Journal of the Nigerian Association of Mathematical Physics
Volume **11 (November 2007), 461 -466**
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Investigation of beta dielectric dispersion in Bovine yellow bone marrow tissue

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Abstract

The relative permitivity or dielectric constant, ε′ of bovine yellow bone marrow tissue has been investigated in this study at an average room temperature of* $27.5 \pm 0.5^{o}C$ *over a frequency range of* 0.15*MHz to 20MHz for ß-dispersion using a resonance technique. This technique makes use of a marconi magnification meter TF* 1245 *working in conjunction with a radio frequently oscillator TF* 1246. *In general the tissue exhibited a decrease in dielectric constant, ε′ with increase in frequency until a lower steady value was attained at high frequency.

Keywords: Dispersion, Dielectric, Relative Permittivity Resonance Technique, Frequency.

1.0 Introduction

Dielectrics store electric energy and the intrinsic property of the material which measures this ability is the relative permittivity or dielectric constant, *ε'*. The electrical characteristics of biological cells and tissues have been of increasing interest to scientists for more than a century. This is because information obtained from such studies is of practical as well as of fundamental importance to the medical scientist because of the diagnostic and therapeutic applications of these electrical properties (Schwan, 1971) [7]. Knowledge of the dielectric properties of biological tissues is of importance for several reasons. For example, in order to determine the specific energy absorption rate in tissues, information on the dielectric properties of the various tissues is required. Nowadays, radio frequency induced hypothermia is often used for tumour destruction thus providing an effective treatment in certain tissues. This becomes easier when the characteristics tissue permittivity dispersion are known.

A bone marrow is a soft pulpy tissue which is found not only in the cylindrical marrow cavities of the long bones but also in the spaces between the trabecules of all bones and even in the haversian canals of the bone. It differs in composition in different bones and at different ages and occurs in the forms of a red and yellow marrow.

In this study, however, attention was focused on the yellow bone marrow which has a predominance of adipose cells with an admixture of macrophages. The yellow bone marrow is a storage organ, by virtue of its richness in fat and it represent a reverse of hematopoietic tissue becoming the site of production of cells in pathologic situations marked by frequent hemorrhages or excessive destruction of erythrocytes (Gulati, 1988) [3].

The yellow bone marrow is a biological substance whose electrical properties is related to the chemical composition, cell structure, temperature and other physical conditions. The dielectric properties commonly used in accessing the electrical characteristics of biological substances are the dielectric constant or relative permittivity, ε' and dielectric loss factor, ε'', which are the real and imaginary parts of the complex permittivity, ε^*, given by the equation of the form.

$$\varepsilon^* = \varepsilon' - j\varepsilon'' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} \tag{1.1}$$

Where ε_∞ is the permittivity measured at a sufficiently high frequency for the orientational polarization to have disappeared, ε_s is the limiting low frequency permittivity, ω in the angular frequency $2\pi f$, j is $\sqrt{-1}$ and τ is the characteristics macroscopic dielectric relaxation time for the relaxation mechanism.

The electrical properties of a yellow bone marrow tissue which is frequency dependent helps to acknowledge the quality of the yellow bone marrow tissue. Direct experimentation with the living human yellow bone marrow is impermissible because of the tissue damage caused by the experimental procedure. Therefore typical experiments usually involve the use of excised animal tissues. The magnetic properties of this tissue are not considered since most biological materials are non-magnetic and consequently magnetic losses are negligible (Schwan and Foster, 1980 [[8]).

2.0 Materials and methods

The bone marrow used in this study is the yellow type and was extracted from the hinged leg of freshly slaughtered adult cows in a governmental owned abattoir at Ikpoba Slope, Benin City, Edo State, Nigeria. All measurements were made at a mean room temperature of 27.5 ± 0.5^oC and within 2 – 6 hours of sacrifice of the animal. Mean dielectric characteristics of yellow bone marrow tissues sample where determined at frequency in the range 0.15 – 20MHz.

The accuracy of the measurement of capacitance depends critically on the measuring dielectric cell in which the sample of specimen is mounted. A possible source of error in this arrangement could be associated with inductance of the leads to the electrodes. Using short leads however, minimizing this error. Furthermore, the sample cell used in this study was constructed following the method suggested by Laogun et al (1983) [[4. The sample cell is a parallel plate capacitor consisting of two circular brass electrodes each of diameter 2mm separated by 2.95cm. The measurement of the real part of the complex permittivity, ε^*, is generally done by measuring the change in capacitance of a condenser brought about by the introduction of the dielectric between its electrodes. Values of the relative permittivity, ε', were obtained at frequencies in the range 0.15 – 20MHz using a resonance technique discussed elsewhere (Laogun et al, *ibid* [4]). This technique makes use of a commercially available magnification meter made by Marconi instruments Co. England and includes a Q-meter TF1245 working in conjunction with an oscillator TF1246 covering the frequency range 0.04 – 50MHz. Using a suitable resonating inductor (O, L, Q, F, E, P, A) the capacitance, C_1, of the test circuit without the specimen connected was determined at resonance. The test circuit was resonated with the sample or specimen connected and the new capacitance, C_2, was again determined at resonance. The effective capacitance, of the specimen under investigation is given by the equation (Okhaishie n' Avhianwu and Laogun, 2004 [5]).

$$C = C_1 - C_2 = \varepsilon' \varepsilon_o K + C_o \tag{2.1}$$

where ε_o (= 8.854 x 10^{-12} Fm-^{1}) is the permittivity of free space while C_o and K are the cell residual capacitance and constant respectively. Whence, ε', the relative permittivity of the sample was calculated for each frequency of measurement.

The values of the cell constant, K, and the cell residual capacitance, C_o were determined from measurements of the effective capacitance made for air and distilled water at frequencies between 0.10 – 40MHz using the method of Laogun et al (*ibid*) [4]. The relevant equations in this case are then

$$K = \frac{C_w - C_A}{\varepsilon'_w - 1} \tag{2.2}$$

and

$$C_o = C_A - K \qquad (2.3)$$

Where C_w is the effective capacitance of water, C_A is the effective capacitance of air and ε'_w is the relative permittivity of water.

3.0 Results and discussion

The results of dielectric measurements with air and distilled water are given in tables 1 and 2 where it may be seen that the measured permittivity is independent of frequency over the range considered. The data, also demonstrate the fact that the cell constant K is independent of frequency. The values of K and C_o were found from tables 1 and 2 to be 0.0052700 and 0.7816974 respectively.

The results of the relative permittivity ε', measurement for the bovine yellow bone marrow tissue over the frequency range 0.15 – 20MHz at room temperature are presented in table 3. A plot of the relative permittivity, ε', of the sample against frequency is shown in figure 1. It can be seen that the tissue exhibited pronounced frequency dependence of the relative permittivity, ε' from 0.15 to around 5.0MHz. That is a decline in the relative permittivity ε', with increasing frequency occurs at frequencies between 0.15 to 20MHz. Approaching 20MHz the curve levels off. It is off particular importance to note that the trend of values of relative permittivity obtained in this study as shown in table 3 and fig. 1 is quite comparable to similar results previously reported by Okhaishei n' Avhianwu et al (*ibid*) [5] for wet bovine ocular tissues and by Ajayi et al (2004) [1] for bovine aqueous and vitreous humour eye tissues. In general, the change is well understood. It is due to the fact that cellular membranes with a capacity known to be about 1μF/cm^2 membrane surface affect the tissue membrane at low frequencies (Schwan, 1971 [7]).

Most biological materials contain membranes, macromolecules of a wide range of size and shape and also ions. For a complex tissue it may be impossible to quantify individually the contributions to the dielectric dispersion at any particular frequency (Gabriel and Grant, 1985 [2]). However, the complexity in structure and composition of the tissue studied can be used in explaining the origin of observed dispersion. For the bovine yellow marrow tissue in this study it is found that it exhibited the beta dispersion spectrum in the frequency range 0.15 – 20MHz. Some of the reasons giving rise to this dispersion in solid have been associated with the Maxwell – Wagner or interfacial polarization effect (Pethig, 1978 [6]).

Table 1: Dielectric Measurement of Air

Inductor	**Frequency (MHz)**	**Open C_1 (μF)**	**Close C_2 (μF)**	**Effective Capacitance $C_A = C_1 - C_2$ (μF)**
O	0.10	128.7	127.9	0.8
L	0.15	488.8	488.0	0.8
	0.20	296.1	295.2	0.9
I	0.80	177.0	176.2	0.8
	1.00	128.8	128.1	0.7

Inductor	**Frequency (MHz)**	**Open C_1 (μF)**	**Close C_2 (μF)**	**Effective Capacitance $C_A = C_1 - C_2$ (μF)**
Q	1.50	79.2	78.6	0.6
F	2.00	281.0	280.3	0.7
	2.50	186.6	185.5	0.8
E	3.00	303.4	302.6	0.8
	5.00	130.4	129.6	0.8
P	10.0	192.2	191.4	0.8
A	20.0	326.4	325.4	1.0
	40.0	106.8	106.0	0.8

C_1 = capacitance of the test circuit without the sample connected and C_2 = capacitance of the test circuit with the sample connected.

Table 2: Dielectric Measurement of Distilled Water

Inductor	**Frequency (MHz)**	**Open C_1 (µF)**	**Close C_2 (µF)**	**Effective Capacitance $C_W = C_1 - C_2$ (µF)**
O	0.1	124.2	123.0	1.2
L	0.2	305.0	303.8	1.2
Q	1.5	83.5	82.0	1.3
F	2.0	283.4	282.2	1.2
	2.5	185.2	184.0	1.2
E	3.0	311.4	310.2	1.2
	5.0	128.8	127.6	1.2
P	10.0	194.8	193.6	1.2
A	20.0	326.0	324.8	1.2
	40.0	103.8	102.6	1.2

C_1 = capacitance of the test circuit without the sample connected and C_2 = capacitance of the test circuit with the sample connected.

Table 3: Dielectric Measurement of Bovine Yellow Bone Marrow Tissue.

Inductor	**Frequency (MHz)**	**Open C_1 (µF)**	**Close C_2 (µF)**	**Effective Capacitance $C_S = C_1 - C_2$ (µF)**	**Relative Permittivity ε'**
L	0.15	392.2	390.4	1.8	178.8
	0.20	292.8	291.4	1.4	108.3
I	0.80	197.2	196.2	1.0	37.74
	1.00	146.6	145.8	0.9	20.11
E	3.00	302.6	301.8	0.8	2.47
	5.00	155.2	154.4	0.8	2.47
A	20.00	313.0	312.2	0.8	2.47

C_1 = capacitance of the test circuit without the sample connected and C_2 = capacitance of the test circuit with the sample connected.

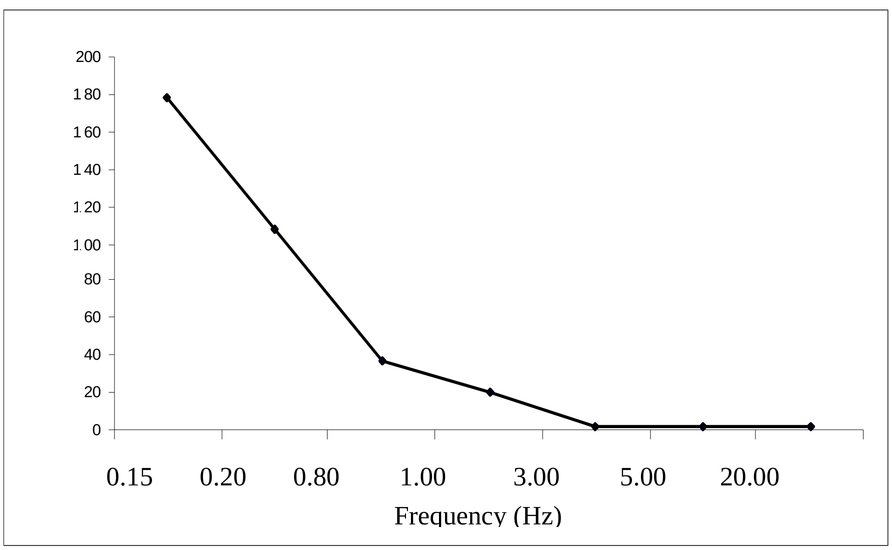

Figure 1: Variation of relative permittivity with frequency

4.0 Conclusion

Though much has been done in the study of the dielectric behaviour of biological substances, much still remains to be done and known considering the complexity in structure and composition of such substances since biological systems are subjected to natural variability especially in structure it is expected that differences in dielectric properties may occur.

The choice of bovine tissue in this study was deliberate. The general anatomy and physiology of the bovine tissue is very similar to that of the human tissue although with some notable exceptions. However, conclusions drawn from experimental work on bovine tissue can be used as inferences in the study of similar human tissue Ajayi et al (*ibid*) [1]. That being as it may, the need for accurate data on various animal and human tissue has been recognised for some time (Cook, 1951), since such data are of prime importance in the evaluation of possible hazards posed by non-ionizing radiation.

High values of the relative permittivity are usually found at the lower part of the frequency range of dielectric dispersion. This is characteristic of all dielectric dispersions and is also exhibited by the tissue in this study. This observed dispersion may be explained in general by the polarization of tissues membranes and can also be influenced by the protein content of tissues.

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