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Electrical and Dielectric Properties of Bio-Nanoparticles

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ABSTRACT

Nanoparticles display exclusive spectroscopic, electronic, biomaterials and chemical properties that arise from their smaller size and large specific surface area, which differ appreciably from those of bulk materials. Now a days, the biomaterials are downsized to the nanoscale. Nanotechnology brings a revolutionary change in biomaterials which may be used as new devices. In the present investigation, the bovine bones namely pelvis, skull, backbone, rib, scapula, radius/ulna, humerus, tibia, femur, metatarsus and metacarpus are crushed into fine nanoparticles. Specimens (pellets/discs) were prepared by applying pressure in hydraulic machine. Dielectric properties (dielectric constant and dielectric loss) and electrical properties (conductivity and resistivity) were measured for this pellets/discs as a function of temperature and frequency. In the present investigation, it is observed that, when size of the particle decreases dielectric constant, dielectric loss and conductivity increase and resistivity decrease. Using an inductance (L), capacitance (C), and resistance (R) (LCR) meter (pacific; PLCR 8a) the dielectric constant and dielectric loss were measured.

Key words: *Bovine bones, Dielectric constant, Dielectric loss, Conductivity, Resistivity, Bio nanoparticles, Inductance (L), capacitance (C), and resistance (R) meter, Frequency and temperature.*

1. INTRODUCTION

Nanotechnology owes its existence to the astonishing development within the field of microelectronics. Since the invention of the integrated circuit nearly half a century ago in 1958, there has been an exponential growth in the number of transistors per microchip and an associated decrease in the smallest width of the wires in the electronic circuits. As a result, extremely powerful computers and efficient communication systems have emerged with a subsequent profound change in our daily life. Nanotechnology deals with natural and artificial structures on the nanometer scale, i.e., in the range from 1 μm down to 10 Å. One nanometer (1 nm=10^{-9} m) is roughly the distance from one end to the other of a line of five neighboring atoms in an ordinary solid. Their unique size-dependent properties make these materials superior and indispensable in many areas of human activity. A biomaterial is defined as any systemically, pharmacologically inert substance or combination of substances utilized for implantation within or incorporation with a living system to supplement or replace functions of living tissues or organs. In order to achieve that purpose, a biomaterial must be in contact with living tissues or body fluids resulting in an interface between living and non-living substances. Bone as tissue, because of its wide application to many fields of medicine, was selected as the subject for discussion in the present investigation. Bones act as blood-forming organs, protective coverings, and aids to locomotion and respiration. *In vitro* and postmortem evaluation of biomaterial surfaces and tissue material interfaces provide an understanding of changes in the surface chemistry of the implant and reactions in the tissues. The physiology, anatomy, biochemistry and biomechanics of normal tissues are considered for the effective design of medical devices. The present paper is to summaries the most recent developments in the field of applied nanomaterials, in particular their application in biology and medicine [1]. The solid materials such as polymer, electric insulator, personal computer board, the ceramic substrate, etc. will act as good dielectrics. Dielectric measurements are useful for detecting explosives, plastic and metal weapons, drugs, chemical and biological agents. The dielectric data are required on a large variety of materials under different physical conditions for many industrial, scientific and medical applications of microwave energy [2-5].

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2. EXPERIMENTAL SECTION

2.1. Materials

Fresh bovine bones such as pelvis, skull, backbone, rib, scapula, radius/ulna, humerus, tibia, femur, metatarsus and metacarpus were collected from slaughterhouses in different places of Andhra Pradesh, in India for the present investigation. The skeleton of bovine is shown in Figure 1.

Fresh material present on the bone is removed. They were first cleaned and washed with tap water, and then sun dried. Specimens (pellets or discs) were cut from the mid region of the bone.

2.2. Sample Preparation

All samples used in the present study were prepared in the same way. Small pieces were cut from the specimens of bones (pellets or discs) and grained; the powder is shifted to ball mill (Model No: RETSCH PM 200, Germany) to achieve nanoparticles size [6]. Using this powder pellets/discs are prepared by applying a pressure in hydraulic machine. The nanoparticles size powder as shown in Figure 2.

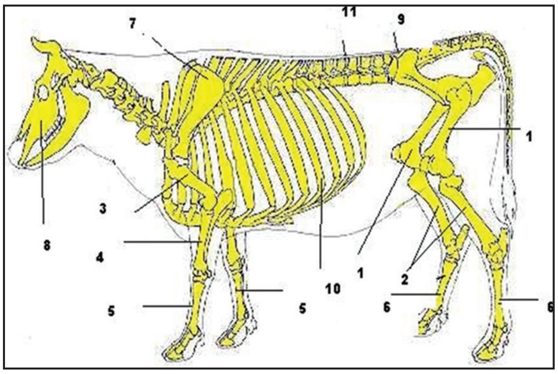

Figure 1: Skeleton of bovine, (1) Fumur, (2) Tibia, (3) Humerus, (4) Radius/ulna (fore arm), (5) Metacarpus, (6) Metatarsus, (7) Scapula, (8) Skull, (9) Pelvis, (10) Rib, (11) Backbone.

Figure 2: Nanoparticles size powder.

2.3. Experimental

2.3.1. Dielectric constant measurements

For the dielectric measurements, a two terminal cell was constructed in the laboratory. The cell consists of two parallel circular plates made up of copper. The diameter and thickness of the plates are 1.2 cm and 0.5 cm respectively. The lower circular plate electrode plugs directly into the live terminal of the capacitance measuring bridge while the upper one, at earth potential, is moved by means of a micrometer having least count 0.001 cm. This serves two purposes. One is to apply a slight pressure on the specimen placed between them, and the other is to measure the separation of the plates or the thickness of the sample. To eliminate capacitance due to leads, the capacitance (Ca) of the cell for different inter-electrode spacing (d) was measured. A plot is drawn between air capacitance on y-axis and 1/d on x-axis. The plot is linear and the capacitance C_a at infinite distance of the plates (i.e. 1/d=0) gives the value of lead capacitance (C_L) of the cell is shown in Figure 3. This value is to be subtracted from the measured value of capacitance with the sample C'_S and with air C'_a to have an exact value of the capacitance with sample (Cs) and with air (Ca).

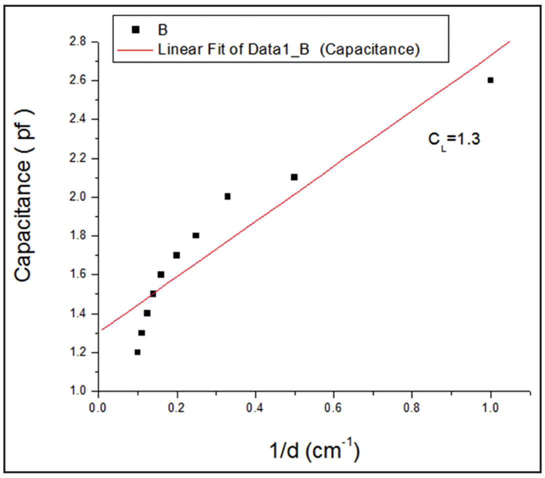

Figure 3: Graph between 1/d versus capacitance.

Figure 4: Experimental set-up for the determination of bone electrical and dielectric properties.

$C_s = C'_s - C_L$ and $Ca = C'_a - C_L$

The experimental set-up for the measurement of electrical and dielectric properties of bio-nanoparticles is shown in Figure 4. A commercial digital inductance (L), capacitance (C), and resistance (R) (LCR) meter (Pacific, PLCR 8C) was used to measure the capacitance and dissipation factor (tan d) [7]. The dielectric behavior of bovine femur, tibia, radius/ulna (fore arm), metacarpus, metatarsus, scapula, skull, pelvis, rib, and backbone in the applied alternating filed of frequency 1 KHz capacitance and dissipation factor were measured with the sample in the cell. All the measurements were taken at room temperature. The dielectric constant (e¢) of the sample is given by***:***

$\varepsilon' = C_S/Ca = C'_S - C_L / C'_a - C_L$

where,
Cs=Actual capacitance of the cell with the sample**.**
C_a=Actual capacitance of the cell with air**.**
C'_s=Measured capacitance of the cell with sample**.**
C'_a=Measured capacitance of the cell with air.
C_L=Lead capacitance.

Knowing the value of ε′ and tan δ, the dielectric loss was calculated by using the formula $\varepsilon''=\tan\delta.\ \varepsilon'$. The specific alternating current conductance K was calculated from the relation $\varepsilon''=1.8 \times 10^{12}$ K/ν where ν is the frequency of the applied electric field in Hertz. The dielectric constant and dielectric loss of bone specimen were measured along its z-direction. But it was not possible to measure along x and y-directions due to the limitations in the dimensions of the specimens.

3. RESULTS AND DISCUSSION

The results of electrical and dielectric parameters such as dielectric constant (ε′), dielectric loss (ε″), resistivity (ρ) and conductivity (K) of 11 types of bovine bone samples (taking 10 samples of each) in wet/normal dry condition and compressed nano bone powder are presented in Tables 1 and 2, respectively. The parameters were determined at a frequency of 1 KHz and at room temperature. Here the standard deviation values of the parameters reveal the variation among the different bone specimens of above-mentioned, but not the uncertainty of the measurement. It is evident from the data that there exists a considerable variation in the observed parameters.

Results on electrical parameters of 11 types of bovine bone samples reveal the considerable variation in different bone samples and also in different specimens of the same bone, obtained from the various parts of the bone. This may be attributed to the inhomogeneous deposition of calcium phosphate and water content of the bones. Bone density and investigated electrical parameters were significantly interrelated, as reported earlier (Saha and Williams, 1989, Seirpowska et al.[11] 2003) [8]. Influence of water on the electrical behavior is specific to bone because of the fact that mineral content of the bone is found to be in different proportion, which also affect the electrical makeup of the bone. Here it is the water content**,** which causes a lot of variation in dielectric parameters. The three parameters namely water content; mineral content (calcium phosphate) and orientation of the collagen fibers with respect to the applied electric field play an important role in influencing the electrical parameters such as

Table 1: The electrical and dielectric properties of bovine bone measured at 1 KHz (fresh/normal dry).

Bone sample	Average value for 10 samples each				
	Tan δ	Dielectric Constant ε′	Dielectric Loss ε″	Conductivity K (mho.cm^{-1})×10^{-9}	Resistivity ρ (ohm-cm)×10^{9}
FMC	0.427±0.14	15.24±3.67	6.94±3.65	3.8737±2.04	0.3431±0.18
FMT	0.558±0.04	23.69±3.58	13.29±2.68	7.3887±1.49	0.1409±0.03
FR/U	0.514±0.03	16.76±1.67	8.65±1.32	4.8091±0.73	0.2126±0.04
FH	0.396±0.06	17.27±2.10	6.88±1.53	3.8245±0.85	0.2744±0.07
FT	0.556±0.06	22.33±1.71	12.50±2.26	6.9460±1.26	0.1483±0.03
FF	0.552±0.05	25.12±1.38	13.91±1.86	7.7296±1.03	0.1314±0.02
FBB	0.346±0.09	9.01±3.75	3.40±2.35	1.8920±1.31	0.7479±0.41
FPV	0.562±0.25	18.20±8.77	12.20±8.44	6.7792±4.69	0.5055±0.71
FSK	0.269±0.13	13.68±6.12	4.31±4.24	2.3952±2.35	0.7213±0.45
FSC	0.332±0.18	16.02±3.91	5.81±4.43	3.2290±2.46	0.4683±0.26
FRB	0.6960±0.21	24.55±4.34	17.20±6.00	9.5568±3.33	0.1268±0.07

Table 2: The electrical and dielectric properties of bovine bone measured at 1 KHz (compressed bone powder/ nano powder).

Bone sample	Average value for 10 samples each				
	Tan δ	Dielectric Constant ε′	Dielectric Loss ε″	Conductivity K (mho.cm^{-1})×10^{-9}	Resistivity ρ (ohm-cm)×10^{9}
PMC	0.734±0.01	29.96±0.28	21.9006±0.51	12.167±0.28	0.0822±0.0019
PMT	0.703±0.01	44.62±0.3	31.3694±0.71	17.4274±0.4	0.0574±0.0013
PR/U	0.666±0.01	33.94±0.19	22.605±0.42	12.5583±0.23	0.0796±0.0015
PH	0.532±0.01	32.36±0.21	17.2152±0.33	9.564±0.19	0.1046±0.002
PT	0.715±0.01	43.8±0.27	31.318±0.71	17.3989±0.39	0.0575±0.0013
PF	0.733±0.01	49.9±0.22	36.5774±0.55	20.3207±0.31	0.0492±0.0008
PBB	0.447±0.01	19.7±0.19	8.807±0.29	4.8928±0.16	0.2045±0.0067
PPV	0.667±0.01	34.72±0.19	23.1574±0.33	12.8652±0.18	0.0777±0.0011
PSK	0.389±0.01	26.34±0.25	10.2456±0.18	5.692±0.1	0.1757±0.0031
PSC	0.444±0.01	32.32±0.23	14.3506±0.49	7.9723±0.27	0.1255±0.0044
PRB	0.696±0.01	42.46±0.21	29.5516±0.52	16.4175±0.29	0.0609±0.0011

dielectric constant, dielectric loss, and conductivity of the bone tissues when measured at the bulk level. The sharp fractional change in dielectric constant and resistivity with the water content and compressed nano bone powder suggest that the electrical parameters are very sensitive to particle size and free water present in bones. However, a decrease in resistivity was observed as grain size increased, which can be explained due to an increase in the mean free path of electrons [9]. Nanomaterials are at the leading edge of the rapidly developing field of ***n***anotechnology.

4. CONCLUSION

The results of electrical and dielectric properties of bio nanoparticles are measured at 1 KHz frequency are presented. When size of the particle decreases dielectric constant, dielectric loss and conductivity are increases and resistivity decreases. Bone disease analysis could be possible through the measurement of dielectric constant, dielectric loss, conductivity and resistivity and this paper constitutes a step toward the application of nano biomaterials for future needs. The relationship between dielectric constant and dielectric loss as a function of temperature and frequency may help us to improve techniques related to electrical stimulation and follow-up of the healing process in a fractured bone.

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***Bibliographical Sketch**

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