



## Frequency and Temperature Dependence of Dielectric Properties of Fish Scales Tissues

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### Abstract

Frequency and temperature dependence of the dielectric parameters like dielectric constant ( $\epsilon'$ ) dielectric loss ( $\epsilon''$ ), conductivity ( $\sigma$ ) loss tangent ( $\delta$ ), and capacitance ( $F$ ), of biological tissues have been studied. fish catla catla (cytriniidae) which were scales tissues sample, of thicknesses .75mm and diameter 4X4mm, are studied in the frequency range (1Hz-10MHz and in the temperature range (30-150°C). There frequency and temperature dependence study have been quantitatively explained. The magnitude of dielectric loss decreases with increasing frequency. The temperature dependence of dielectric constant increases rapidly with temperature particularly in temperature region where dielectric loss peak occurs. It is not clear fish scales can used to any advantage. However, the high dielectric constants of these scales at low frequencies (around 1KHz) suggest that they could in, in principle, be used for capacitor applications. Further theoretical and experimental investigations will be carried out to frequency dependence of complex permittivity of biological tissues.

**Keywords:** Dielectric constant, dielectric loss, conductivity and loss tangent, capacitance, frequency and temperature, scales tissues sample (catla catla - cytriniidae).

### Introduction

The dielectric properties of biological cells and tissues are very remarkable. They typically display extremely high dielectric constants at low frequencies, falling off in more or less distinct steps as the excitation frequency is increased. Their frequency dependence permits identification and investigation of a number of completely different underlying mechanisms, and hence, dielectric studies of biomaterials have long been important in electrophysiology and biophysics. As an example, Ho<sup>ber</sup><sup>1,2</sup> deduced from dielectric studies that erythrocytes are composed of a poorly conducting envelope enclosing a conducting electrolyte, and in 1925, Fricke<sup>3</sup> derived a value of 3.3 nm for the thickness of this envelope. Hence their bioimpedance research provided early indication of the ultra thin cell membrane. As we shall see later, interfaces play a significant role in the frequency dependence of complex materials, particularly at audio and sub audio frequencies. Knowledge of the wide-band frequency dielectric properties of biological tissues (scale tissues) is relevant to the design and development of production and processing equipment because heating, attenuation, reflection and transmission during interaction with electromagnetic radiation all depend on the relative complex permittivity<sup>4,5</sup>. Such information could also improve the implementation of time-domain reflectometry (TDR) for the determination of water content<sup>6</sup> and hydraulic conductivity<sup>7</sup> by allowing more accurate instrument calibration; and it could serve as a basis for future refinement for application in the interpretation of remotely sensed data. Electromagnetic

interactions with biological tissues (scale tissues) depend upon the real and imaginary parts of the relative complex permittivity, given as:

$$\epsilon = \epsilon' - j\epsilon'' \quad (1)$$

where  $\epsilon$  is the relative complex permittivity,  $\epsilon'$  is the real part (dielectric constant) which denotes the electric energy storage capacity, and  $\epsilon''$  is the imaginary part - sometimes referred to as the loss factor - which accounts for the dissipation of electrical energy as heat<sup>4,7,8</sup>. The high relative permittivity value of water compared to the very low relative permittivity of the organic matter<sup>9</sup> present in horticultural peat means that the predominant factor in the variation of its relative permittivity is attributable to variation in water content. Permittivity (at constant temperature) generally increases with water content as for other organic substances<sup>9</sup>. The relative proportions and total content of intercellular and inter-particle water depend, on frequency and temperature. The study described in this paper aimed to determine the influence of volumetric water content on the dielectric properties of Biological tissues (scale tissues) in the 1Hz-10MHz region of the electromagnetic spectrum.

### Material and Methods

A large variety of fishes display beautiful silvery sides. Fish scales generally consist of layers of collagen and organic and bony materials<sup>10</sup> (figure.1).

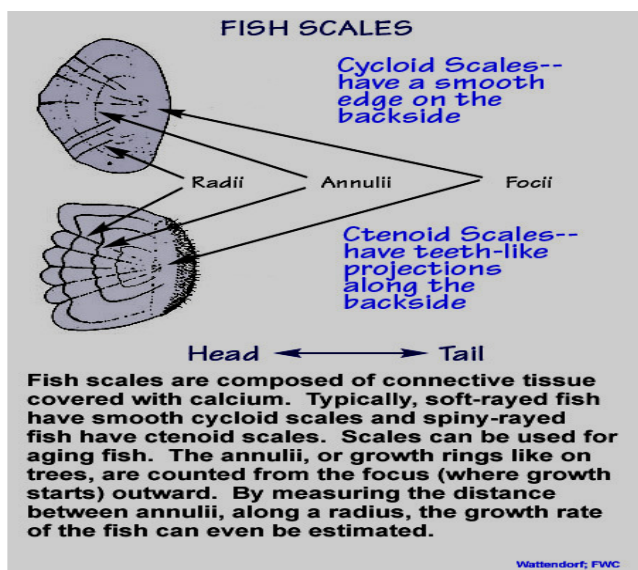


Figure-1 Shows fish scale tissues sample

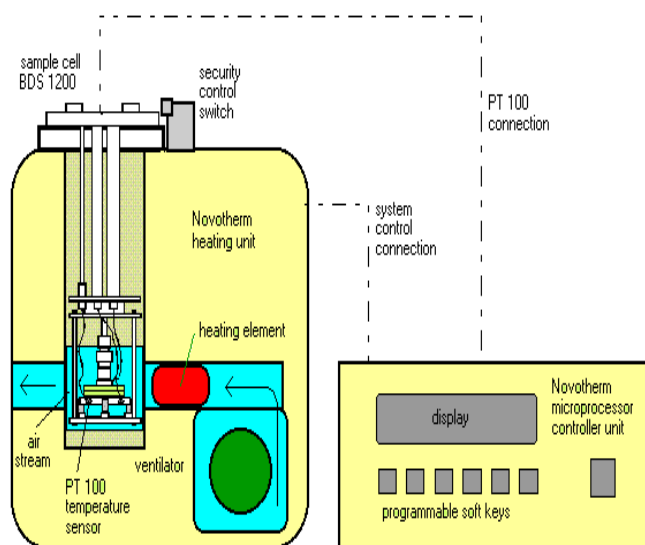


Figure-2 Block diagram of impedance analyzer and LCR meter

The nature of the reflectors in fish scales has been a subject of considerable interest for some time. The reflecting properties are associated with the presence of arrays of crystals of guanine and hypoxanthine, which act like tiny mirrors arranged in special stacks. In view of the presence of layered organic and inorganic matter in fish scales, we examined some features of the scales, especially their dielectric properties. Fish scales of the cycloid type, obtained from *Catla catla* (family Cyprinidae) were washed with distilled water and dried at 300 K for 15 days and Silver past both of scales sample. The Biological tissues used in the present study, as mentioned before, are scales tissues. Extrusion molding process was used for making the biological tissues samples. Fish (*catla catla* and *common carp*), which were scales tissues sample of thicknesses 75mm and diameter 4X4mm are studied in the temperature range (30-150°C) and in the frequency range (1Hz-10MHz). It was observed that the dielectric constant of polar scales tissues decrease with increasing frequency as well as with temperature. The dielectric loss cell was locally designed. The heating coil was made from a resistive wire in the form of circular coil arranged symmetrically in the chamber. The resistance coil is connected to an A.C source variance transformer. The current through this heater could be adjusted to optimal, the temperature gradient in the hollow space enabling a sample temperature to be determined with 1°C or better. To eliminate temperature gradient we heated the system for several hours to attain thermal equilibrium (a pre experiment was performed in which two identical thermocouples was attached to each disc it was found that at thermal equilibrium they record the same temperature). Also we switched off the power supply during the taking of the measurement, otherwise A.C current passed through the electrical heater around the sample cell; this would produce a magnetic field which could have a bad effect on the results.

The sample holder which was two identical discs of 1cm thickness made from aluminum was set at the centre of the circular coil and at the high of 8mm. The lower plate is fixed, while the upper is movable by using a screw to assure good electrical contacts between the electrodes and the sample; this enables us to avoid the parasite capacitance induced by the presence of air interstices at the interfaces between the sample and the electrodes. The thermocouples were not being attached to the capacitor plates because it changes the value of the capacitance, there for it was as close to the capacitor plate as thickness of one mica sheet.

The dielectric properties (Dielectric constant and Dielectric loss) were measured as functions of temperature and frequency. The real and imaginary parts of the relative complex permittivity and capacitance of biomaterial samples were measured by using Programmable Automatic Precision impedance analyzer and RCL meter model type Hewlett-Packard HP4192A (figure 2). The sample temperature was measured by Alumel-Chromel constantan thermocouple, with digital thermometer (0~ 800°C). The thermocouple was not attached to capacitor plates because it produces some leakage which can change the values of the capacitances, therefore it was put as close to the capacitor plate as the thickness of one mica sheet.

### Results and Discussion

The dielectric constant of a material can be expressed as a complex quantity,, consisting of real part ( $\epsilon'$ ) and an imaginary part ( $\epsilon''$ ). The real part of the dielectric constant is the quantity that describes electrical energy converted to stored potential energy, generating a polarization of the dielectric material. This energy storage process is always accompanied by a loss current. This represents energy that is not stored, but is dissipated within

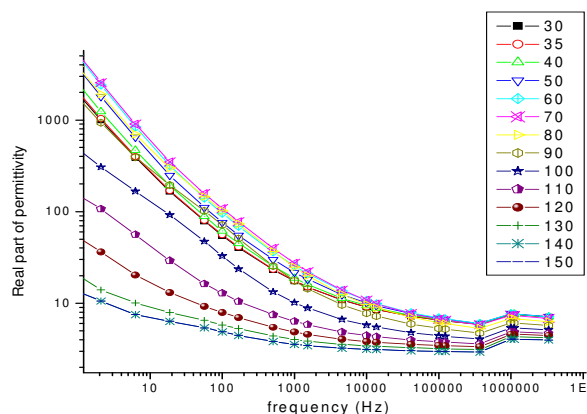
the material in the form of heat. This dielectric loss phenomenon is represented by the imaginary part of the dielectric constant<sup>11</sup>.

Dielectric constant ( $\epsilon'$ ) and dielectric loss ( $\epsilon''$ ) were measured in the frequency range, 1Hz to 10MHz and temperature range 30 to 150°C in both two Biological tissues samples (figure 1 to 12 and table 1)

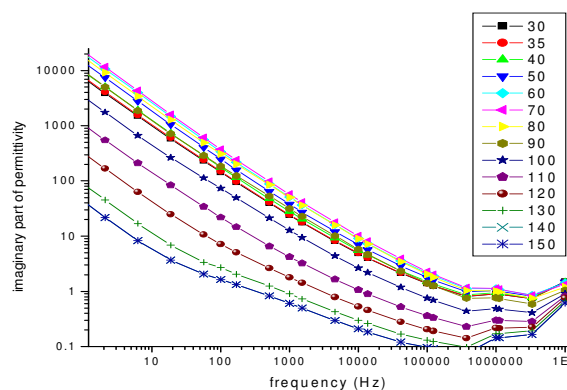
The dielectric constant curves of scales tissues sample (biological tissues) versus frequency at different temperature are presented in figure 3. It can be observed that for these biomaterials, the dielectric constant  $\epsilon'$  is a slight function of frequency with a slight decrease as frequency increases; the total variation of dielectric constant against frequency at different temperature is small as clear from the figure. The figure 1 Shows the variation of dielectric constant as a function of frequency at different temperatures for biomaterials. Dielectric constant is independent of temperature for biomaterials whereas for strong polar biomaterials dielectric constant increases with increasing temperature. However since the specific volume of the biomaterials is temperature-dependent, i.e. it increases as the temperature increases, so that in the case of weakly polar polymers the dielectric constant decreases with increase of temperature<sup>12</sup>, it can be seen from the figure 3 for biomaterials (catla catla) scales tissues sample. The increase of  $\epsilon'$  at 90°C for scale tissues sample relative to its value at 30°C is indicative of the fact the glass transition temperature of scale tissues sample is about (70°C-80°C). The decrease of scale tissues may due to the effect of plasticizers. The plasticizers modifies the rheological properties of high polymeric materials by lowering the melt viscosity, or the elastic modulus of the plastic, thus plasticizers reduce and increase the free volume, and the polymer chain moves more readily at a given temperature<sup>13</sup>.

**Dielectric constant as a function of frequency:** The figure 3 Shows the variation of dielectric constant as a function of frequency at different temperatures for biological tissues. Figure-4 Illustrate the variation of dielectric loss  $\epsilon''$  with frequency at different temperatures for Biological tissues. In scales tissues sample, polarization effects due to the dipole reorientations are minimal, as it is clear from the figures. This is due to a lack of structural components in the repeat unit that can couple to the electric field at radio frequencies<sup>14</sup>.

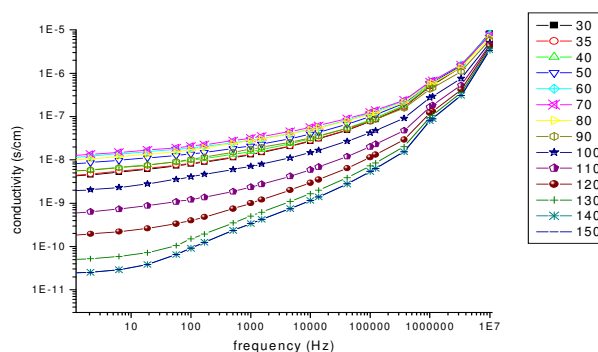
**Dielectric constant as a function of temperature:** Figure (8 to 12 and table 1) shows the variation of dielectric constant  $\epsilon'$  dielectric loss, conductivity, loss tangent and capacitance with temperature at different frequencies for scales tissues sample. From the figure it's clear that the dielectric constant  $\epsilon'$  is higher at low frequencies compared to its value at 1Hz and 1 KHz. The decrease in dielectric constant  $\epsilon'$  with temperature is due to the temperature-dependent of scales tissues sample, i.e. it increases with temperature, and hence the dielectric constant decreases with frequency<sup>15</sup>.



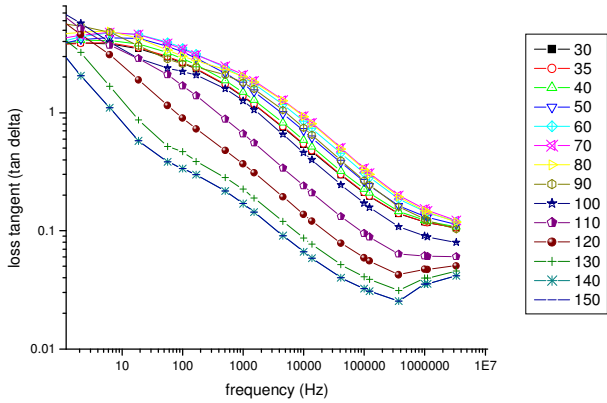
**Figure -3**  
 Real part of permittivity as function of frequency at various temperatures



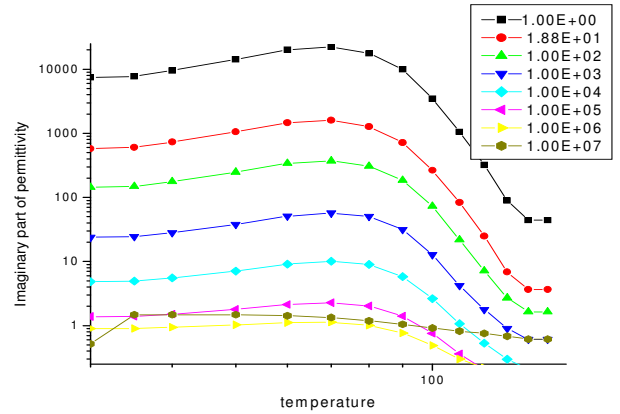
**Figure -4**  
 Imaginary part of permittivity as function of frequency at various temperatures



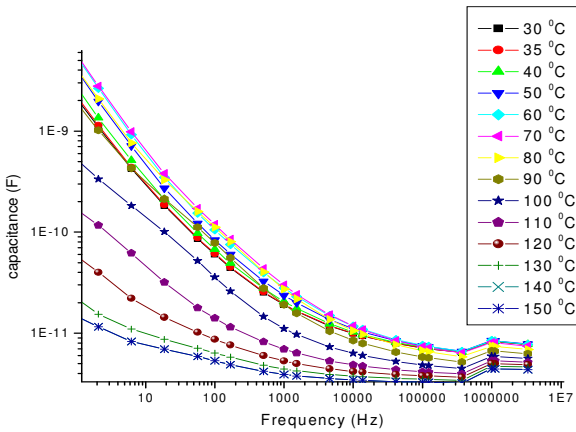
**Figure -5**  
 Conductivity as function of frequency at various temperatures



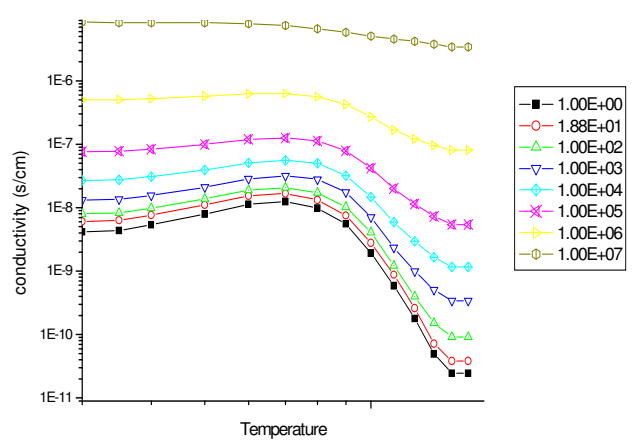
**Figure -6**  
 Loss tangent (tandelta) as function of frequency at various temperatures



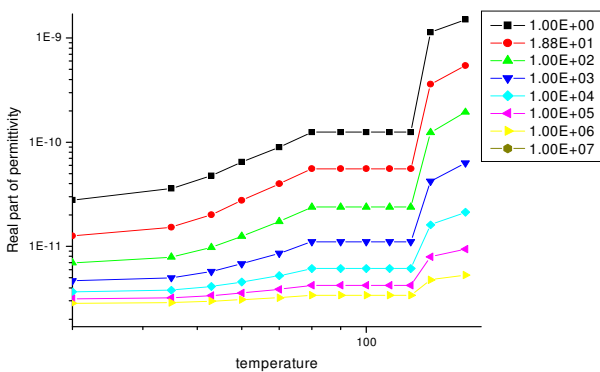
**Figure -9**  
 Imaginary part of permittivity as function of temperature at various frequencies



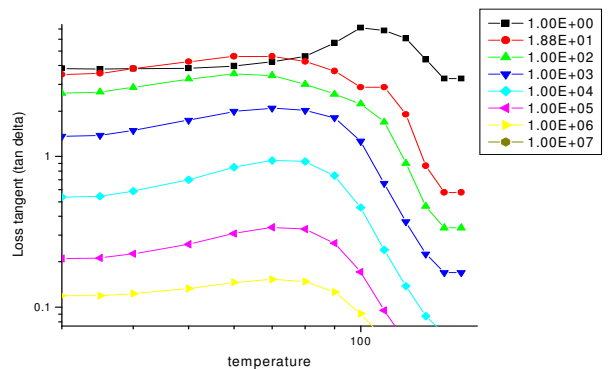
**Figure -7**  
 Capacitance as function of frequency at various temperatures



**Figure -10**  
 Conductivity as function of temperature at various frequencies



**Figure -8**  
 Real part of permittivity as function of temperature at various frequencies



**Figure -11**  
 Loss tangent tan(delta) as function of temperature at various frequencies

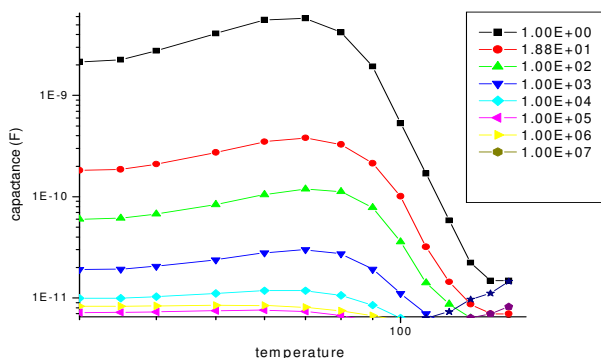


Figure -12

Capacitance as function of temperature at various frequencies

From scales tissues sample it's clear that the dielectric constant  $\epsilon'$  is increasing with temperature, beyond 100 °C, which is the indication of the of the sample, we approach to rubbery state; some segments of a long chain molecule may have freedom of movement while the molecule itself is not free to move. In this case the space between molecules or free volume increase to

allow molecular chain motion<sup>16</sup>. This increase of molecular chain motion by increasing temperature, increase the polarization because they respond to the applied electric field and hence the dielectric constant  $\epsilon'$  is also increased. The dielectric constant ( $\epsilon'$ ) of Scale tissues sample decrease at higher temperatures, this may due to thermal agitation which will not allow the dipoles (by dipoles we mean some fillers and additives which contain in the sample) to orient, as clear in figure (8 to 12 )for Scale tissues sample<sup>17</sup>.

The dielectric constant and the loss tangent of the dried scale are plotted as functions of frequency at 300 K in figure 1. Both quantities with increase in frequency. The dielectric constants at 1 Hz and 10 MHz are quite high, 19.6 and 7.07 respectively; the dielectric constant at 1 MHz is 6.5. the loss of water, which is a major consistent of the scale (30-40) each, water plays a role in the polar structures of the scale the dielectric properties of the scale could have its origin in collagen, which is known to be polar<sup>10</sup>. Hair, Biological tissues and such materials containing oriented collagen ~moleculsa .re known to be piezoelectric a well as pyroelectric<sup>18,19</sup>.

Table-1

Dielectric parameters of scales tissues (catla catla cyrinidae) different frequencies (1 Hz to 10 MHz) at various temperatures

S.N.	Temperature (°C)	Dielectric constant( $\epsilon'$ )	Dielectric loss ( $\epsilon''$ )	Conductivity ( $\sigma$ )	Loss tangent ( $\delta$ )	Capacitance (F)
1	30	196 to 7.07	748 to 1.52	3.83 to -5.96	$4.16 \times 10^{-09}$ to $8.43 \times 10^{-06}$	$2.14 \times 10^{-09}$ to $2.78 \times 10^{-12}$
2	35	205 to 7.07	778 to 1.48	3.79 to -5.77	$4.33 \times 10^{-09}$ to $8.25 \times 10^{-06}$	$2.25 \times 10^{-09}$ to $2.82 \times 10^{-12}$
3	40	252 to 7.11	962 to 1.48	3.81 to -5.72	$5.35 \times 10^{-09}$ to $8.23 \times 10^{-06}$	$2.76 \times 10^{-09}$ to $2.83 \times 10^{-12}$
4	50	372 to 7.17	1430 to 1.48	3.84 to -5.67	$7.95 \times 10^{-09}$ to $8.21 \times 10^{-06}$	$4.08 \times 10^{-09}$ to $2.85 \times 10^{-12}$
5	60	508 to 7.11	2020 to 1.34	3.98 to -5.51	$1.13 \times 10^{-08}$ to $7.98 \times 10^{-06}$	$5.56 \times 10^{-09}$ to $2.85 \times 10^{-12}$
6	70	5.28 to 6.82	2240 to 1.34	4.24 to -5.26	$1.25 \times 10^{-08}$ to $7.44 \times 10^{-06}$	$5.78 \times 10^{-09}$ to $2.79 \times 10^{-12}$
7	80	383 to 6.34	1770 to 1.19	4.26 to -4.87	$9.85 \times 10^{-09}$ to $6.61 \times 10^{-06}$	$4.20 \times 10^{-09}$ to $2.67 \times 10^{-12}$
8	90	176 to 5.73	999 to 1.05	5.66 to -4.53	$5.56 \times 10^{-09}$ to $5.2 \times 10^{-06}$	$1.93 \times 10^{-09}$ to $2.53 \times 10^{-12}$
9	100	485 to 4.74	347 to 1.18	7.14 to -4.22	$1.93 \times 10^{-09}$ to $5.09 \times 10^{-06}$	$5.31 \times 10^{-10}$ to $2.38 \times 10^{-12}$
10	110	154 to 4.72	106 to 1.07	6.48 to -3.97	$5.87 \times 10^{-10}$ to $4.56 \times 10^{-06}$	$1.69 \times 10^{-10}$ to $2.26 \times 10^{-12}$
11	120	53.2 to 4.77	323 to 1.43	6.06 to -3.78	$1.79 \times 10^{-10}$ to $4.19 \times 10^{-06}$	$5.83 \times 10^{-11}$ to $2.18 \times 10^{-12}$
12	130	20.3 to 4.22	893 to 1.25	4.39 to -3.54	$4.97 \times 10^{-11}$ to $3.79 \times 10^{-06}$	$2.23 \times 10^{-11}$ to $2.11 \times 10^{-12}$
13	140	13.5 to 3.98	44.2 to 1.35	3.28 to -3.32	$2.46 \times 10^{-11}$ to $3.42 \times 10^{-06}$	$1.48 \times 10^{-11}$ to $2.03 \times 10^{-12}$
14	150	13.5 to 3.98	44.2 to 1.35	3.28 to -3.32	$2.46 \times 10^{-11}$ to $3.42 \times 10^{-06}$	$1.48 \times 10^{-11}$ to $2.03 \times 10^{-12}$

## Conclusion

The high dielectric constants of these scales at low frequencies (around 1 kHz) suggest that they could, in principle, be used for capacitor applications. Although the fish scale itself is not thermally stable, the hydroxyapatite left after removal of organic matter could be useful as a linear-capacitor material. The experimental results indicate that the decrease in dielectric constant with frequency as well as temperature for biological tissue (scale tissues) samples is ascribed to the weak polar nature of these polymers. The Biological tissue (scale tissues) sample, are low dielectric constant materials. The increase of  $\epsilon'$  for scales tissues sample above 100°C is appropriate to glass transition temperature. The dielectric loss of scale tissues sample, was found to decrease with increasing frequency and some loss peaks are observed owing to the presence of additives and other impurities. The loss peak of Scales tissues sample above 100°C is due to  $\alpha$ -relaxation. It was observed that the dielectric loss of Scale tissues sample increase slightly with increasing temperature. From the dielectric loss measurements it can be concluded that the biological tissue (scale tissues) sample are low loss materials.

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