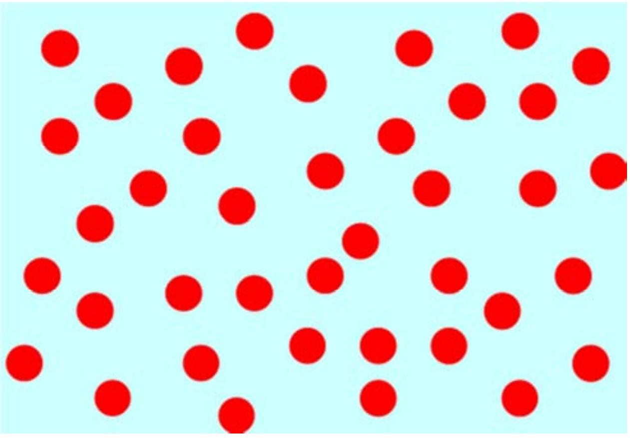

Figure 1. *Randomly inhomogeneous model of two-phase blood system.*

Considering the mechanism of the dielectric fluid within the cell, the cell membrane and intracellular fluid could be regarded aswhole blood. The interface polarization occurs on blood cell during charging and discharging when the external electric field exists. Relaxation of dielectric spectroscopy closely related to the typical biological tissues, so, the internal information of it can further explain the mechanism of permittivity relaxation. Accurately of the dielectric properties calculated from forenamed models are related to the dielectric parameters of compound material. But when the biological tissue concerned, we need a rational computing model [6]. A typical blood model is Debye model, which is put forward on the basis of empirical formula, can meet the dielectric properties of composite materials well [7]. Theoretical calculation method of the dielectric properties may intend to discuss some of the empirical formula in systems. Take Debye polarization equation, it is a widely used model for studying the dielectric properties of biological tissues. Relationship among the dielectric constant and the angular frequency of the external electric field could be theoretically defined as following:

$$\varepsilon = \varepsilon_\infty + \int_0^\infty \alpha(t) e^{j\omega t} dt \qquad (1)$$

Here $\alpha(t)$ is dielectric polarization attenuation law after removing electric field, and it is a decreasing factor, subject to exponential distribution:

$$\alpha(t) = \alpha_0 e^{1/\tau} \qquad (2)$$

Thus, when the frequency factor is concerned, the permittivity in biological tissues can be expressed as follows:

$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\alpha_0}{(1/\tau) - j\omega} \qquad (3)$$

Also, because the initial conditions $\varepsilon(0) = \varepsilon_s$, we get the following equation:

$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\varepsilon_s + \varepsilon_\infty}{1 - j\omega\tau} \qquad (4)$$

So, in the two-phase permittivity model, we get the real and imaginary parts of the multi-phase permittivity of the separation are:

$$\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + (\omega\tau)^2} \qquad (5)$$

$$\varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{1 + \omega^2\tau^2} \qquad (6)$$

Among the formula limits the high frequency dielectric constant of the electrode ε_∞ , the dielectric constant of the low-frequency limit is ε_s , ω denote the frequency, and τ is the relaxation time. We calculated the ε' and ε'' according the parameters in table1.

Table 1. *Parameters used for calculation of ε' and ε'' .*

Frequency rangeω	τ	ε_s	ε_∞
0-10^7	0.0001	12000	80

For biological systems, it should know precisely its dielectric properties. With known dielectric composite system we can obtain dielectric spectroscopy of blood. According to Debye equation we can obtain the results of dielectric constant with frequency spectrum as shown in Figure 2.

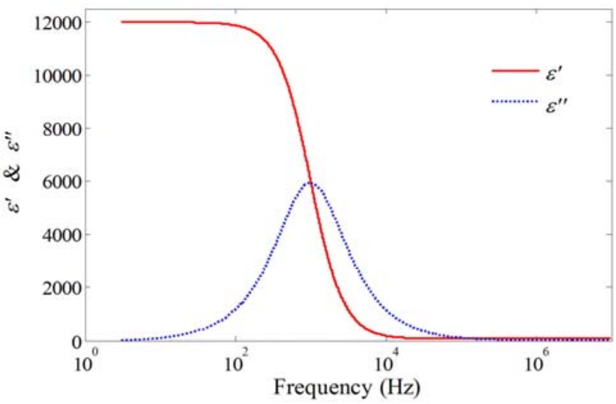

Figure 2. *Frequency characteristics of the ε' and ε'' .*

For biological system, it can not simply be equivalent to a sphere. Similarly, the parallel model can be made of the frequency spectrum as shown in Figure 3. The curve trend is consistent with the typical dielectric properties of biological tissue, and the series model under low-frequency dielectric constant is small, but higher in high-frequency [8]. This is probable due to the parallel models of the system is viewed as a flat structure.

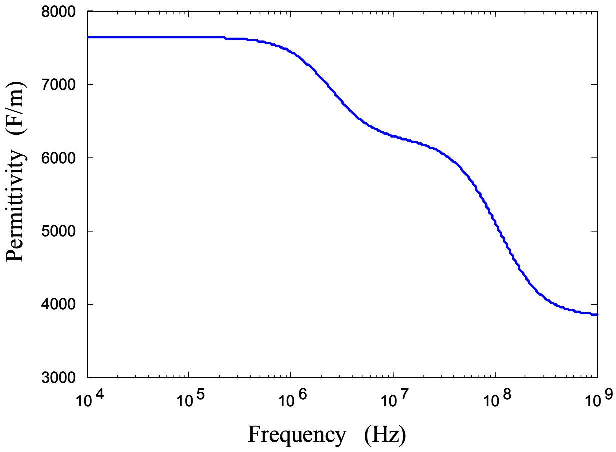

Figure 3. *Frequency characteristics of dielectric in parallel model.*

3. Application of Equivalent Permittivity in Blood

Human tissue is a lossy medium for electromagnetic radiation. Dosimetry of electromagnetic radiation in biological tissue commonly characterized by the SAR value, which can be expressed as follows:

$$SAR(r) = \frac{\sigma(r)\left|E(r)\right|^2}{2\rho(r)} \tag{7}$$

This formula denotes that the Specific absorption rate of electromagnetic power by unit mass of human tissue, the SAR has units of watts per kilogram (W/kg). At the frequency below the 10^6Hz, the biological tissue conductivity σ has unit of S/m, which increases with increasing frequency, can be calculated by the relationship [9-10]: $\sigma = f\times0.8\times10^{-7}+0.07$. Here, we introduce the attenuation factor of electromagnetic field when transmission in human tissue, which can be expressed as follows:

$$\alpha = \omega\sqrt{\mu\varepsilon}\left[\frac{1}{2}\left(\sqrt{1+\frac{\sigma^2}{\varepsilon^2\omega^2}}-1\right)\right]^{\frac{1}{2}} \tag{8}$$

Than, we calculate the SAR of human tissue via blood parameters combined with the attenuation factor. As shown in Figure 4, we calculate SAR with different frequency of electromagnetic field with intensity of 20V/m. The SAR value of human body tissue for electromagnetic radiation is basically stable with showing a downward trend, from 0.014 W/kg down to 0.0134 W/kg. When the frequency is more than 10^5 Hz, the SAR value increased significantly, showing that the biological effect of tissue-based thermal effects of the main features. The SAR value rise here to 0.0165W/kg at the frequency of 10^6 Hz.

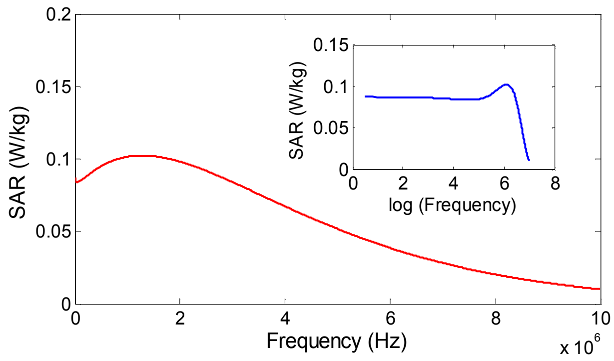

Figure 4. *SAR of blood under different frequencies electromagnetic field.*

From the perspective of electromagnetism, organisms are composed of a large number of cells with different electromagnetic properties. Biological characteristics of tissue under different electromagnetic waves are the corresponding key issue for studying the biological effects of electromagnetic fields [11]. This paper studied the electrical parameters of blood from the theoretical point of view, and the SAR value of blood is discussed for different frequency electromagnetic radiation. The results show that thermal effects apt to occur obviously at the higher frequency range. But on the contrary, in microcosmic aspect, we also need to use quantum mechanics theory to analyze the effect of bio-molecule in electromagnetic field in order to clarify the micro-mechanism of the biological effects of electromagnetic radiation.

4. Conclusions

Dielectric characteristics of blood can help us better to investigate the electrical properties of the blood. Using of the electrical properties of blood we will understand the physiological parameters, diagnosis of disease, physiological phenomena of blood as a hybrid system. Mechanism analysis dielectric characteristics of the blood based on its typical composition structure can be used to modify other physiological tissue model. According to results on changes of dielectric parameters in blood, internal changes and its usages such as hematology diagnostics, imaging, and the biological effects of electromagnetic fields may be very clear. In addition, according to the calculation results in the paper, it is show that the theoretical analysis has a unique advantage in terms of the SAR of biological tissues in electric field.

Acknowledgments

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