Full Length Research Paper

Measurement and modeling of the effect of gamma irradiation on radiofrequency dielectric properties of bovine kidney tissue

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Received 15 April 2012; Accepted 21 June, 2013

The effect of gamma irradiation on the radiofrequency dielectric properties of bovine kidney tissue has been investigated using gamma irradiator (Gs 1000), booton (7200) capacitance meter, signal generator (Lodstars SG-416013) and Dielectric cells. Mathematical models of the following dielectric structural parameter, Dielectric spread parameter (α), dielectric decrement (Δ) and Dielectric relaxation time (τ), were also developed. The mathematics models were found to be polynomial functions of degree 4, 4, and 5 respectively. The coefficient of fit for dielectric decrement, relaxation time and spread parameter (α), were found to be 98.2, 83.9 and 99.5, respectively. This shows that, the mathematical model can be effectively used to generate dielectric data that will facilitate the prediction of the extent of mammalian kidney tissue damage in gamma irradiation doses regime usually encountered in diagnostic and therapeutic radiology.

Key word: Gamma irradiation, spread parameter (α), dielectric decrement (Δ), dielectric relaxation time (τ), dielectric permittivity (ε').

INTRODUCTION

The dielectric methods of investigating structural and molecular characteristics of biological tissues is a well established techniques (Essex et al., 1975; Kyber et al., 1991; and Laogun et al., 2005). They have been frequently used to study changes in material composition, cell structure and water content under certain physical conditions (Laogun, 1986). The common feature of all these methods is that, the biological sample is contained in a sample holder and its complex permittivity is measured at various discrete frequency points (Burdette et al., 1980; Grant et al., 1978). Alterations or change induced to biological tissues is as a result of the its interaction with ionizing radiation can be measured or inferred from beta-dielectric dispersion properties of the irradiated tissues. These studies are prompted by the pride of place given to the use of ionizing radiation in diagnostic and therapeutic applications in healthcare and the need to established safety radiation levels (Laogun et al., 2005; and Agba et al., 2008).

Mathematical models of biological tissues provides...
reasonable mathematical approximation of the physicochemical changes occurring in a biological system and is calibrated against real data obtained from experimental investigations. Effect of Ionizing radiations on human health has been reported by researchers such as Pethig (1991), AAMP (1992), UNSCEAR (1993), Roger (2006) and Russel and Bradley (2007). This study is aimed at modeling the effect of gamma irradiation on bovine tissue at radiofrequency so as to predict its effects on mammalian tissues at doses within the diagnostic and therapeutic dose regime often encountered in radiology.

**METHODOLOGY**

The kidney tissue samples were excised from certified freshly slaughtered adult cow at Gwagwalada Central Abattoir in Gwagwalada Area Council Abuja, Nigeria. The excised tissue samples were washed with double distilled water and preserved in laboratory oven maintained at a temperature of 37 ± 0.5°C for 6 h so as to remove water from its surface. The samples were sealed and labeled in eight (8) plastic film bags. They were irradiated while the sample holders were positioned along their length at the centre of the irradiation field with irradiation doses: 0 Gy, 1 Gy, 4 Gy, 11 Gy, 20 Gy, 43 Gy, 60 Gy and 85 Gy, respectively.

The sample cells used in this research were constructed and calibrated in line with the method of Laogun et al. (2005) and Agba et al. (2008). The gamma irradiator (GS 1000) located at the Gamma irradiation facility (GIF) unit of National Nuclear Technology Centre, Abuja was used for the irradiation of the bovine kidney tissue samples at the dose rate of 0.36 kGy/h. Dielectric measurements were carried out using boonton (7200) capacitance meter in conjunction with signal generators (Lodstar, SG 416013 and Harris, G857993). The effective capacitance \( \Delta C \) and dissipation factor \( \tan \delta \) of the gamma irradiated kidney tissue samples were first measured after which the dielectric permittivity \( \varepsilon' \) and dielectric conductivity \( \sigma \) were obtained using the equations below:

\[
\Delta C = k \varepsilon' \tag{1}
\]

\[
\varepsilon'' = \varepsilon' \tan \delta \tag{2}
\]

\[
\sigma = 2\pi f \varepsilon_0 \varepsilon' \tag{3}
\]

Where, \( \varepsilon_0 \) = permittivity of free space, \( k \) = cell constant, \( \Delta C \) = Effective capacitance, \( \varepsilon'' \) = Dielectric loss factor, \( \sigma \) = Dielectric conductivity values measured at limiting frequency and static frequency.

The dielectric relaxation time and the dielectric spread parameter \( \alpha \) were evaluated using the frequency of the peak values of dielectric loss-factors for each dose and the cole-cole plots of dielectric loss factor \( (\varepsilon''/\varepsilon'') \) versus dielectric permittivity \( (\varepsilon') \) respectively. All measurement were carried out at the temperature of 28.0 ± 0.5°C and radiofrequency range of 0.5 to 50 MHz. The dielectric structure parameters were then modeled using computer aided curve fitting procedure.

**RESULTS AND DISCUSSION**

The dielectric conductivity \( (\sigma) \), of the \( \gamma \)-irradiated bovine kidney tissue samples was found to be larger than that of the non-irradiated kidney tissue. The result also revealed that the dielectric conductivity increased with increase in gamma irradiation doses as in Table 1 and Figure 1. This
Figure 1. The mean permittivity $\varepsilon'$ of $\gamma$-irradiation and non-irradiated bovin kidney from frequency range of 0.5 to 50.0 mHz.

Figure 2. Variation of dielectric decrement with $\gamma$-irradiation dose for kidney (MHz).

may be as a result of increase in ionization produced by gamma radiation in the irradiated kidney tissues. The spread parameter ($\alpha$), which is the degree of heterogeneity in the tissue samples also increased with increase in gamma irradiation doses as shown in Figure 2 and Table 2. The curve of Figure 2 shows a sharp increase in the
spread parameter values from 11 Gy to a peak value at 60 Gy after which a gradual decrease in the spread parameter began to manifest. This indicates that the ionization produced by gamma irradiation increases the heterogeneous distribution of ions in the kidney tissues (Laogun et al., 2005).

The dielectric permittivity $\varepsilon'$ values of $\gamma$-irradiated kidney tissues were found to decrease as the $\gamma$-irradiation doses increase as seen in Table 3 and Figure 3. Consequently, reduction in the dielectric decrement was observed as seen in Figure 4. The curve in figure 4 showed fluctuations in dielectric permittivity value at 0 Gy and a steady decrease at 20 Gy – 85 Gy. The decrease may be attributed to changes in the integrity and structural properties of the cellular membrane along with the reduction in the Maxwell-Wager interfacial polarization effect, which is responsible for the dielectric permittivity values at the radiofrequencies (Pettig, 1991 and Grant et al., 1978).

The dielectric relaxation time ($\tau$), of the $\gamma$-irradiated kidney tissues decrease as the gamma irradiation doses increased as shown in Figure 5. The curve of figure 5 reveals that the relaxation time decrease steadily between 0 Gy and maintained a constant value at 20 Gy – 43 Gy after which a sharp decrease was observed between 43 Gy – 85 Gy. This suggest that more ions are produce in the irradiated kidney tissue. Thus, time required to charge up the cell membrane of the irradiated kidney tissue decreased.

The mathematical models developed from the dielectric parameter data obtained from experimental investigations (have about 90% fit coefficients.) are presented as:

For spread parameter, $\alpha$,

(i) Bovine kidney at MHz frequency range (99.4%)

$$y = 2E - 08x^4 - 06x^2 + 0.101$$

For dielectric decrement, $\Delta$

(ii) Bovine kidney at MHz frequency range (83.8%)

$$y = 2E - 06x^5 - 011x^3 + 1.125x^2 - 29.87x + 1374$$

For relaxation time

(iii) Bovine kidney at MHz frequency range (98.2%)

$$y = 2E - 08x^4 - 3E - 06x^3 - 0.004x + 0.318$$

Conclusion

The result of this investigation revealed that, $\gamma$-irradiation doses usually encountered in radiology has measurable effect on the $\gamma$-irradiated mammalian tissue and that, the extent of damage increase with increase in $\gamma$-irradiation doses. Parameters modelled suggests that, these mathematical models are adequate for generation of dielectric data which can be used in the development of dielectric imaging system for diagnosis of certain kidney disease.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGEMENTS

We are grateful to the Director General, Nigeria Atomic Energy Commission and the Director, gamma irradiation facility, Nigeria Nuclear Technology Centre Abuja for the irradiation of our samples and in the course of this research. We are also grateful to the Technologist at the Departments of Physics and Biology of Benue State University Makurdi for their assistance throughout the period of this research.
Table 3. The mean permittivity, $\varepsilon'$ of $\gamma$-irradiated and non-irradiated bovine kidney from frequency range 0.5 to 50.0 MHz.

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>5.0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2311.8 ± 19.6</td>
<td>2250.7 ± 29.6</td>
<td>2153.5 ± 77.8</td>
<td>2075.7 ± 98.2</td>
<td>1917.4 ± 139.5</td>
<td>1503.5 ± 105.4</td>
<td>1342.4 ± 74.6</td>
<td>1164.6 ± 54.6</td>
<td>1064.6 ± 96.2</td>
</tr>
<tr>
<td>1</td>
<td>2061.9 ± 34.2</td>
<td>2136.9 ± 44.6</td>
<td>2031.3 ± 22.6</td>
<td>1717.4 ± 99.2</td>
<td>1414.6 ± 67.8</td>
<td>1120.2 ± 34.7</td>
<td>903.5 ± 48.6</td>
<td>759.1 ± 27.6</td>
<td>667.4 ± 74.8</td>
</tr>
<tr>
<td>4</td>
<td>1923.0 ± 98.3</td>
<td>1897.8 ± 79.8</td>
<td>1695.2 ± 77.8</td>
<td>1461.8 ± 58.2</td>
<td>1286.9 ± 60.1</td>
<td>1042.4 ± 38.6</td>
<td>820.2 ± 64.3</td>
<td>659.1 ± 82.8</td>
<td>586.8 ± 62.6</td>
</tr>
<tr>
<td>11</td>
<td>1439.6 ± 98.6</td>
<td>1531.3 ± 78.1</td>
<td>1459.1 ± 49.2</td>
<td>1325.7 ± 90.2</td>
<td>1206.5 ± 54.1</td>
<td>978.5 ± 41.8</td>
<td>739.6 ± 37.3</td>
<td>623.0 ± 38.2</td>
<td>470.2 ± 63.2</td>
</tr>
<tr>
<td>20</td>
<td>1612.0 ± 29.3</td>
<td>1286.9 ± 44.9</td>
<td>1192.5 ± 74.1</td>
<td>1123.0 ± 81.2</td>
<td>986.8 ± 45.8</td>
<td>803.5 ± 85.1</td>
<td>648.0 ± 42.9</td>
<td>545.2 ± 34.6</td>
<td>434.1 ± 28.6</td>
</tr>
<tr>
<td>43</td>
<td>1439.6 ± 34.2</td>
<td>1156.3 ± 53.0</td>
<td>1095.4 ± 74.8</td>
<td>920.2 ± 68.1</td>
<td>753.5 ± 68.8</td>
<td>678.5 ± 28.8</td>
<td>500.7 ± 34.8</td>
<td>386.8 ± 37.6</td>
<td>339.5 ± 77.4</td>
</tr>
<tr>
<td>60</td>
<td>1186.8 ± 74.3</td>
<td>967.4 ± 48.2</td>
<td>836.8 ± 51.0</td>
<td>661.8 ± 77.8</td>
<td>533.5 ± 70.1</td>
<td>453.5 ± 54.4</td>
<td>350.7 ± 59.2</td>
<td>292.4 ± 76.8</td>
<td>278.5 ± 28.9</td>
</tr>
<tr>
<td>85</td>
<td>1063.3 ± 124.6</td>
<td>846.6 ± 91.8</td>
<td>675.8 ± 34.6</td>
<td>575.8 ± 34.8</td>
<td>484.2 ± 66.7</td>
<td>396.2 ± 29.8</td>
<td>217.2 ± 29.4</td>
<td>271.6 ± 55.2</td>
<td>254.9 ± 47.0</td>
</tr>
</tbody>
</table>

**Figure 3.** Variation of spread parameter $\alpha$ with $\gamma$-irradiation dose for kidney (MHz).
Figure 4. Variation of relaxation time with γ-irradiation dose for Kidney (MHz).

![Graph showing relaxation time variation with dose](image1)

Figure 5. Variation of relaxation time with γ-irradiation dose for Kidney (MHz).

![Graph showing relaxation time variation with dose](image2)

REFERENCES


