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Dielectric Properties of Breast Phantom Model

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Abstract—*High Voltage Engineering has broad applications in various fields. This paper includes one such application of pulsed electric field (PEF) in medical field. 0Breast cancer is the second leading disease in women exceeded only by lung cancer according to American Cancer Society. The incidence in every country is rising especially in India. This initiates new treatment and detection method which are both cost efficient and effective. Exposing the real tumor breast tissues to pulsed electric fields leads to the variation in dielectric properties at different frequencies.*

In this paper breast and tumor phantoms are modelled and the effect of electric field were observed in the phantoms which helps in screening of breast cancer. Here both homogenous and heterogenous breast phantoms were made by using different mimicking materials such as agar, gelatin,etc,. which exactly matches the dielectric properties of original breast and tumor tissues .Debye model has been used to validate the experimental values of permittivity and conductivity of the modelled phantoms. First, tumor phantoms were embedded in homogenous breast phantom and the effect of PEF were observed. Secondly, tumor phantoms were embedded in each layer of heterogenous phantom and the effect of pulses were observed. When exposed to pulses it alters dielectric properties. Here the phantoms are exposed to 10 number of high intensity unidirectional pulse with rise time of 1.2µs and tail time of 50µs at 1kV and 2kV and its corresponding changes are observed. From this the permittivity decreases and conductivity increases with the frequency range of 50Hz to 50MHz. After the exposure of PEF the permittivity of tumor tissue, reaches almost nearer to the permittivity of normal tissue and the conductivity increases due to formation of pores which stimulates electroporation. On comparing the results of 1kV and 2kV the permittivity and conductivity is found to be better when phantoms are treated with 2kV.

1. INTRODUCTION

Out of every 100 women with breast cancer in the US, 89 women are likely to survive for atleast 5 years. This shows that, breast cancer accounts for 25% to 32% of all female cancers. This implies, one forth of all female cancer cases are breast cancer. Conventional methods for treatment of cancer results in more side effects and more costlier and produces only timely solution and hence it is not effective. There is a need for effective, safe, affordable alternative treatments. Electroporation is a technique of applying high intensity, short duration pulses for cancer therapies [1]. The application of electric pulses along with non-permeant chemotherapeutic drug such as bleomycin, cisplatin is known as Electrochemotheraphy. The pulses transiently permeabilize cell membrane, thus allowing transport of molecules. The application of Pulse Electric Field has emerged as a local, nonthermal and drug free theraphy for cancer. The pulses are used to provoke either permanent permeabilization of cancer cells or destabilize the cell membranes and intracellular components to which the cells are unable to repair resulting in their death. Hence electric pulses are used to prevent the growth of tumor tissue. Numerous models of cancer have been developed to quantify the behaviour of tumor in order to develop a novel treatment technique for cancer [1][2]. Breast cancer treatments need an evaluation stage in terms of their potential, limitations, and patient safety prior to employ it into clinical practice [3]. For cancer treatment it is very useful to mimick the real tissues and several trials for treatment can be done on the phantoms and can be evaluated. Hence phantoms can be used to evaluate treatment process. A phantom is a mixture of different components, with human tissue- like characteristics, in order to get the required properties for a specific application[4].

In published data,it is illustrated that the permittivity of tumor tissue is 10-20% greater than that of normal tissue [5]. In almost all the previous studies, the breast phantoms were constructed relatively long time. It is found that the water content will migrate with time which may produce inconsistent results [6 ,7]. In this paper, homogenous, heterogenous breast and tumor phantoms were modeled which exactly matches the real tissues . Tumor is embedded inside the breast phantom and the effect of PEF is observed.

2. MATERIALS AND METHODS

2.1 Modelling of Breast phantom

Homogenous breast phantom is modelled by using following materials and its dielectric properties were observed by using Wayne Kerr6500B Precision Impedance Analyser and the values are validated by using Debye model.

The materials and quantities for breast phantom were:

- 1ml corn oil
- 20ml deionised tridistilled water
- 10ml Ctab
- 1.5g agar-agar (bacto)

The breast phantom model was prepared by protocol given below as reported in [8].

a. The quantity of materials required for the phantom are measured.

b.Deionised tridistilled water is mixed with neutral detergent.

c.Corn oil is added to the mixture.

d. The compounds are heated and at 80ºC, agar is added.

Heterogenous breast phantom is modelled by using materials given in table 1 [9]. Slight variations in the compositions has been made in order to ensure the reproducibility of phantoms.

a. Mix distilled water with propylene glycol and place in double boiler.

b. Raise the temperature of the mixture upto 50^{0}C.

c. Gelatin is added and mixed until it dissolves completely.

d. Surfactant, Formalin and Safflower oil are mixed separately and it is added with the heated solution.

e. Mixture is continuously stirred and removed from the boiler and allow it cool.

f. But stirring is continued until it reaches 30^{0}C and place it in icebath.

g. When the mixture reaches 25^{0}C it was poured into the PVC pipes for molding and refrigerated overnight.

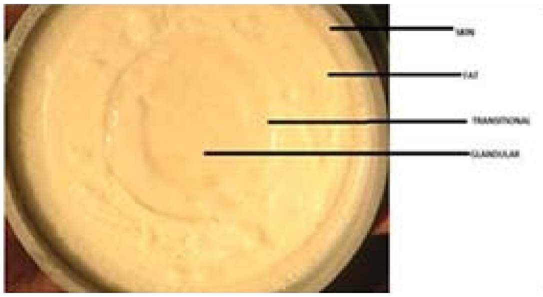
Table 1: Composition of materials

Materials	Glandular	Trans	Fat	Skin
Distilled water	80ml	40ml	40ml	80ml
Safflower oil	21ml	13ml	39ml	14ml
Propylene gylcol	7ml	5.88ml	2ml	7ml
Gelatin	5ml	5ml	7ml	5.88ml
Formalin	0.30ml	0.30ml	0.30ml	0.30ml
Ctab	0.30ml	0.30ml	0.30ml	0.30ml

Cylindrical molds are used here for construction of different layers of breast phantom. This phantom consists of four layers which includes transitional layer, glandular layer, fat layer and skin layer. PVC pipes used here are of following sizes 3 inch,2.5 inch, 1.5 inch and 0.75 inch.

Firstly, the PVC pipes are arranged and the layers are done with the help of above protocol. To create a model of phantom with layers, Skin layer is made first and it is poured in the 3 inch PVC mold and it is allowed to set. Then fat layer is made and it is poured in the 2.5inch PVC mold. Transitional layer and glandular layer is made and it is poured in 1.5 inch and 0.75inch PVC mold and it is allowed to set at 25^{0}C and it is kept overnight.

Fig. 1: Cylindrical molds for each layer



2.2 Modelling of Tumor Phantom

The materials and quantities for tumor phantom are as follows,

- 100ml deionised tridistilled water
- 60ml ethanol
- 1g NaCl
- 1.5g agar

The following protocol is used as reported in [8].

a. Deionised tridistilled water is mixed with NaCl.

b. Ethanol is added to the mixture.

c. The compounds are heated and at 80ºC, agar is added to it.

Fig. 3: Tumor phantom

Fig. 3 shows the tumor phantom after mixing

2.3 Tumor embedded in breast phantoms

Tumor phantom is set first and it is allowed cool then the breast phantom is prepared and it is poured over the tumor phantom. This tumor phantom is cut into half and embedded inside the breast phantom and also the whole tumor is embedded inside the breast phantom.

Fig. 4 shows the tumor embedded inside the breast phantom. Then depending upon the thickness of the breast layers the tumor is kept accordingly. Following are the sizes of the tumor embedded inside each layer, in glandular (1cm*1cm), Transitional layer(1cm*0.5cm), Fat layer(1cm*1cm),Skin(1cm*0.7cm) as shown in Fig. 5.

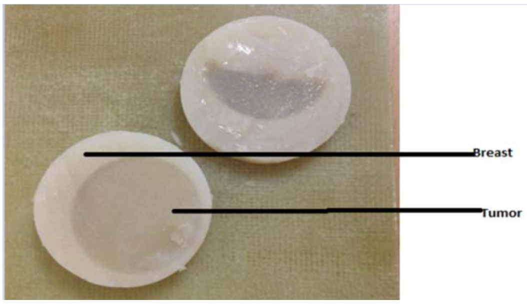


Fig. 4: Tumor embedded in homogenous breast phantom

Fig. 5: Tumor embedded in each layer of heterogenous phantom.

3. MEASUREMENT OF DIELECTRIC PROPERTIES

3.1 Homogenous Phantom

Measurements were obtained by using Wayne Kerr6500B Precision Impedance Analyser over the frequency range of 50Hz to 50MHz.

Permittivity and conductivity is the main area of interest and so here capacitance and conductance are measured for different frequencies and the permittivity and conductivity can be calculated using

Permittivity $\varepsilon_r = C*d/\varepsilon_o A$, Conductivity $\sigma=G*d/A$

Where d is the thickness of sample, A is area of sample, C is capacitance and G is conductance of the sample. $\varepsilon_o=8.854e^{-12}$F/m .

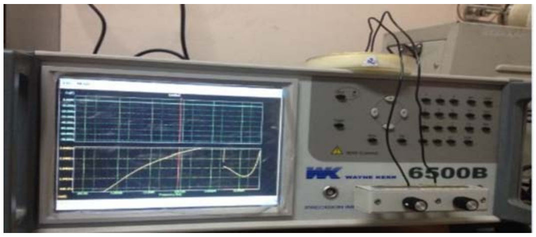


Fig. 6: Measurement setup

3.2 Heterogenous Phantom

Debye model is more realistic for biological tissues. Therefore this model is adopted to validate the nature of model. The selection of normal and malignant tissue is a difficult task due to its complex nature (heterogeneity) of the breast tissue. Since the Debye model has been shown to be a good approximation to experimental data ,we choose to use this model (for the frequency range of interest) in the following form.

$$\varepsilon(f) = \varepsilon_\infty - j\frac{\sigma}{2\pi f \varepsilon_0} + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\left(\frac{f}{f_p}\right)}$$

where, for normal tissue,$\varepsilon_\infty=7$, $\varepsilon_s=10$, $\sigma=0.15$S/m, for a tumor $\varepsilon_\infty=35$, $\varepsilon_s=50$ $\sigma=0.15\text{-}1.5$S/m

4. PULSE ELECTRIC FIELD EXPOSURE

Pulsed Electric Fields are used in many applications. The most advanced medical application of PEF is cancer treatment. Tissues can be permeabilised. Hence this process is attempted in phantoms. Tumor phantoms are subjected to 10 number of high intensity unidirectional pulse with rise time of 1.2μs and tail time of 50μs at 1kV and 2kV.The changes in the dielectric properties of the tumor phantom over a frequency span of 50Hz to 50MHz, after the exposure of PEF is observed.

Fig. 7: Experimental setup

5. CONCLUSIONS AND DISCUSSIONS

In homogenous phantoms, following Fig. shows that there is about 55% increase in full tumor (S2) than half tumor(S1) and about 58% difference between S1 and S2 conductance values.

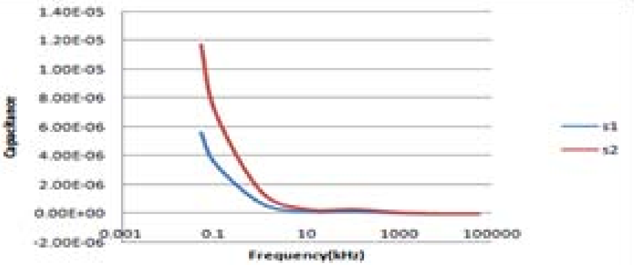


Fig. 8: Variation of Capacitance(F) values

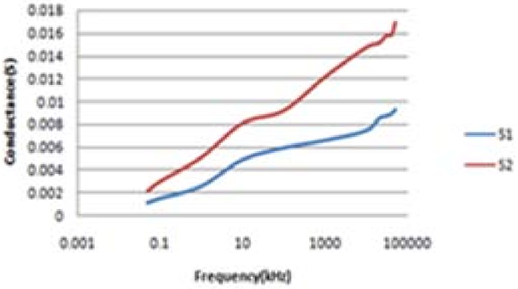


Fig. 9: Variation of Conductance values

In homogenous phantom, the effect of pulses shows that there is decrease in the capacitance values and increase in conductance values in both tumor phantoms.

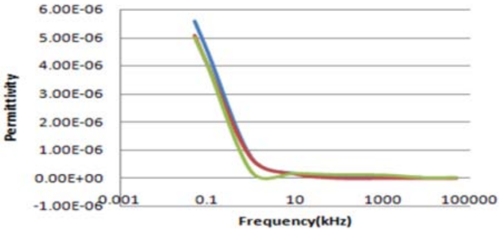


Fig. 10: Effect of PEF on half tumor

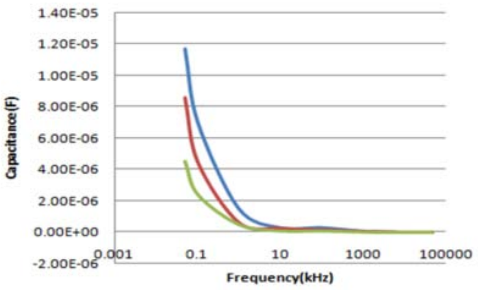


Fig. 11: Effect of PEF on full tumor

From above results, the effect of PEF on full tumor embedded inside the breast phantom.There is 18.18% decrease in capacitance values for half tumor (S1) and for full tumor phantom(S2), 81.65% decrease for full tumor (S2).

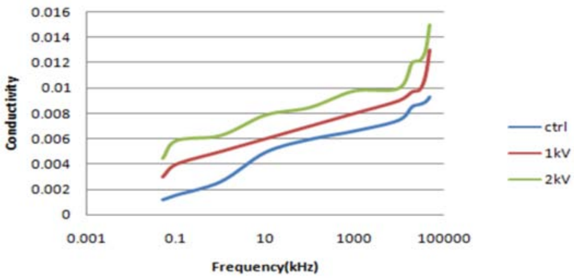


Fig. 12 Variation in conductivity in half tumor

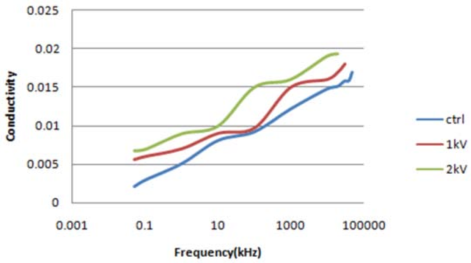


Fig. 13: Variation in Full tumor

In heterogenous phantom, validation is done by using debye model.

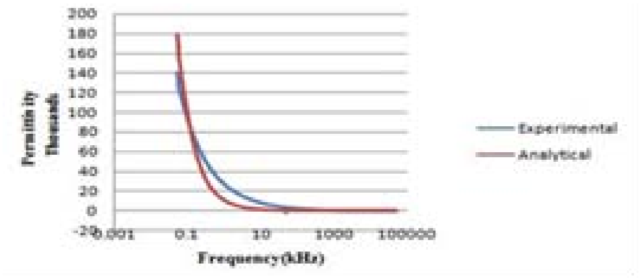


Fig. 14: Skin Layer

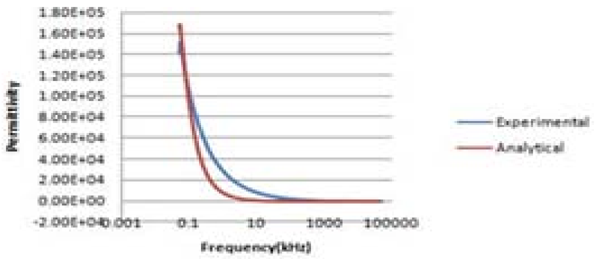


Fig. 15 Fatty layer

Fig. 14 and Fig. 15 shows the comparison between the experimental and analytical values, where for higher frequencies the values are similar and for lower frequencies the difference between them is more.

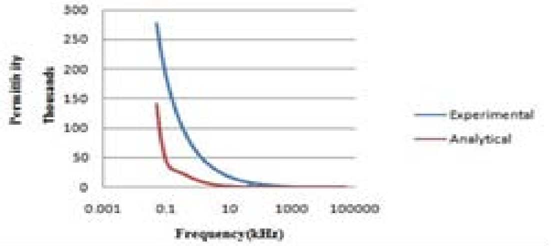


Fig. 16: Transitional layer

Fig. 16 and Fig. 17 shows the transitional and glandular layer for the frequency range of 50Hz to 50MHz.

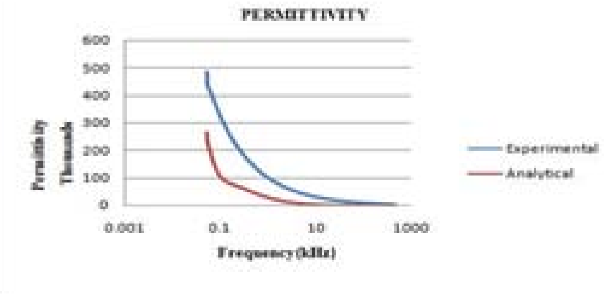


Fig. 17: Fibro glandular layer

The pattern is similar to the literature [9]. The dielectric properties of the phantoms are measured and are validated using Debye model. In heterogenous phantom, each tumor in each layer is exposed to pulses and its effect is observed. Electrode configuration used here is needle-needle configuration which is used to deliver pulses accurately on the tumor phantoms which is embedded in each layer of the constructed breast phantom whose distance between the electrodes is 1cm.

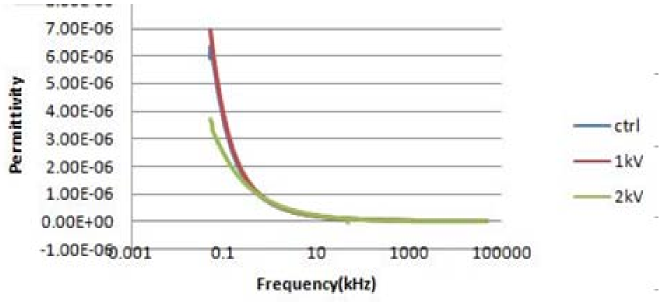


Fig. 18: Permittivity changes in skin layer

There is 18.18% increase in the conductivity values of PEF treated phantoms than the normal phantom.

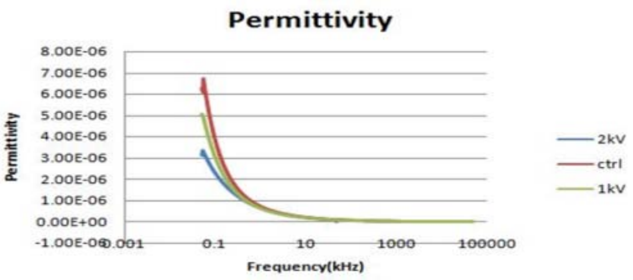


Fig. 19: Effect of PEF on Fat layer

Above graph shows the effect of pulses on fat layer which is the second outermost layer in the breast phantom which shows 66% increase than normal tissue.

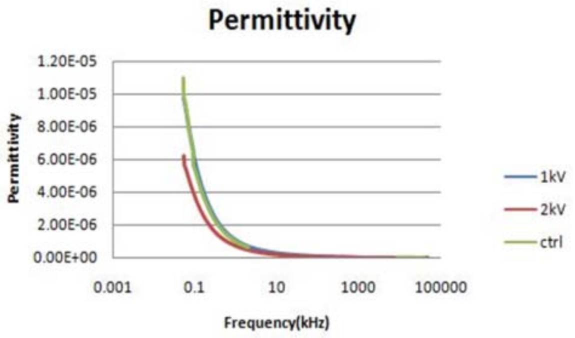


Fig. 20: Effect of PEF on transitional layer

From above results, it is clear that the conductivity values increases after the exposure of pulses and it is high for 2kV when compared to 1kV where it shows about 86% increase for 2kV.

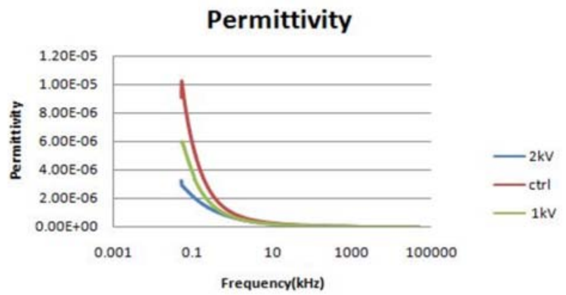


Fig. 21: Effect of pulses on Glandular layer

Above graph shows the variation in conductivity values due to the exposure to PEF on glandular tissues.There is 30% increase in conductivity of tumor than normal tissue.

6. CONCLUSIONS

Homogenous, Heterogenous breast and tumor phantom models are made whose dielectric properties matches the properties of real tissues by using the mimicking materials such as gelatin, agar etc,. Permittivity of tumor phantom is about 10 to 20% more than breast phantom. By using Debye model the experimental datas were validated. Tumor is cut into half (S1) and full tumor(S2) are embedded inside breast phantom where capacitance of S2 is 55% more than S1 and conductance values of S2 is 58% more than S1.After PEF treatment, there is 18.18% decrease in capacitance values for half tumor (S1) and for full tumor phantom(S2), 81.65% decrease for full tumor (S2).The effect of PEF shows increase in conductivity values to about 50% for half tumor (s1) phantom and 20% increase than the full tumor phantom. After the exposure of PEF on phantoms the conductivity increases which ensures to facilitate electroporation and permittivity decreases which nears the actual normal breast tissue[8].

In heterogenous phantom,permittivity of the skin layer is changed after the exposure of PEF which shows 66.6% reduction of permittivity after the application of PEF at 2kV than normal tissue and 18.18% increase in conductivity values. In fatty layer, when 2kV is applied there 66% reduction in permittivity than normal and 66% increase in conductivity values than normal breast phantom.In transitional layer, there is 28% difference in reduction of permittivity values when phantom is subjected to 2kVthan 1kV and 86% increase in conductivity values .In glandular layer, there is 66% decrease in permittivity values of 2kV applied phantoms and 30% increase in conductivity values than 1kV.

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