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UNIVERSITI TEKNOLOGI PETRONAS

"DIELECTRIC PROPERTIES OF PROPERLY SLAUGHTERED AND NON PROPERLY SLAUGHTERED CHICKEN"

by

ALMUR ABDELKREEM SAEED RABIH

The undersigned certify that they have read, and recommend to The Postgraduate Studies Programme for acceptance this thesis for the fulfillment of the requirements for the degree of Master of Science in Electrical and Electronics Engineering.

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UNIVERSITI TEKNOLOGI PETRONAS

DIELECTRIC PROPERTIES OF PROPERLY SLAUGHTERED AND NON PROPERLY SLAUGHTERED CHICKEN

by

ALMUR ABDELKREEM SAEED RABIH

A Thesis

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BANDAR SRI ISKANDAR

PERAK

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DECLARATION OF THESIS

Title of thesis	DIELECTRIC PROPERTIES OF PROPERLY SLAUGHTERED AND NON PROPERLY SLAUGHTERED CHICKEN

I ALMUR ABDELKREEM SAEED RABIH

hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTP or other institutions.

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I would like to devote my thesis to my mother's soul and to my beloved father, to my sincere uncle (Uncle Adam). To my beloved wife Ameena and all my teachers who taught me the meaning of success.

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ABSTRACT

Meat is considered as a healthy source of food. To get the nutritional values of meat, some precautions and considerations have to be taken into account. One of the most effective and powerful parameters that can influence and affect the quality of meat is the amount of residual blood in the meat after slaughtering the animal. Blood is a good medium for microorganisms to grow and multiply. Proper slaughtering of animals is considered as a key factor to reduce the blood volume in the meat. It is believed that only one-third of the total body blood remains as the residual blood inside an animal flesh when that animal is slaughtered in a proper way. Currently, there is lack of a suitable device to differentiate properly slaughtered meat from non properly slaughtered meat. The aim of this research work is to design a capacitive device to differentiate properly slaughtered chicken from non properly slaughtered chicken. Dielectric properties (relative permittivity and dissipation factor) of properly slaughtered chicken and non properly slaughtered chicken were measured using the designed parallel plate capacitor and LCR meter in the frequency range 100 Hz to 2 kHz. The measurements were conducted at 3 hours, 24 hours, 48 hours and up to 15 days after slaughtering. There was a clear difference between properly slaughtered chicken and non properly slaughtered chicken with regard to dielectric properties and colour. The performance of the designed parallel plate capacitor was verified by measuring the dielectric constants of perfect dielectrics such as A4 paper and FR4 substrate. Very low percentage error (0.47%) was achieved, which makes this technique reliable to be used to measure the dielectric properties of meat. Experimental results were validated through theoretical calculation using Maxwell Garnett Mixing Rule.

ABSTRAK

Daging dianggap sebagai sumber makanan yang sihat. Untuk mendapatkan nilai-nilai nutrisi daging beberapa langkah berjaga-jaga dan pertimbangan perlu diambil kira. Salah satu parameter yang paling berkesan dan berkuasa yang boleh mempengaruhi dan menjejaskan kualiti daging tersebut adalah jumlah baki darah dalam daging selepas penyembelihan haiwan. Darah adalah media yang baik untuk mikroorganisma untuk berkembang dan membiak. Penyembelihan haiwan yang sempurna dianggap sebagai faktor utama untuk mengurangkan jumlah darah dalam daging. Adalah dipercayai bahawa hanya satu pertiga daripada jumlah darah badan kekal sebagai baki darah di dalam daging haiwan yang apabila haiwan yang disembelih dengan cara yang sepatutnya. Pada masa ini, terdapat kekurangan alat yang sesuai untuk membezakan daging yang disembelih dengan sempurna dari daging yang tidak disembelih dengan sempurna. Tujuan kerja-kerja penyelidikan ini adalah untuk mereka bentuk peranti kapasitif untuk membezakan ayam yang disembelih dengan sempurna daripada ayam yang tidak disembelih dengan sempurna. Ciri-ciri dielektrik (ketelusan relatif dan faktor pelesapan) ayam yang disembelih dengan sempurna dan ayam yang tidak disembelih dengan sempurna diukur menggunakan kapasitor plat selari yang direka dan meter LCR dalam julat frekuensi 100 Hz hingga 2 kHz. Ukuran telah dijalankan 3 jam, 24 jam, 48 jam sehingga 15 hari selepas penyembelihan. Terdapat perbezaan yang jelas antara ayam yang disembelih dengan sempurna dan ayam bukan disembelih dengan sempurna berpandukan ciri-ciri dielectik dan kandungan warna. Prestasi kapasitor plat selari yang direka telah disahkan dengan mengukur pemalar dielektrik dielektrik sempurna seperti kertas A4 dan FR4 substrat. Peratusan ralat yang sangat rendah (0.47%) telah dicapai, yang menjadikan teknik ini boleh dipercayai untuk digunakan untuk mengukur sifat-sifat dielektrik daging. Keputusan uji kaji telah disahkan melalui pengiraan teori yang menggunakan Peraturan Mencampurkan Maxwell Garnett.

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LIST OF ABBREVIATIONS

MUT	Material Under Test
DC	Direct current
AC	Alternating current
LCR	Inductance, Capacitance, Resistance meter
slgt	Properly slaughtered chicken
non slgt	Non properly slaughtered chicken
PSE	Pale Soft Exudative
DFD	Dark Firm Dry
RFN	Red Firm Not exudative
STDEV	Standard Deviation

NOMENCLATURE

ε_r^*	Complex relative permittivity
μ^*	Complex permeability
$\mu^/$	Relative permeability
$\varepsilon^/$	Relative permittivity
$\varepsilon^{//}$	Relative dielectric loss factor
j	$\sqrt{-1}$
B	Magnetic Induction
E	Electric field
D	Dielectric displacement current
ε_0	Permittivity of free space
μ_0	Permeability of free space
c	Velocity of light in the free space
ρe	Density of charges
H	Magnetic field

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter covers the background of material characterization and the importance of characterization. Techniques used to characterize the materials and a brief knowledge on parallel plate capacitor characterization are also provided in this chapter. The aim of the research work and the reason for choosing the capacitor method are justified and finally the organization of the thesis is mentioned.

1.2 Background

For a long time the characterization of dielectric materials has been an interesting issue for researchers. Dielectric properties such as permittivity, permeability and conductivity of the Material Under Test (MUT) determine the utilization of the MUT in its applications [1]. Biological tissues display very remarkable dielectric properties; these properties are extremely high at low frequencies, while they decrease as the frequency increases. Due to their frequency dependence, the dielectric properties have become important in electrophysiology and biophysics, they permit distinguishing a number of completely different underlying mechanisms [2]. Dielectric properties of materials vary not only with the frequency of the applied field; they also vary with moisture content, density, composition and structure, water activity and temperature [3]. Biological tissues consist mainly of water; as a result, they behave neither like a conductor nor as a dielectric. However, they behave as a dielectric with loss; the more the wetness in the tissues, the heavier is the loss while the dried ones have low loss. Among blood, muscle and fat, blood has the highest water content, fat has the least and muscle has water content between that of blood and fat. On the other hand, the electrical permeability of biological tissues is that of free space [4]. According to Sewall [1], the electrical properties of materials have become significant for the following reasons:

- The concentration of the field within a material subjected to an electric field is highly related to the complex permittivity of that material.
- The wave propagation through material substrates is considered as the most influential parameter to the performance of high speed circuits.
- Better manufacturing quality control could be achieved by the effective measurement of the used materials.
- Exact measurement of the materials allows engineers and scientists to use them successfully in their intended applications.
- Recently, the advanced industrial processing of foods, rubber, plastic, ceramic and other materials has given an additional knowledge of their electrical properties.

There are several techniques for measuring dielectric properties of materials with different electric sources, ranging from Direct Current (DC) to microwaves. The choice of the measurement technique is influenced by many things, such as the kind of dielectric material, frequency, accuracy, availability of instrumentation, cost and suitability to on-line application. Some of the most common devices and instruments to measure dielectric properties of materials include [3]:

- Parallel plate capacitor
- Coaxial probe
- Waveguide
- Resonance structure
- Inductance, capacitance , reactance(LCR) meter
- Impedance analyzer
- Scalar and vector network analyzer

This work is centered on using a parallel plate capacitor to measure the electrical properties of properly slaughtered and non properly slaughtered chicken; i.e. measuring the capacitance, dissipation factor at low frequencies (100 Hz - 2 kHz) and then calculating the values of the relative permittivities at these frequencies. Relative permittivity of A4 paper and FR4 substrate will be determined to investigate the performance of the parallel plate capacitor technique. Maxwell Garnett Mixing Rule will be used to validate the experimenatal work with theoretical calculations.

1.3 Parallel plate capacitor

A capacitor is a circuit element used to receive, store and produce charges and create electrical potential energy. Typically, it consists of two parallel plates isolated from each other by an insulator (dielectric material). The two plates are charged by equal and opposite charges, and the capacitor is said to be charged, while when the plates have no charges the capacitor will be uncharged. When the applied voltage is DC, the plates pick up charges and store them. On the other hand, if the applied signal is AC, the plates pick up and give out charges with alternating voltage.

There are many techniques to characterize dielectric materials, amongst which, the parallel plate capacitor is the most commonly used method at low frequencies, typically below 100 MHz [5]. In addition, materials characterization using the parallel plate capacitor is the simplest and has low percentage error to determine the relative permittivity of the MUT [1]. The simplicity of this method is explained in equation 1.1.

$$C = \frac{\varepsilon A}{d} \tag{1.1}$$

where C is the capacitance of the parallel plate capacitor in farad, ε is the absolute permittivity of the MUT in farad per meter, A is the surface area of the plates in square meter, and d is the distance between the plates in meter.

$$\varepsilon = \varepsilon_0 \varepsilon_r \tag{1.2}$$

where ε_0, 8.85×10^{-12} (F/m) is the permittivity of free space and ε_r is the relative dielectric permittivity of the MUT to the free space.

Figure 1.1 shows the summay for some dielectric measurement techniques and their frequency range. Coaxial proble is used to measure the relative permittivity of high loss materials like liquids and semi-solids. Transmission line is used for both relative permittivity and relative permeability measurements of high loss materials and low loss materials. Free space is suitable for non contacting measurements to determine relative permittivity and permeability of large size and flat samples. Resonant cavity is best for low loss materials and small size samples for relative permittivity and permeability measurements. Parallel plate capacitor technique is an accurate method to determine relative permittivity of thin and flat sheets at low frequencies.

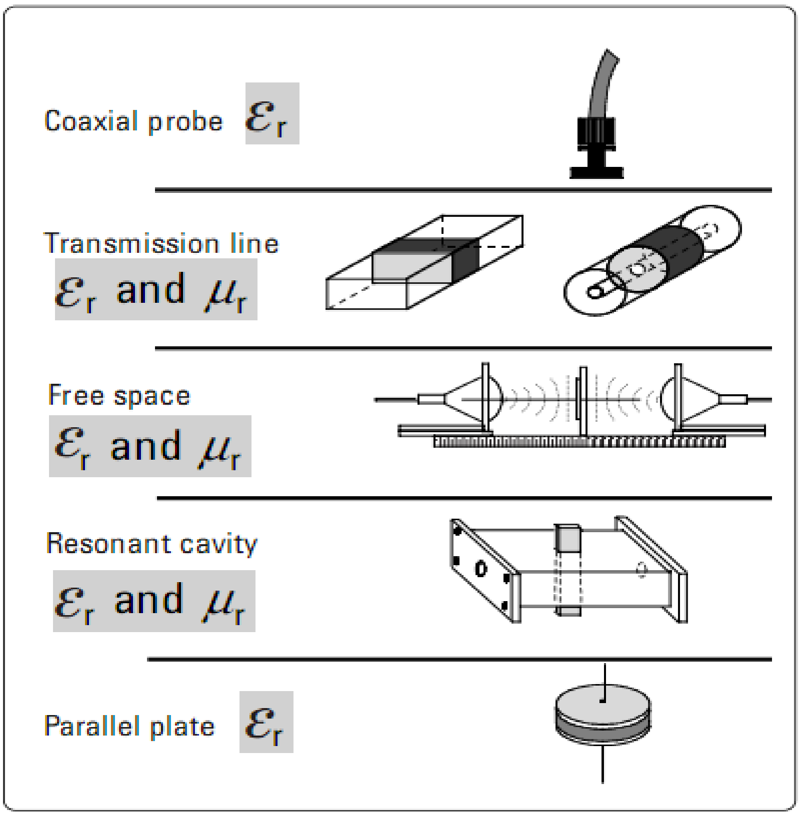


Figure 1.1: Summary of dielectric measurement techniques [6]

1.4 Problem statement

The essential requirement for meat quality is the removal of blood from the animal flesh, as much as possible. To decrease the blood volume in meat, animals should be slaughtered properly by cutting the throat, esophagus, carotid arteries and jugular vein while the animal is alive, which allows blood to gush out easily and thoroughly. Today, there is no specific device available to differentiate properly slaughtered meat from non properly slaughtered meat.

1.5 Objectives of the research

The main objective of this research is to construct a capacitive device which is able to distinguish between properly slaughtered chicken and non properly slaughtered chicken. The specific objectives of this research are:

- To determine the dielectric properties of properly slaughtered chicken and non properly slaughtered chicken using parallel plate capacitor.
- To study the effect of frequency on the relative permittivity and the dissipation factor of the chicken meat.
- To examine the influence of postmortem-time on the relative permittivity and the dissipation factor of the chicken meat.

1.6 Scope of the work

This work is devoted to the study of electrical properties of white female broiler chickens. The meat samples were mainly taken from the breast part of the chickens only due to its low fat content.

1.7 Thesis outline

The first chapter is an introductory chapter. It includes the background of characterization of materials and capacitor, problem statement and objectives of this research and the rest of the thesis is organized as below:

Chapter 2 covers a comprehensive literature review, including dielectric properties of biological tissues, blood volume in meat, methods for animal slaughter, the previous work done in meat dielectric properties and the importance of studying dielectric properties of biological tissues.

Chapter 3 covers the measurement technique used in this research. The design and all components, instruments and materials used, the operation and the analysis of this method and how it is organized to obtain results are presented.

Chapter 4 includes the results obtained, analysis of these results; change of meat dielectric properties with applied frequency and postmortem-time, discussing these results and making a validation.

The last chapter concludes this work by highlighting the important findings and contributions of this project, and recommendations for the future studies to improve and develop the present technique.

1.8 Summary

Measurements of electrical properties of materials have become significant for researchers and engineers to characterize and use them in their intended applications. Characterization of biological tissues such as meat may be crucial to determine the quality of the meat. Many techniques exist for material characterization, and parallel plate capaciter technique is considered as one of the best method used to measure the relative permittivity of materials at low frequencies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an additional explanations for the dielectric properties of biological materials such as meat, and the interaction of these materials with the electromagnetic waves. To determine the degree of interaction between electromagnetic waves which is affected by residual blood in the meat, blood volume in the meat is discussed in this chapter. Slaughtering methods can contribute in determining the residual blood in meat. Therefore, the existing methods of slaughtering are discussed with their advantages and disadvantages. Finally related works and the proposed method to measure the dielectric properties of chicken are discussed.

2.2 Dielectric properties of materials

A material has electrical characteristics that depend on its dielectric properties; accurate measurement of these properties can provide engineers and scientist with valuable information about the material under test to use it in applications [6]. Dielectric properties of materials describe the behavior of a material when exposed to an electric field; i.e. the interaction of the material with electromagnetic waves. These properties encompass dielectric permittivity, dielectric permeability, resistivity and conductivity [7]. Some materials, such as the natural biological materials do not interact with a magnetic field [7], [8]. Thus, their dielectric permeability is the same as the dielectric permeability of free space. This research is focussed only on the relative dielectric permittivity.

2.2.1 Relative dielectric permittivity

Relative dielectric permittivity is the dielectric property used to explain interactions of materials with electric fields. It determines the interaction of electromagnetic waves with the matter and defines the charge density in an electric field. Relative dielectric permittivity is normally written in a complex number. The real part is the dielectric constant, and the imaginary part is the dielectric loss factor.

2.2.1.1 Dielectric constant (relative permittivity), $\varepsilon^{'}$

Dielectric constant is related to the capacitance of a substance and its ability to store electrical energy when an external electric field is applied [6]. Dielectric constant is also named as relative permittivity or dielectric factor. It is useful to know that the value of this parameter is not constant; although it carries the name dielectric constant and it varies from material to material. Relative permittivity, like other parameters, changes with temperature, humidity, moisture, composition, frequency of the applied field, etc.

2.2.1.2 Dielectric loss factor, $\varepsilon^{''}$

The relative dielectric loss factor is a measure of the amount of energy that a material dissipates when subjected to an alternating electrical field. Loss factor is usually defined as the imaginary part of the complex dielectric permittivity of the material under test. The value of the loss factor is always greater than zero but is usually less than the value of the relative permittivity (the real part of the complex permittivity). Equation 2.1 represents the complex relative dielectric permittivity.

$$\varepsilon_r^* = \varepsilon^{'} - j\varepsilon^{''} \tag{2.1}$$

where ε_r^* is the complex relative permittivity of the material under test, j is $\sqrt{-1}$, $\varepsilon^{'}$ is the relative permittivity of the material and $\varepsilon^{''}$ is the relative dielectric loss factor of that material.

2.3 Interactions between electromagnetic field and biological tissues

The behavior of the electromagnetic field propagating through biological tissue is determined by the dielectric properties of the tissue. For instance, the human body exhibits large inhomogenity in both its physical make up, and subsequently its dielectric properties. The body for instance is composed of a number of different tissue layers, each presented by its own permittivity [4], [7].

The interaction of electromagnetic fields with biological materials is described by Maxwell equations as follow:

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad 2.2$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad 2.3$$

$$\nabla . D = \rho e \qquad 2.4$$

$$\nabla . B = 0 \qquad 2.5$$

where E and H are the electric and the magnetic field of the electromagnetic wave, respectively, D is the dielectric displacement current, B is magnetic induction, J is the current density and ρe is the density of charges. The electric and magnetic fields are related to the dielectric displacement current and magnetic induction by equations 2.6 and 2.7, respectively.

$$D = \varepsilon_r^* \varepsilon_0 E \qquad 2.6$$

$$B = \mu_0 \mu^* H \qquad 2.7$$

where $\mu_0 = 4\pi \times 10^{-7}$ (H/m) is the dielectric permeability of the free space and μ^* is the complex dielectic permeability of the material under test. The dielectric permittivity and permeability of the free space are related by the speed of light as in equation 2.8 [8].

$$\varepsilon_0 \mu_0 = \frac{1}{c^2} \qquad 2.8$$

where c is the speed of light in the free space = 3×10^8 (m/s)

Foster and Schwan [9] used a wide range of frequencies to measure the electrical properties of biological tissues.

They found that the interaction of electromagnetic field with biological tissues has three major dispersions, namely: Alpha, Beta and Gamma. Figure 2.1 shows the dielectric dispersion for biological tissues.

- Alpha dispersion (α)

  As shown in Figure 2.1, Alpha dispersion happens at low frequencies and the dielectric properties of tissues exhibit relatively high values. This dispersion is associated with the polarization mechanism and it is mainly caused by the ions movements in tissues. It is worth mentioning that this research study is concentrated on the alpha dispersion only.

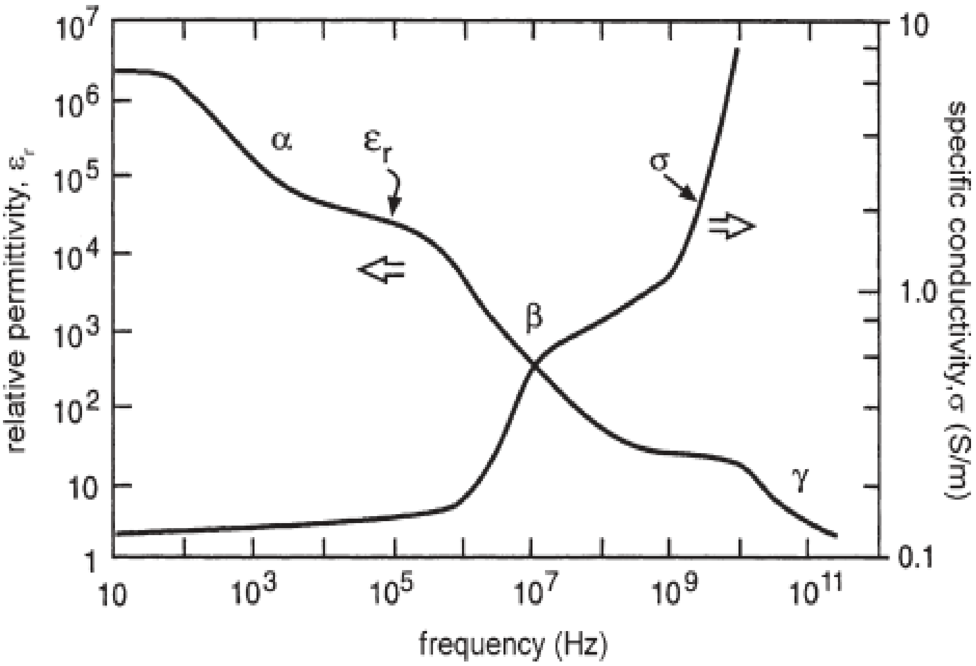


Figure 2.1: Dielectric dispersion for biological tissues [10]

- Beta dispersion (β)

  Beta dispersion covers radio frequencies, first it was investigated and recognized as Maxwell-Wagner relaxation caused by cell membranes. Polarization of cellular membranes is the main factor for beta polarization. Other parameters such as polarization of some proteins contribute to the beta dispersion. It is used to measure the integrity of the cell membrane of the biological tissues.

- Gamma dispersion (γ)

  It takes place at microwave frequencies due to the relaxation of permanent dipole existing in some molecules like water. It happens mainly due to rotational relaxation of water molecules [2].

2.4 Electrical properties of meat

Like all biological tissues, meat has electrical properties when exposed to electromagnetic field. These electrical properties depend on the structure and the composition of the meat [11]. Different structures and compositions of meat lead to various electrical properties of the meat. For instance, blood and brain are very good electric conductors; lungs, skin and bone are poor conductors to some extent; liver, spleen and muscle have medium conductivities [10]. Ions are the most influential factor for the dielectric properties of meat at low frequencies [11]. Further information about dielectric properties of different biological materials can be found in Gabriel et al. [12] and Gabriel et al. [13], [14].

2.5 Blood volume in meat

Blood accounts to about 8% of the body weight of animals, varying with the species and the stage of life [15]. A circulating blood volume in fish ranges from 1.5% - 3% of the body weight, however, most of it is located in the internal organs [16]. Blood volume in cattle and pig is 60 ml/kg and 65 ml/kg, respectively [17]. In chicken as the rest of animals, blood varies with the body weight; large chickens have less blood when compared to the small chickens. Nevertheless, the percentage of blood is about 7.5% of the body weight when the chicken is about 4.5 lb of the body weight [18].

Blood in properly slaughtered animals is only one third of the total body blood of the live animal or less [19]. On the other hand, the meat of stunned animals contains about 50% of the total blood volume [19], [20]. Kiepper [18] stated that only 50% of the total blood can be collected from electrically stunned chickens. Stunning is considered as an improper way of killing animals. The stunning usually kills the animals before bleeding [21]. This method affects the central nerves system of the animal, and interferes with the drainage blood [22].

2.6 Methods of slaughtering

Several methods are available to be used for animal slaughter. The selected method may play an important role in determining the quality of meat. Some of the slaughtering methods are governed by religious doctrine. For instance, Judaism (shechita slaughter), and Islam (halal slaughter) prohibit consuming the meat from animals which are not slaughtered according to the religious code [23]. The common practice in most religious slaughter is that the animals are killed by severing the major blood vessels and the throat. In addition, they are not stunned before they are killed by sticking (cutting main blood vessels) and exsanguinations (bleeding out).

2.6.1 Stunning

Stunning renders the animals unconscious before they are killed by sticking and exsanguinations. Sticking is cutting some major blood vessels in the neck or thorax whereas exsanguination is the bleeding of the animals until death [23]. Stunning has many forms, it uses mechanical, electrical and pneumatic machines.

2.6.1.1 Mechanical stunning

Mechanical stunning uses a mechanical instrument such as captive bolt pistol, percussion stunner or free bullet in order to traumatize the brain of the animal so that it losses consciousness immediately. In case of captive bolt pistol, the bolt is driven into the animal brain either by the blasting of a detonating cartridge or by compressed air [23]. Figure 2.2 shows the captive bolt pistol used to stun animals.

Captive bolt is generally used to stun cattle [24], however, this method is also used for rabbits and all farmed animals [25]. It has been stated by Lawrie [24] that the sheep killed by captive bolt pistol has microbial impacts due to the epithelial lining of the intestines.

A recent research carried out at Texas A&M University by Canada's Food Inspection Agency declared that mad cow disease can transfer to the humans from sick cows slaughtered by captive bolt stunning [25].

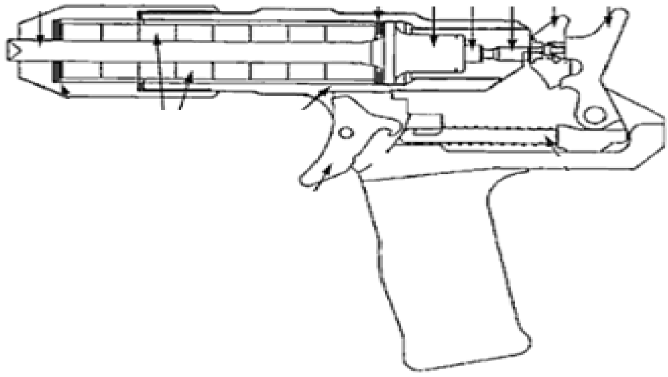


Figure 2.2: Schematic diagram of one type of captive bolt pistol [23]

Additionally, Davis and Cole [26] stated that mechanical stunning of broilers causes poor bleeding which means large amount of blood will remain in the broilers chicken fillet. Figure 2.3 shows how the captive bolt pistol is applied to the animal's brain.

Figure 2.3: Captive bolt pistol is being used to stun a cow [25]

2.6.1.2 Electrical stunning

Electrical stunning is used to induce an epileptic state in the brain of the animal under slaughtering process by positioning electrodes in particular places to permit sufficient current to pass to the animal's brain to cause unconsciousness [27].

This type of slaughtering is most commonly used for calves, sheeps and lambs [28]. Electrical stunning may take one of three methods, such as head stunning (reversible), cardiac arrest stunning (irreversible) and water bath stunning.

In head stunning (reversible) method, the electrodes are positioned in such a way to permit current to span the brain and pass through it, reversible stunning will not kill the animal directly, killing is brought about by sticking as a result of reducing the amount of blood flowing to the brain [28]. This method is used to stun animals such as cattles, sheeps, goats and ostriches by applying a pair of electric tongs on both sides of the animal's head [25] as shown in Figure 2.4.

Cardiac arrest stunning (irreversible) method kills animals immediately after stunning due to the flow of current to the heart as well as the brain and forcing the heart to stop [28]. It is worth mentioning that the position of the electrodes in this method differs from the position for the head only stunning. Cardiac arrest can also be used to stun cattle, sheep, goats, pigs and rabbits [25]. Figure 2.5 shows a lamb being stunned by cardiac arrest stunning.

Figure 2.4: Head stunning for sheep [25]

Electrical water bath stunning method is generally used for poultry, and it is performed by shackling the poultries upside down and immersing their head in water by maintaining a potential difference at a particular current and frequency. This type of stunning is commonly used for chickens, turkeys, geese and ducks [25], [29]. Figure 2.6 shows the electrical water bath stunning for chicken.

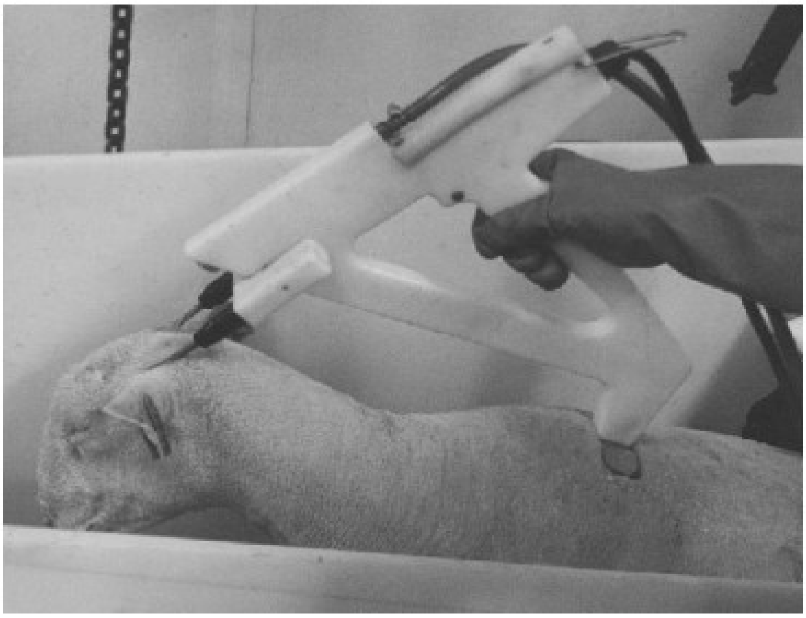


Figure 2.5: Cardiac arrest stunning for sheep [27]

Figure 2.6: Electrical water bath for chicken [25]

There are some contraversies with the electrical stunning among the authors; Chrysrall et al. [30] could not find any differences in terms of blood loss in lamb stunned in several ways, however, Kirton et al. [31] state that head to back stunning arrests the heart resulting in more residual blood in the carcass of the animal . To achieve better stunning, voltage, current and frequency need to be adjusted However, different values in electrical resistance due to different thickness of the skulls can cause ineffective stunning [29]. A report released by Australian Meat Processor Corporation (AMPC) and Meat & Livestock Australia (MLA) has shown that stunning affects the meat quality; it can break vertebrae, blood speckle in the fat of the stunned animal can also be related to the stunning. Furthermore, electrical stunning equipments are potentially dangerous to the operators if misused [28]. Lopez et al. [32] indicate that blood loss in rabbits slaughtered after stunning is lower compared to the animals slaughtered in Islamic way without stunning, pH value was lower in case of Islamic slaughtering than stunning. It is known that the microorganisms prefer to grow in a medium with high pH levels [24]. Blood loss could be estimated indirectly by measuring the hemoglobin content in the meat. Griffiths et al. [33] state that halal slaughtered shows the lowest hemoglobin in the breast muscle of birds compared to the birds slaughtered by stunning and decapitation. Complete bleeding can be achieved by cutting carotid arteries, jugular veins, trachea and esophagus without prior stunning [34], [35]. Lawrie [24] suggested that the stress of the stunning will cause vasoconstrictive effect which will expel most of the blood from the musculature, so it will affect the bleeding. Electroencephalograph (EEG) voltage, less than 10 μV is related to the insensibility of animals to the pain during slaughtering; however, in sheep and calves subjected to the stunning before bleeding, the voltage takes longer time to fall below 10 μV when this method is compared to cutting throats without prior stunning. This result reveals that in stunning the animals take more time to lose consciousness compared to the slaughtering by cutting the throats. In addition, Grogory and Wilkins [36] state that broken pectoral bones which is usually associated to the hemorrhaging (flowing of blood) in the breast muscle occurs due to the electrical stunning.

2.6.1.3 Pneumatic stunning

Pneumatic or gas stunning is the induction of unconsciousness by subjecting the animal to an anesthetic gas such as carbon dioxide [23]. The disadvantage of using gas stunning is the different susceptibility of the animals to the anesthesia. In addition, animals suffer considerable stress before the anesthesia, so the carbon dioxide anesthesia does not agree with generally accepted definition of stunning prior to slaughter [24].

Moreover, blood may remain in muscles due to the hypoxemia and cause less bleeding [29].

2.6.1.4 Religous slaughter

There are three main religious slaughter; shechita, used by Jews; halal, used by Muslims and jatka, used by Sikhs. The common practice in all the three methods is that animals are not stunned prior to the slaughter, although some adherents of the Islamic faith accept some forms of stunning. In the case of the Muslims and Jews slaughter, the animals are killed by severing the major vessels of the throat, while in jatka, a sword is used in a single stroke to decapitate the animal [23].

Halal slaughter uses a technique called dhabh (*Arabic word meaning slaughtering animals in a perfect way to fit for human consumption*) to kill the animals. It is believed that by performing dhabh, residual blood content in meat becomes less than thirty percent of the total body blood [19]. As such, halal meat is considered as the best for the human consumption. The properly slaughtered chickens used for this research were slaughtered in halal method for that reason. The following conditions must be fulfilled to meet the requirements of the halal meat [21].

- The person who performs dhabh has to be a sane, adult Muslim.
- Very sharp tool must be used to cut the throat, esophagus, jugular veins and carotid arteries without prior stunning.
- Invocation of the name of Allah, the Almighty God before the act of cutting by saying Bismillah (in the name of Allah) or Bismillah Allahu Akbar (in the name of Allah, Allah is Great). If the person neglects the invocation unintentionally, the meat will still be considered halal.

2.7 Previous work

Castro-Giraldez et al. [37] used Agilent 4194A impedance analyzer, Agilent 16451B parallel plate fixture to measure the dielectric properties (dielectric constant and loss factor) for three types of porcine meat; Pale Soft Exudative (PSE), Dark Firm Dry (DFD) and Red Firm Non exudative (RFN) in the frequency range 100 Hz to

0.4 MHz. The measurements were conducted 12 hours up to 7 days after slaughtering. The results showed that the dielectric constant at α-dispersion tends to increase with postmortem time while for β- dispersion the dielectric constant tends to decrease with postmortem time. Furthermore, the results revealed that the normal quality meat which is presented by RFN has shown a dielectric constant value (1×10^7 at 100 Hz) greater than the value (6×10^6at 100 Hz) for the DFD and less than the value (3×10^7 at 100 Hz) for the PSE when the dielectric constant is measured parallel to the meat fiber.

Nelson et al. [38] used HP 85070 open-ended coaxial probe, HP 4291A impedance analyzer to measure dielectric constant and loss factor for fresh chicken breast meat at temperatures from 5 to 65°C over the frequency range 10 - 1800 MHz. The results have shown that the dielectric constants of the pectoral minor muscle are larger compared to the pectoral major muscles. In addition, for the stated temperature range, the dielectric constant has increased with increasing temperature and vice versa.

Bodakian and Hart [39] measured the dielectric conductivity and permittivity for commercially purchased and freshly slaughtered beef and chicken samples. HP 4192A low frequency impedance analyzer, array of stainless steel electrodes were used as the measuring system. The dielectric properties of the freshly slaughtered samples were shown highly anisotropic compared to that of the commercially purchased one. The reduction of the anisotropic property for the commercially purchased samples is probably due to the deterioration of its cell membrane [39].

Another study by Ghatass et al. [40] on beef meat quality using LCR Meter Model 4277A, over the frequency range 10 kHz - 1 MHz indicates that the permittivity of the beef meat decreases rapidly with increasing the frequency, decreases with increasing the storage time, and the dielectric loss factor is proportional to the frequency used.

2.8 Summary

Dielectric properties of biological tissues like meat give different dispersions such as α, β and γ dispersions during interaction with electromagnetic waves. In α dispersion which happens at low frequencies, the dielectric constants of meat are remarkably high. The degree of the interaction between meat and electromagnetic waves is determined by the residual blood in the meat after slaughtering the animal. Several techniques exist to be used for animal slaughter. Selection of the proper method for slaughtering is criticial in order to minimize the residual blood volume in the meat. To characterize meat and determine the quality of different types such as PSE, DFD and RFN, suitable and reliable mesurement technique has to be used. Connecting parallel platinum plates to LCR meter is proposed as an accurate and reliable method.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the method used to measure the electrical properties of meat and the measurement set up. Meat sample was prepared and inserted into a parallel platinum plate capacitor. The parallel plate capacitor is designed to hold the meat sample. LCR meter is connected to the parallel plate capacitor to directly measure the capacitance and the dissipation factor of the meat sample. The measured capacitance is used to calculate the relative permittivity of the chicken meat. This chapter is divided into six sections; proposed method, construction of the parallel plate capacitor, LCR meter, sample preparation and measurements, theoretical calculations and summary.

3.2 Proposed method

Parallel plate capacitor technique is used in this research work. Two parallel platinium plates are used to construct the capacitor as shown in Figure 3.1. The parallel platinum plates capacitor containing the meat sample is connected to LCR meter using LCR clip test leads to apply an AC signal from the LCR meter to the meat sample. The dielectric properties of the meat sample is affected by the blood content in the meat, and these dielectric properties are measured by the connected LCR meter.

3.3 Construction of the parallel plate capacitor

The parallel plate capacitor was designed using platinum, acrylic material, screws, ruler, paste and copper wires.

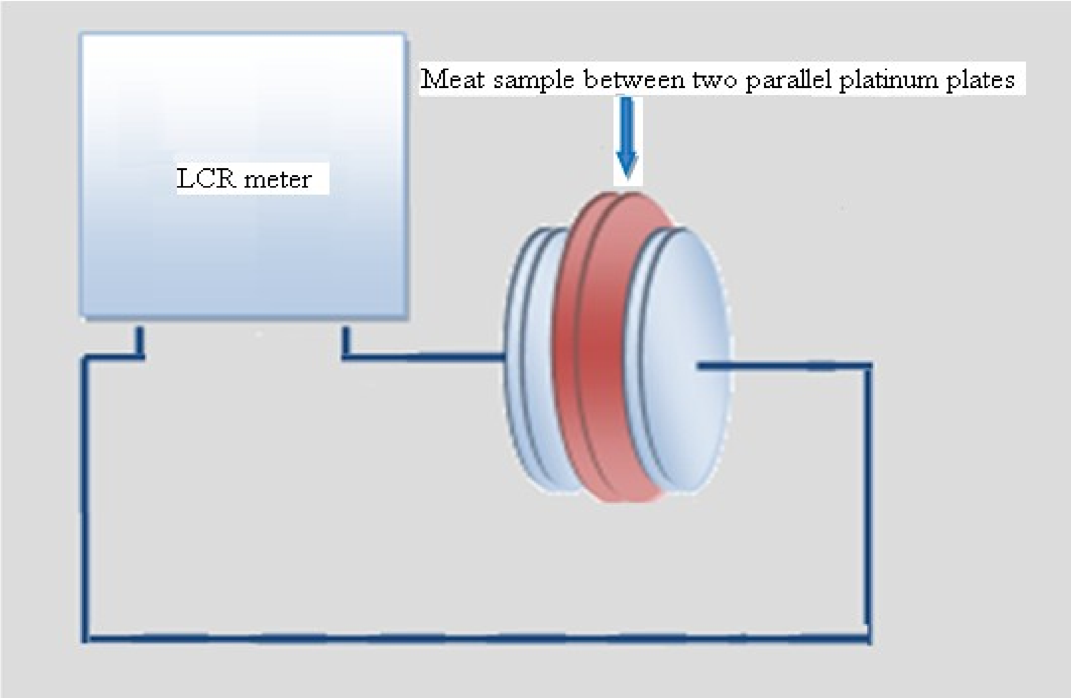


Figure 3.1: Proposed method for dielectric measurement

Platinum was used to form the two parallel plates of the capacitor. The thickness of the platinum used is 0.05 mm and the plates were shaped in a circular disc of diameter 2.5 cm. The platinum plates are used for many reasons which relate to its characteristics: the resistance of platinum to the oxidation and sulfidization results in circuit reliability and stability. Platinum is very resistive to corrosion which makes it suitable to be used as electrodes in laboratory [41], its ductility and malleability make it flexible to be connected to wires [42]. The schematic diagram of the designed parallel plate capacitor is shown in Figure 3.2.

The platinum plates are fixed and encased in two parts of the acrylic material; fixed part and movable part. The bottom electrode is pasted to the fixed part; however the upper electrode is fixed to the movable part of the acrylic part to adjust the distance between the two plates. The movable part of the acrylic material is attached to the tip of a screw to assist the movement of the movable plate. A ruler is fixed parallel to the screw to measure the distance between the two platinum plates. Copper wires were attached to the platinum plates to connect the setup to the measuring system.

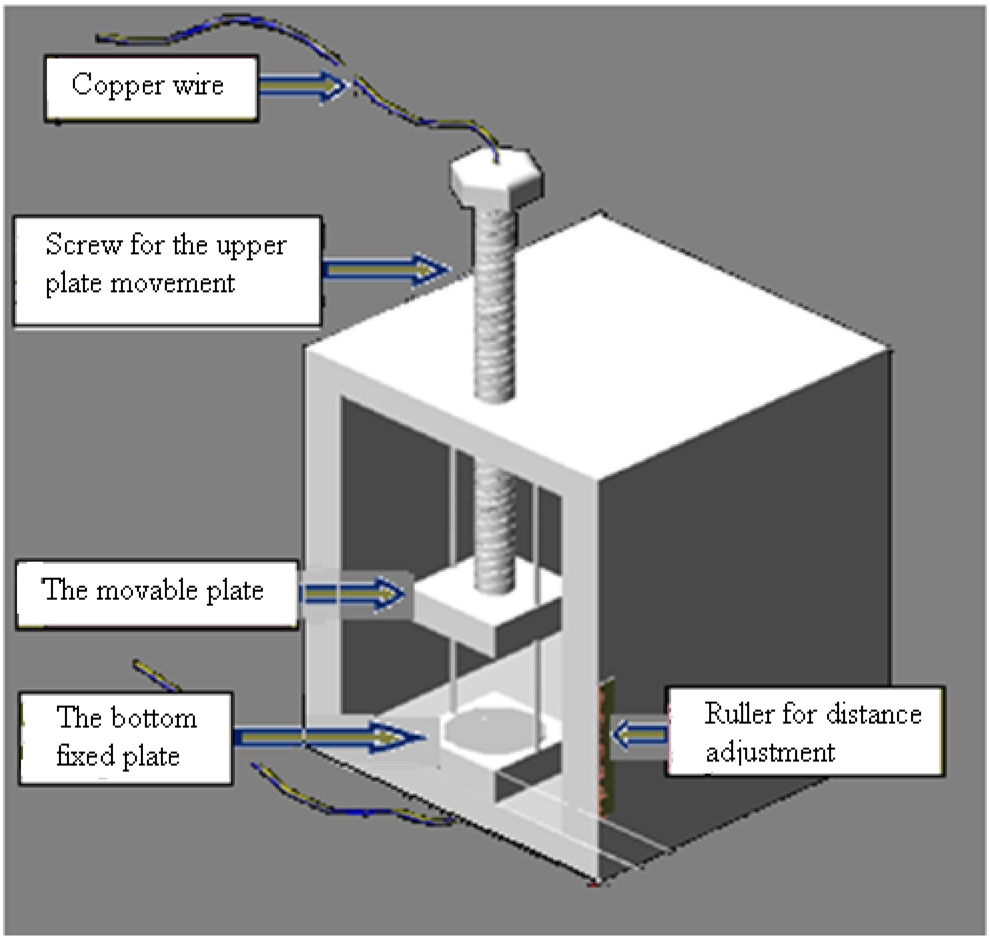


Figure 3.2: Schematic diagram of the parallel plate capacitor

3.4 LCR meter

Figure 3.3 shows GW Instek LCR 816 meter and LCR 06A kelvin clip test leads. The test leads are used to connect the parallel plate capacitor to the LCR meter for dielectric measurements. This meter is applicable for the need of researchers and scientists due to its features and characteristics. The frequency range for this instrument is from 100 Hz up to 2 kHz.

3.4.1 Zeroing of the LCR meter

Prior to each measurement and before the LCR is connected to the cell detector, the LCR meter undergoes zeroing in order to eliminate the measurement errors such as the stray capacitance and the cabling impedance.

Two measurements correction are used for this instrument namely open correction and short correction.

Figure 3.3: LCR meter for dielectric properties measurement

3.4.1.1 Open compensation

Open zeroing is important for the instrument to measure accurately. In this case the test cable or the test fixture is left open without connecting to any part. Steps for the open zeroing are provided in LCR user manual.

3.4.1.2 Short compensation

For the short correction the test cables should be connected or shorted using a clean copper wire as short as possible.

3.5 Preparation of the meat sample and measurement

Undoubtedly the preparation of the measurement sample is the most important and influential factor in determining the properties of meat. Without a proper handling of the sample, the measurements may give inaccurate results. The preparation of the samples starts from the slaughtering of the animals until inserting the meat sample into the cell detector for the measurements. Figure 3.4 shows the flow-chart for sample preparation.

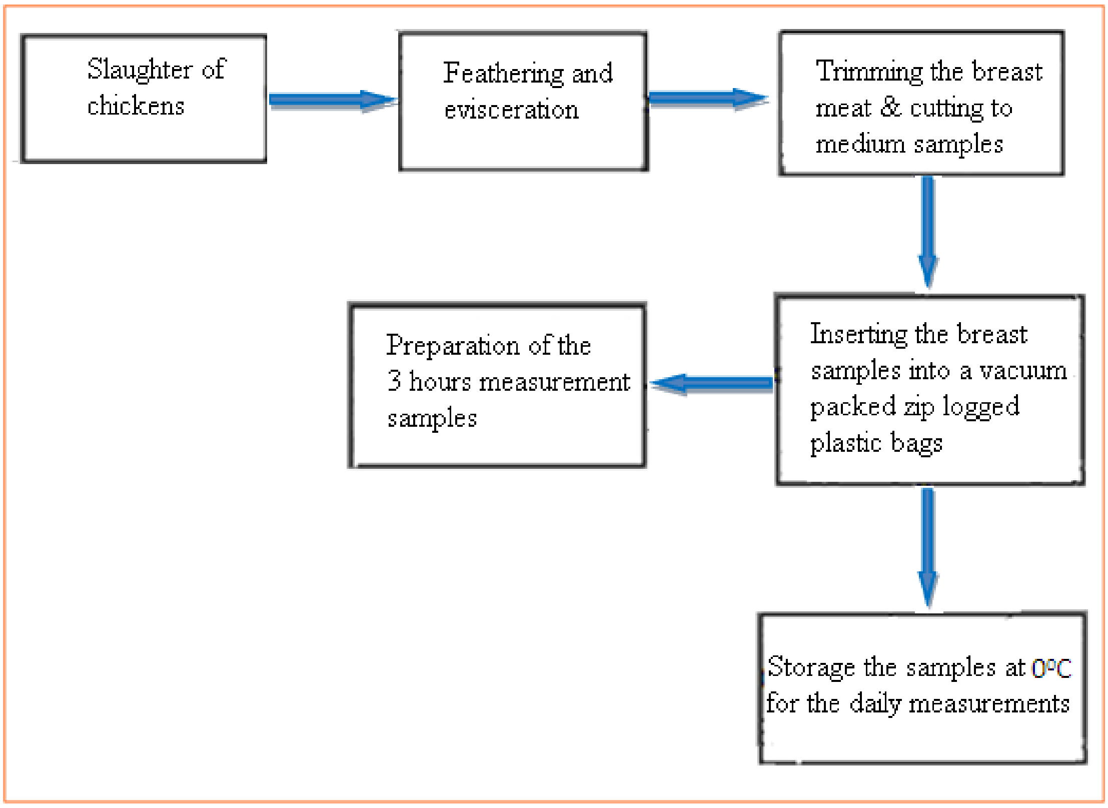


Figure 3.4: Flow-chart for samples preparation

Properly slaughtered chickens (slgt) were killed in proper Islamic way, where the chickens were slaughtered by swiftly severing the throat, carotid arteries and the two jugular veins using very sharp knife [43]. On the other hand, the non properly slaughtered chickens (non slgt) were killed by hastily twisting the neck and breaking the spinal cord.

After the chickens were feathered and eviscerated, only the breast meat were taken, cut to 15 pieces and packed in vacuum plastic bags with seal. Oxygen was carefully extracted and then the bags were sealed hermetically. The sealed bags were stored in a freezer at 0°C during the 15 days of the measurement to avoid the storage of meat at temperatures close to the danger zone (above 4°C); which is the best for pathogenic becteria to grow [44]. On each day, one plastic bag was taken out from the Freezer, put in the laboratory temperature (22°C) for 3 hours in order for the meat sample to defreeze and get measurement temperature stability. After defreezing the meat, samples of 5 mm thickness and 2.5 cm were prepared using a cylindrical jig with a diameter of 2.5 cm, and razor to flatten the surface of the samples. Figure 3.5 shows the sample preparation.

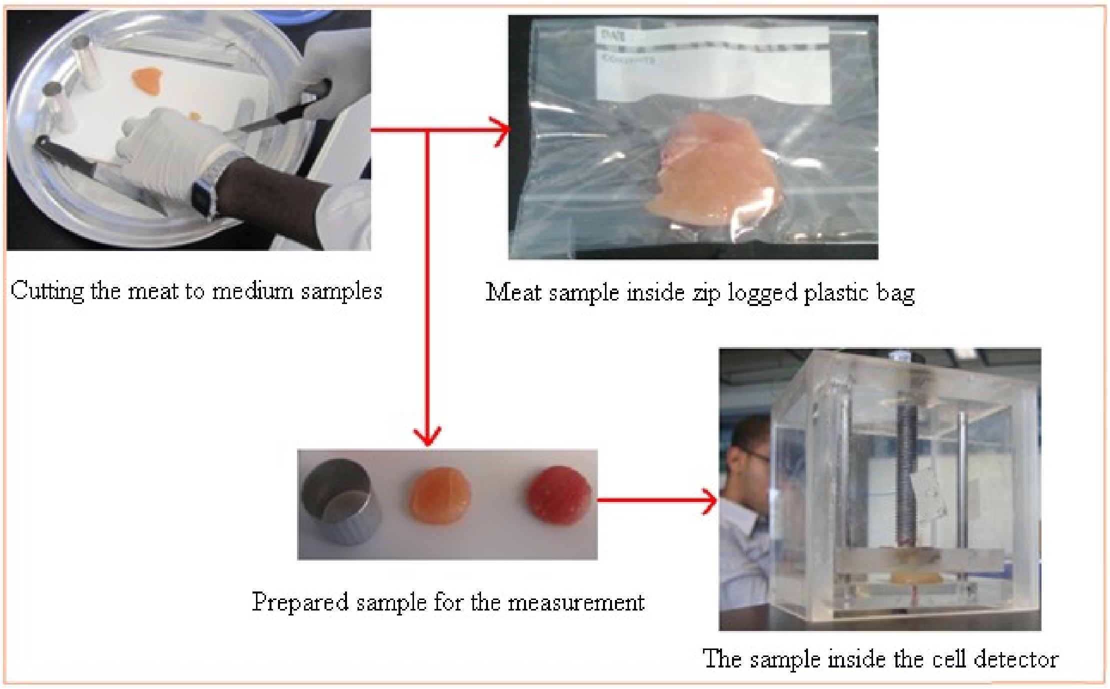


Figure 3.5: Preparation of meat sample

Measurements were conducted in laboratory temperature (22°C) for 15 days to measure capacitance and dissipation factor of properly slaughterd chicken and non properly slaughtered chicken directly by the LCR meter. The measured capacitance was used to calculate the relative permittivity of the chicken's meat. The relative permittivity and the dissipation factor were plotted versus postmortem-time and frequency to see the influence of both frequency and time.

3.6 Theoretical calculations

3.6.1 Permittivity of composite materials and mixing rules

A composite material is defined in material science as a multiphase material formed of a combination of materials that have different chemical compositions and shapes, however remained bonded together and they can retain their properties. It can also be defined as an inhomogeneous material in electromagnetic [45]. Composite materials consist of two or more different components called phases, it is worth mentioning that each ingredient has its own identity or electromagnetic properties. The main phase of the composite material is called background medium, matrix, host or base, the other phases are called guests, particles or inclusions, and they are distributed throughout the main phase [45], [46]. The main advantage of the composite materials is to construct a material that has unique dielectric properties that is different from that owned by the primary constituents [47]. Biological tissues are considered to be composite materials when subjected to electromagnetic waves, for example blood [45]. If blood is considered composite, then meat is also composite since it consists of blood, lipids, proteins, carbohydrate, water molecules, amino acids, minerals and other organic and inorganic materials [23]. Effective permittivity is always attributed to the composite materials, and it can be estimated and calculated by knowing the polarizabilities and dipole moments of the inclusions which make up the composite material [48].

Dielectric mixing rules are algebraic formulas that can be used to calculate the effective permittivity of the composite materials as a function of permittivities and volume fractions of their constituents [46]. There are different mixing rules available to be used to calculate the effective permittivity of the composite materials. For instance, Clausius-Mossoti (Lorenz-Lorenz) Mixing Rule, Rayleigh Mixing Rule, Maxwell Garnet Rules, etc. Some mixing rules are restricted to calculate the effective permittivity of two phase materials and others can be used for multiphase (more than 2 phases) mixtures. Maxwell Garnett Mixing Rule as in equation 3.1 was used to calculate the effective permittivity of the properly slaughtered and non properly slaughtered chicken's breast.

$$\varepsilon_{eff} = \varepsilon_h + 3v\varepsilon_h \frac{\varepsilon_i - \varepsilon_h}{\varepsilon_i + 2\varepsilon_h - v(\varepsilon_i - \varepsilon_h)} \qquad 3.1$$

where ε_{eff} is the effective relative permittivity of the composite material (chicken's breast), ε_h is the relative permittivity of the host (chicken's breast muscle), ε_i is the relative permittivity of the inclusion (chicken's blood) and v is the volume fraction of the blood.

3.6.1.1 Volume fraction of blood in meat sample

Meat was assumed to be a two phase mixture; blood and muscle. Muscle was considered to be a host and the blood was considered as an inclusion. The volume fraction of the blood was calculated based on the percentage of the blood in the life chicken which is 8% of the body weight. Blood was assumed to be equally distributed throughout the chicken's body. As a result, the chicken's breast blood was assumed to be 8%. As stated in Chapter 2, the blood in slgt chicken is only one-third of the total body blood and for the non slgt chicken it is more than 50% of the total body blood. For slgt chicken, blood volume constituted from 1% to 33% of the total body blood and for the non slgt chicken; blood was taken in range of 40% to 100% of the total body blood. Volume fraction of slgt chicken was calculated by multyplying the percentage of total body blood by the percentage of blood in slgt meat, while for the non slgt chicken it was calculated using the percentage of blood in non slgt meat.

3.6.1.2 The extraction of meat

To get the relative permittivity of muscle alone, blood was totally extracted from the chicken's breast using Soxhlet extractor apparatus as shown in Figure 3.6. Extraction in this case is a process of separating blood from the meat sample; or the process of obtaining the pure muscle using chemical solvent. The ethanol in the reservoir is heated up to generate vapor which is cooled and condensed into a liquid by the condenser placed in the top of the apparatus. The condensed vapor drips back onto the meat sample placed in a porous sample cup. When the condensed liquid reaches a certain level, it passes through the porous cup back to the reservoir. The process was repeated continuously until the blood was removed thoroughly from the meat sample.

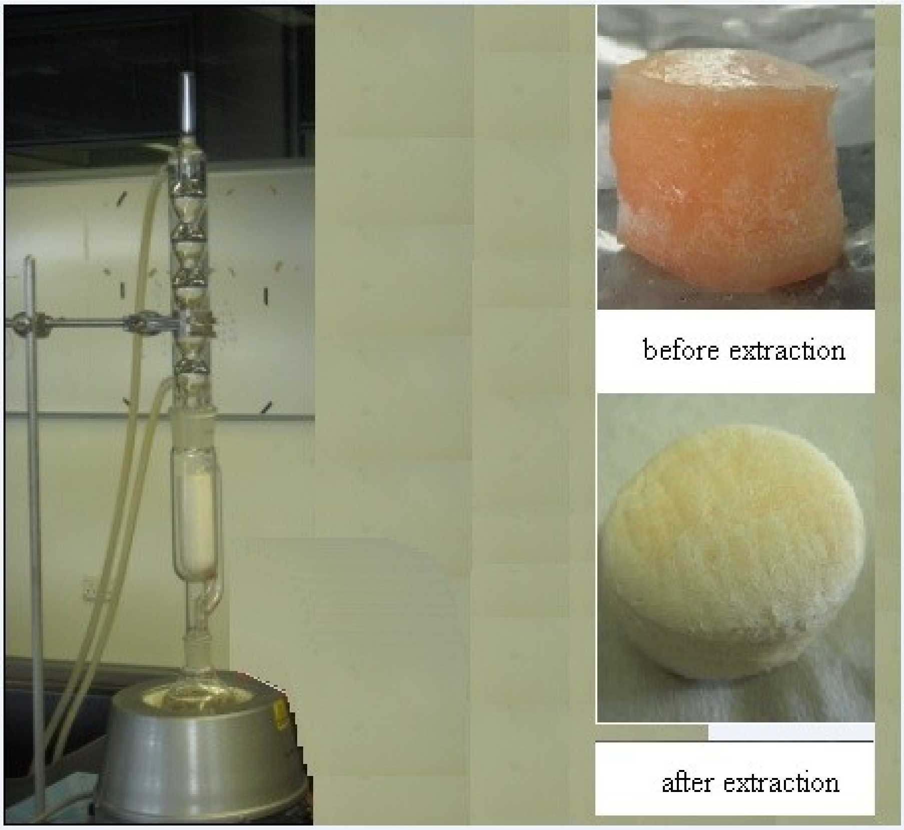


Figure 3.6: Soxhlet extractor apparatus and the sample before and after extraction

3.7 Summary

Platinum has very good characteristics such as its resistance to oxidation and corrosion, which make it suitable to be used as electrode for several applications in many areas of research [41]. It has very low electrode polarization impedance. Thus it is used as a plate for the capacitor design to measure the dielectric properties of meat. LCR meters are suitable and reliable and accurate instruments for the measuremnts of dielectric properties at low frequencies. The reliability and the accuracy of these meters are achieved by performing the compensations prior to the actual measurements. In addition, the preparation of the meat sample and the storage also play an important role in determining the reliability of the measurements. Without a proper handling of the meat sample, the measurements may not be accurate. The samples need to be stored at certain temperature in order to minimize the effect of the microorganisims.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter describes the results obtained using the designed parallel plate capacitor in order to differentiate properly slaughtered chicken from non properly slaughtered chicken. It is composed of four sections. The first section explains the experimental results of the dielectric properties of properly slaughtered chicken (slgt) and non properly slaughtered chicken (non slgt). The next section covers the determination of dielectric constant of two perfect dielectrics namely A4 paper and Flame Retardant 4 (FR4) substrate. The last two sections describe the methods used to validate the experimental results.

4.2 Dielectric properties of chicken

Dielectric properties such as relative permittivity and dissipation factor were determined for two types of chicken, namely properly slaughtered (slgt) and non properly slaughtered (non slgt). One type of chicken was slaughtered in the Islamic way as explained in Chapter 3. On the other hand, non properly slaughtered chicken was obtained by slaughtering the chickens after swiftly twisting the neck to break the spinal cord. A total of ten chickens were used for these measurements. Five chickens were slaughtered properly and five were not properly slaughtered. Experiments were conducted in a lab temperature (22°C) using parallel plate capacitor to hold the meat samples and LCR meter to measure the dielectric properties of the samples at various frequencies (100 Hz-2 kHz). The capacitance and the dissipation factor of slgt and non slgt meat were measured using the LCR meter. The relative permittivity was calculated using equation 4.1.

$$\varepsilon = \frac{Cd}{\varepsilon_0 A} \qquad 4.1$$

where ε, C and d are the calculated relative permittivity of the chicken, the measured capacitance (F) and the distance (m) between the two parallel plates (it was fixed to 5 mm for the whole measurements), respectively. ε_0 is the permittivity of the free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ (F/m) and A is the cross-sectional area of the plates (m^2), $A = \pi r^2$, where r is the radius of the plate (m), fixed at 1.25 mm.

Individual relative permittivities of ten chickens (five slgt and five non slgt) were calculated. The obtained values were averaged in each case for the purpose of comparison. In the same way, dissipation factor was averaged for comparison. In addition, standard deviations (STDEV) of the samples from the mean were calculated to observe the deviations of the samples from the mean. The average values of the dielectric properties of slgt chicken and the average values of the non slgt chicken in addition to their standard deviations are tabulated in Appendix A. The values of the relative permittivity and the dissipation factor after 3 hours of slaughtering were plotted as a function of frequency as shown in Figure 4.1. It is found that both relative permittivity and dissipation factor of slgt and non slgt chicken decrease with frequency.

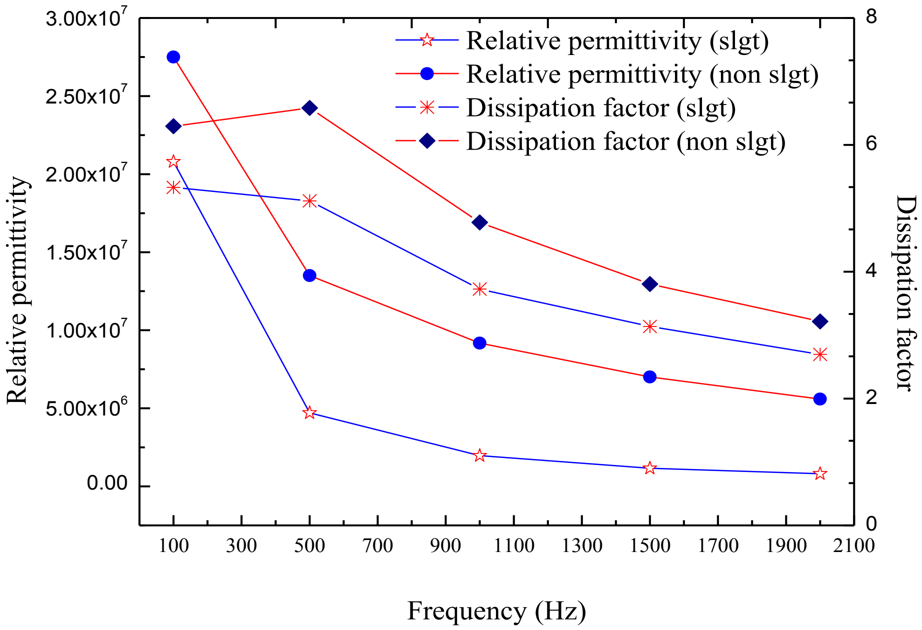


Figure 4.1: Dielectric properties versus frequency after 3 hours of slaughtering

The relative permittivity of the non slgt chicken is greater than that of the slgt chicken (25.75% higher). This is due to the difference in the blood volume which is higher in the case of non slgt. Blood has a very high water content [4], as a result it increases the relative permittivity due to the addition of extra ions and water molecules. The dissipation factor is affected by the blood content as well, where the non slgt chicken has high blood volume, so it exhibits higher dissipation factor.

After 24 hours of slaughtering, the measurements were found to follow a different trend, especially in the case of the dissipation factor. It is found to increase with frequency unlike the previous case (3 hours after slaughtering). Figure 4.2 shows the variation of the relative permittivity and the dissipation factor as a function of frequency after 24 hours of slaughtering.

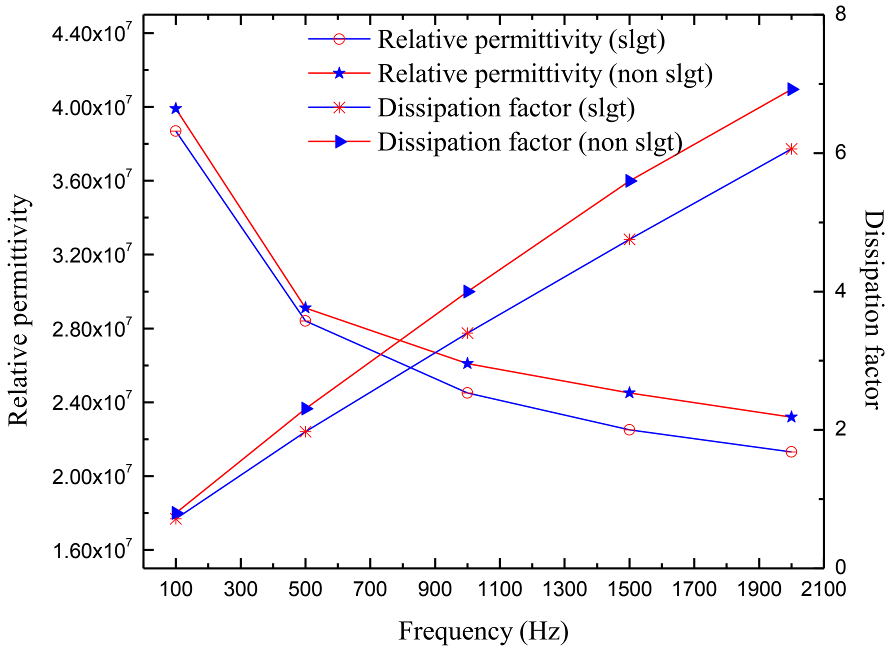


Figure 4.2: Dielectric properties versus frequency, 24 hours after slaughtering

No specific explanation is found for the the change of the trend in the dissipation factor, however, it may be due to the complete conversion of the muscle to meat which involves biochemical process such as denaturation of proteins and physical changes [27]. In addition to the change of the dissipation factor's trend, the difference in values between the permittivities of slgt and non slgt is found to narrow down due to the ageing of the meat. Freezing and the defrosting of the meat have increased the moisture content of the meat to some extent which makes the relative permittivity to increase compared to the fresh meat (3 hours measurement). The dielectric properties of meat are affected by the water tissue molecules and the ions [37]. The relative permittivity of non slgt chicken is reduced from its highest value at the lowest frequency to the lowest value at the highest frequency, the corresponding values for slgt chicken also followed the same trend. The dissipation factor of non slgt chicken is higher than the values of slgt chicken, and both increase with increasing frequency.

Figure 4.3 shows the dielectric properties of slgt and non slgt after 48 hours of slaughtering.

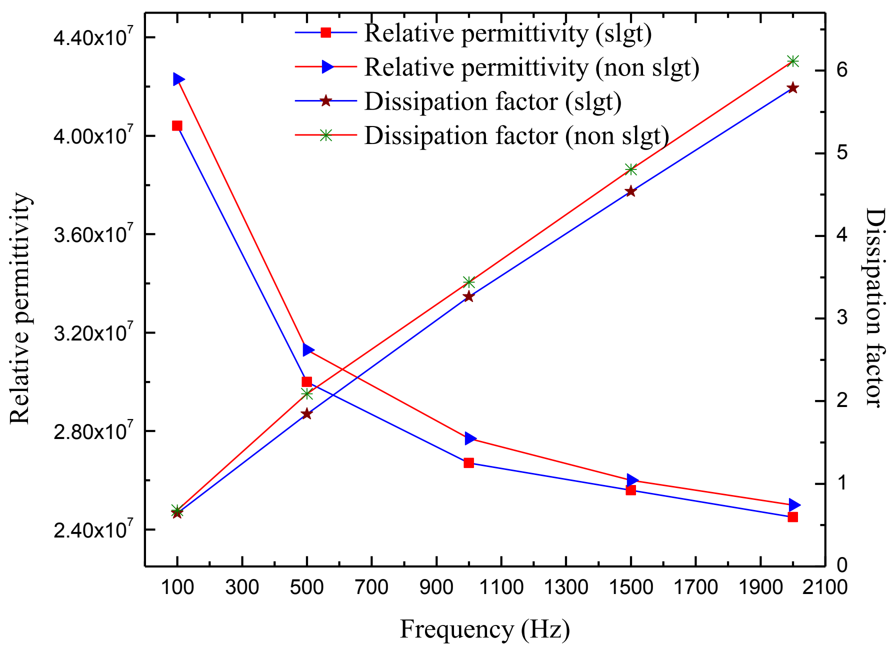


Figure 4.3: Dielectric properties versus frequency, 48 hours after slaughtering

The dielectric properties of the chicken breast after 48 hours has follow the same trend as for 24 hours of slaughtering, where no significant changes are observed. The relative permittivity and the dissipation factor of slgt chicken are lower than the corresponding values in non slgt chicken.

The relative permittivity and the dissipation factor of both chicken after 72 hours (three days) of slaughtering are plotted versus frequency as shown in Figure 4.4. The dissipation factor of the non slgt slaughtered chicken is found to decrease and come to values close to the values of slgt chicken. In addition, the relative permittivity seems not to show significant changes.

After four days of slaughtering (Figure 4.5), the values of the relative permittivity and the dissipation factor do not show significant changes compared to their correspondences in day three. The relative permittivities of the slgt chicken and the non slgt chicken decrease with frequency while the dissipation factors increase with increasing frequency. Non properly slaughtered chicken still has higher dielectric properties compared to the slgt chicken.

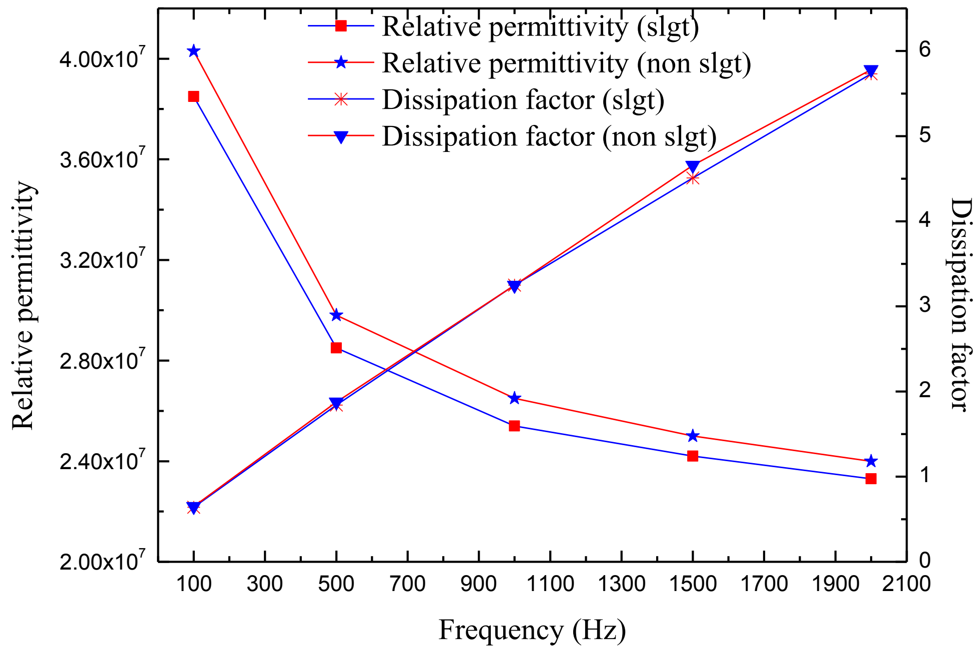


Figure 4.4: Dielectric properties versus frequency, 72 hours after slaughtering

Starting from day five of slaughtereing onwards the relative permittivity of the non slgt chicken and the relative permittivity of the slgt chicken come very close to each other. However, the values for the non slgt chicken are still higher than the corresponding values in the slgt chicken. It is believed that after five days of freezing, the cell membrane of the chicken's muscle has a great deterioration and the connective tissues have become weakened [37]. Thus, the values of dissipation factor and relative permittivity to be very close to each other in both types of meat. Figure 4.6 shows the plotting of the relative permittivity and the dissipation factor versus frequency after five days of slaughtering.

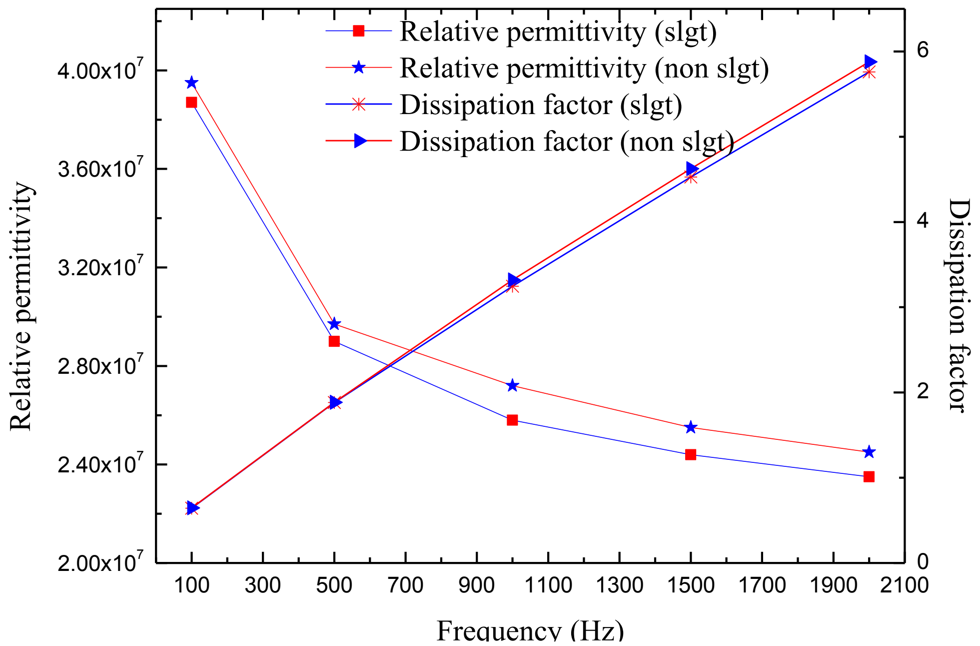


Figure 4.5: Dielectric properties versus frequency, 4 days after slaughtering

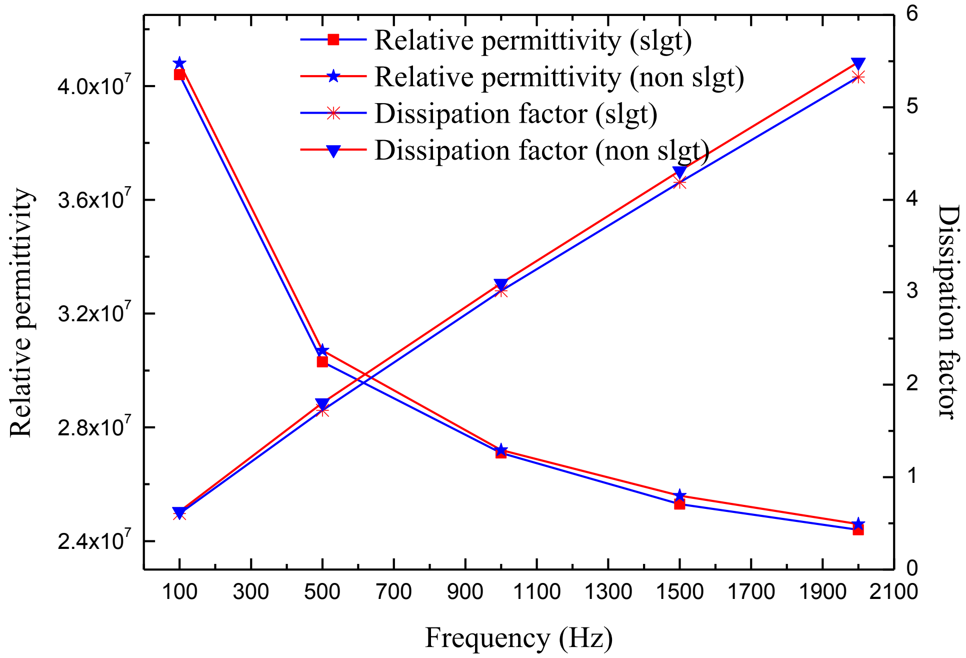


Figure 4.6: Dielectric properties versus frequency, 5 days after slaughtering

Other results (day six after slaughtering until day fifteen of slaughtering) do not show any significant difference in dissipation factor or relative permittivity for both slgt and non slgt chicken. The values and the trends are very close to the results of day 5 after slaughtering. The tables and graphs of day 6, day 7 up to day 14 of slaughtering are furnished in Appendix A and Appendix B, respectively.

In the second part of the measurements, the dielectric properties are plotted as a function of time for 15 days to examine the influence of postmortem-time. The relative permitivity and dissipation factor of slgt and non slgt at 100 Hz chicken as a function of time is shown in Figure 4.7. Dissipation factor values of day 0 (3 hours of slaughtering) are not included in the graph because it has very high values compared to the values of the rest of days. The relative permittivity of the slgt chicken and non slgt chicken have increase from day 0 to day 2 of slaughtering. Beyond day 2, the relative permittivities for the both meat (slgt and non slgt chicken) start decreasing with time up to day 4 and then they remain constant up to day 14 of the measurements.

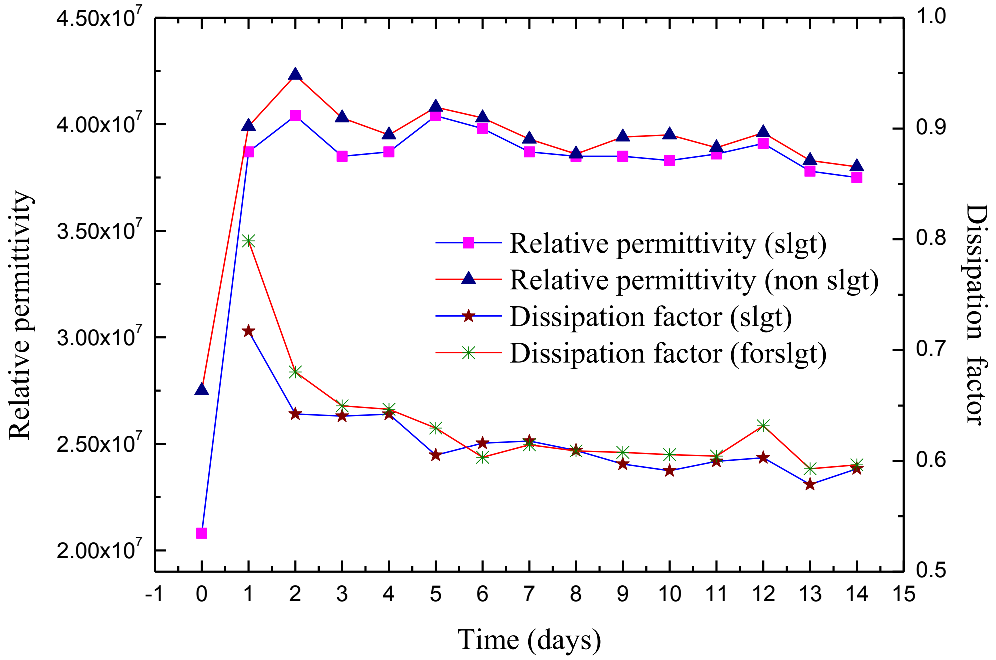


Figure 4.7: Dielectric properties versus time, 100 Hz

There are slight changes of increasing and decreasing; however no significant changes are noticed. The dissipation factor values decrease for both meats from day 0 to day 6. As in the case of relative permittivity, the dissipation factor after 6 days has quite constant values for both cases. The dissipation factor of the non slgt chicken for day 6 and day 7 becomes lower than that for the slgt chicken. It is believed that the dielectric properties of the chicken meat were influenced by the change of its chemical compositions and the physical structure as stated by Kremer and Schonhals [49]. The dielectric properties of any material are affected by the composition and the structure of that material. Also, it is reported by Bodakian and Hart [39] that the permittivity and conductivity of freshly slaughtered beef and chicken displayed a great directional anisotropy compared to the commercially purchased one. In addition freezing and defrosting process increases the conductivity of the chicken breast. The influence of the freezing on the conductivity could be extended to the permittivity and the dissipation factor as well. Furthermore, Castro-Giraldez et al. [50] have noticed an increase in the relative permittivity of pig meat with postmortem-time. Undoubtedly, after 2 days of freezing, the chicken meat has reached a certain degree of deterioration which makes the values of the properly slaughtered and non properly slaughtered chicken to be close to each other and in some cases even equal in their values.

The relative permittivity and the dissipation factor at 500 Hz do not reveal significant differences compared to the values at 100 Hz as shown in Figure 4.8. The dissipation factor of day 0 is ommitted from the gragh for the same reason stated in 100 Hz. The relative permittivity increases from day 0 up to day 2, decreases in day 3, and then it remains quite constant for the rest of the days. It can be seen that the dissipation factor has some differences, for instance, it decreases from day 0 up to day 6 and then it is constant for the rest of days. It gives results similar to 100 Hz results, it can be said that the trends of low frequencies (100 Hz and 500 Hz) are quite same. Although the difference between slgt and non slgt in term of dissipation factor is noticed up to day 6 at both frequencies, it could be concluded that 100 Hz is better than 500 Hz in distinguishing slgt chicken from non slgt chicken. The difference is well seen in 100 Hz compared to 500 Hz.

No significant differences are observed at 1 kHz except for the relative permittivity which shows some differences in values compared to the measurements of frequencies less than 1 kHz. However, the trend remains the same. Figure 4.9 shows the variation of the dissipation factor and relative permitivity of slgt and non slgt chicken at 1 kHz.

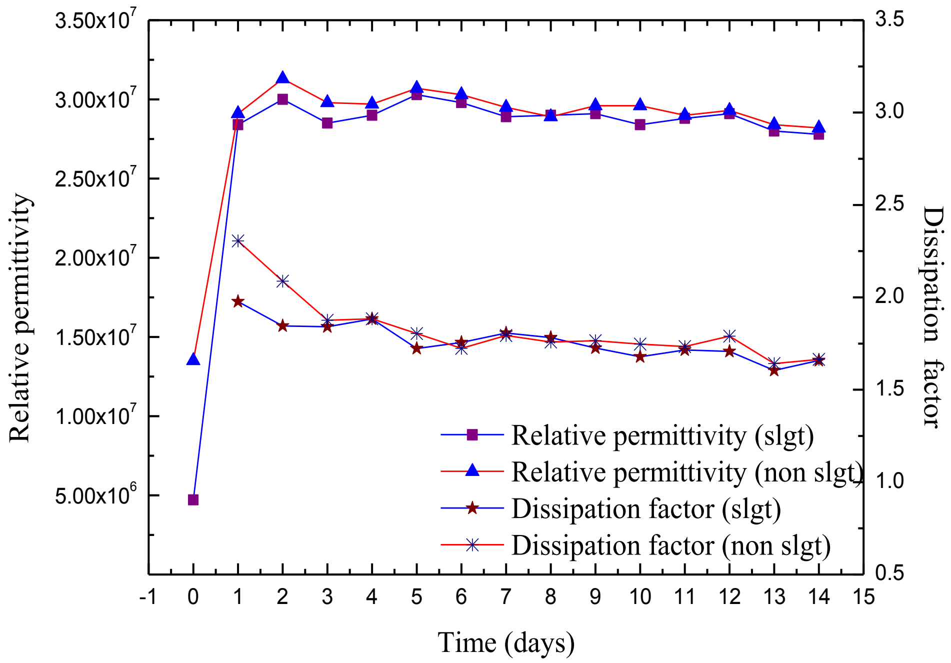


Figure 4.8: Dielectric properties versus time, 500 Hz

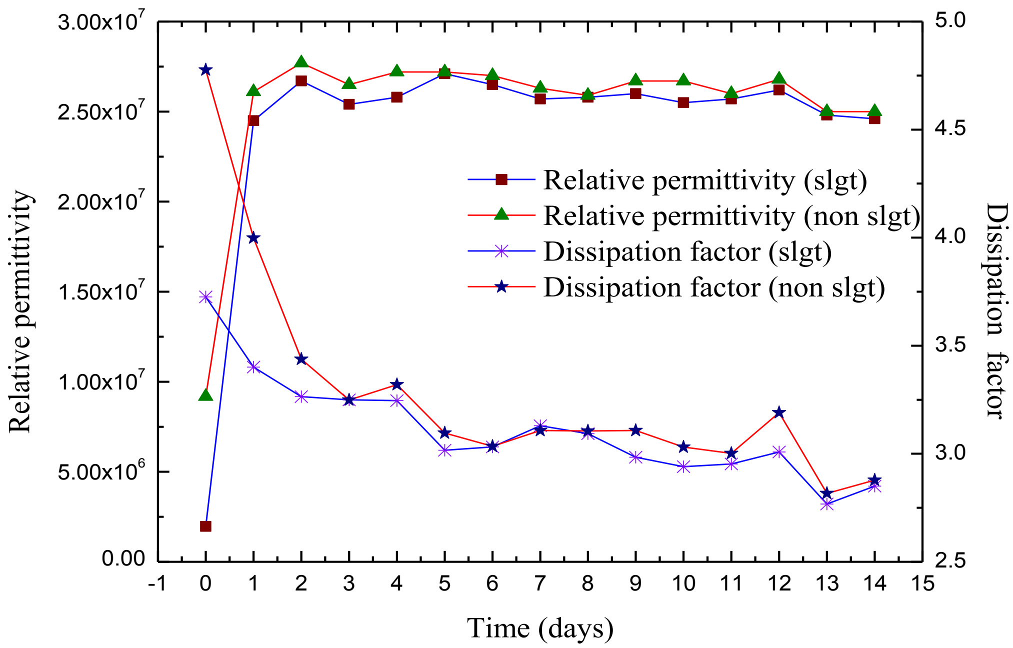


Figure 4.9: Dielectric properties versus time, 1 kHz

At 1.5 kHz and 2 kHz, the relative permittivity and dissipation factor show differences in values compared to the other frequencies; 100 Hz, 500 Hz and 1 kHz, however, keeping the same trend where the relative permittivity for both slgt and non slgt chicken increase from day 0 to day 2, and then remain connstant, but the dissipation factor decreases from day 0 to day 6, remains constant from then on.

Figure 4.10 shows the the relative permittivity and the dissipation factor of slgt and non slgt at 1.5 kHz as a function of time.

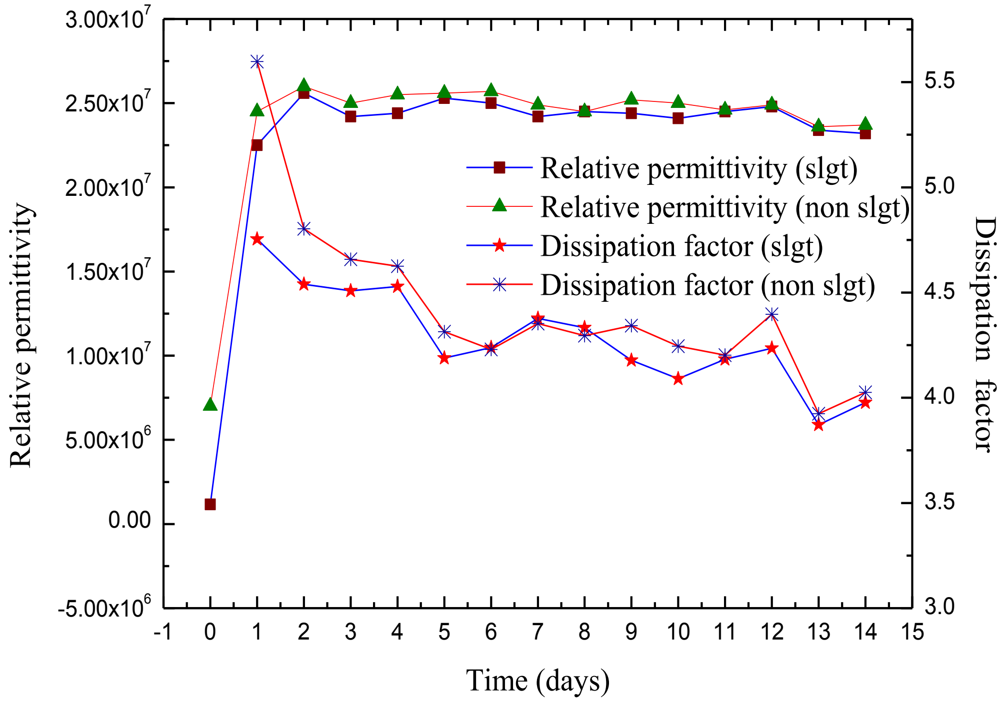


Figure 4.10: Dielectric properties versus time, 1.5 kHz

The values of the relative permittivity and dissipation factor at 2 kHz are shown in Figure 4.11. It can be seen that the difference between these values and the previous values for 100 Hz, 500 Hz, 1 kHz and 1.5 kHz is that these values are lower.

4.3 Dielectric constant of perfect dielectrics

In order to validate the experimental setup, perfect dielectrics were used to measure their dielectric constant. After performing the open and short compensation for the LCR meter, dielectric constants of FR4 substrate and 80 gsm A4 paper were measured.

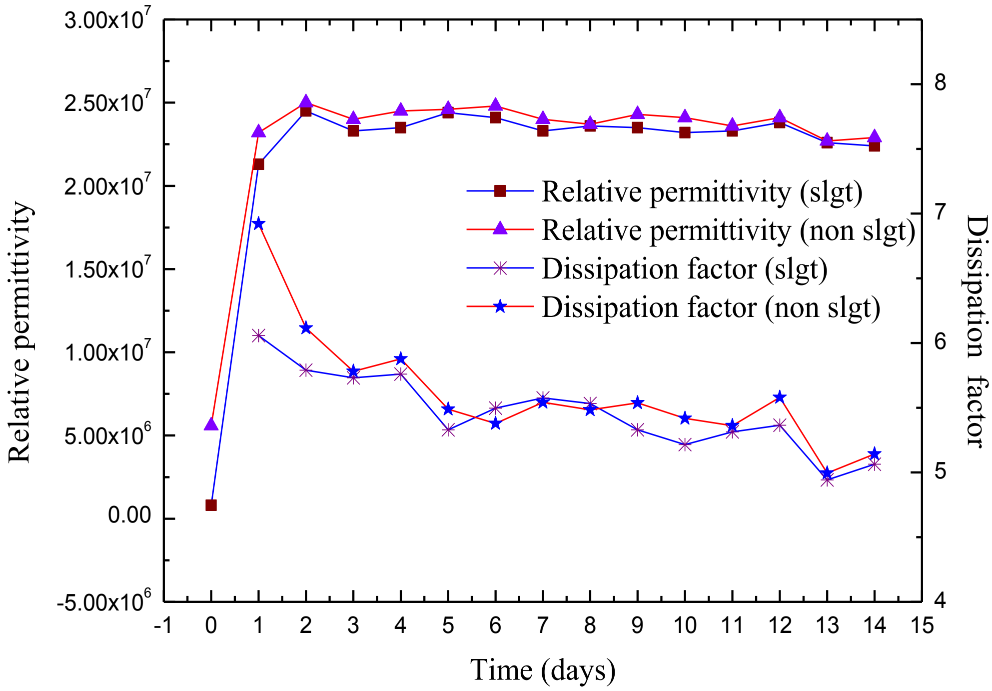


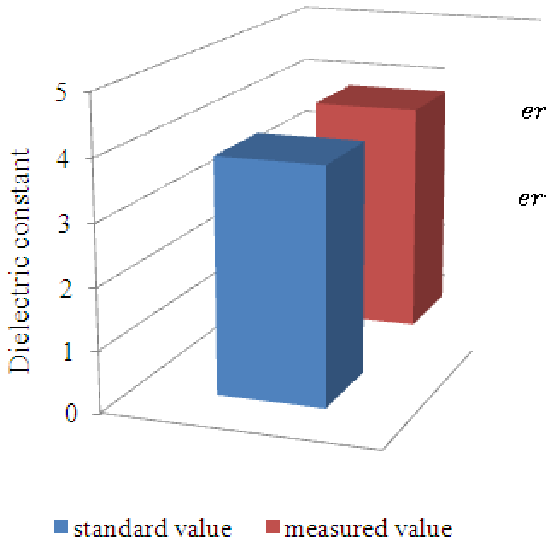
Figure 4.11: Dielectric properties versus time, 2 kHz

4.3.1 A4 Paper, 80 gsm

The dielectric constant of the A4 paper at 1 kHz was measured and compared to the standard value at that particular frequency to examine the accuracy of the capacitor design and to determine the percentage error in the measurements prior the actual measurements done on the chicken. The standard value at 1 kHz is 3.85 [51] and the measured value at that frequency is 3.83. Therefore, the percentage error is only 0.47 and acceptable for further analysis.

4.3.2 FR4 Substrate

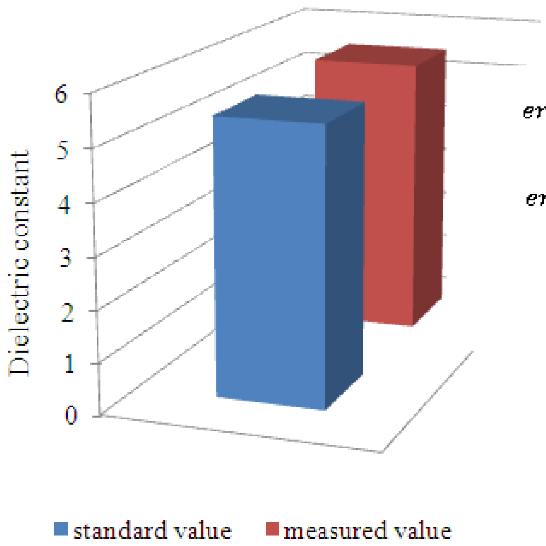
FR4 is the most commonly used laminate as a base material for printed circuit boards. The dielectric constant of the FR4 laminate at 100 Hz is 5.4 [52]. The measured value at 100 Hz using the parallel plate capacitor and LCR meter was 5.54. Figure 4.13 shows the dielectric constant and the percentage error of the FR4 material.



$$error\% = \frac{standard - measured}{standard} \times 100\%$$

$$error\% = \frac{3.85 - 3.83}{3.85} \times 100\% = 0.47\%$$

Figure 4.12: Standard and measured dielectric constant of A4 paper



$$error\% = \frac{measured - standard}{standard} \times 100\%$$

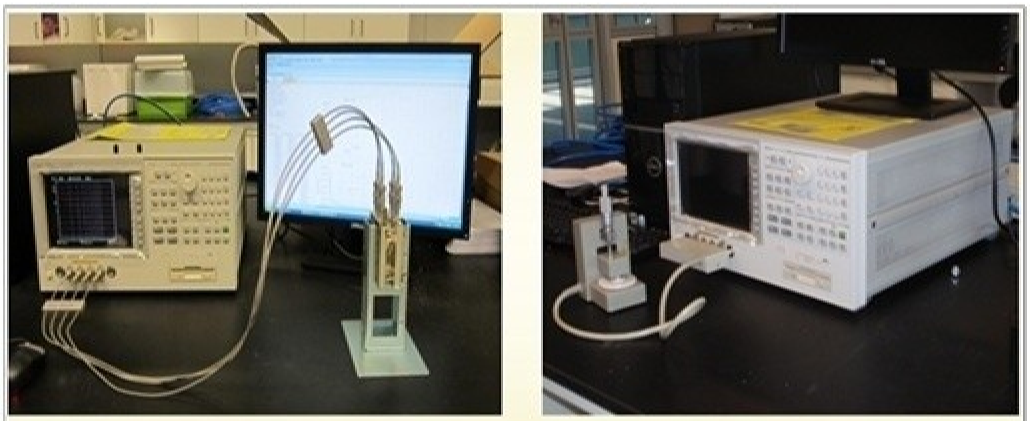
$$error\% = \frac{5.54 - 5.4}{5.4} \times 100\% = 2.56\%$$

Figure 4.13: Standard and measured dielectric constant of FR4

4.4 Relative permittivity measurements of blood and muscle

The relative permittivity of the chicken's muscle was measured using impedance analyser and dielectric test fixture in the frequency sweep 100 Hz to 2 kHz. The relative permittivity of chicken's blood was measured in the same frequency range using the same impedance analyser and liquid test fixture. Figure 4.14 shows the instruments used for the relative permittivity measurement of muscle and blood.

The results of relative permittivity of blood and muscle are shown in Figure 4.15. The relative permittivity of blood has high values compared to relative permittivity of the muscle in the same frequency range. This result may be due to the extraction of all the other components (blood, lipids, proteins, carbohydrate, water molecules, amino acids and minerals) [53] from meat except muscle fibers.



Impedance analyzer connected to Liquid Test Fixture for blood's permittivity measurement

Impedance analyzer connected to Dielectric Test Fixture for muscle's permittivity measurement

Figure 4.14: Experimental set up used for the relative permittivity measurement

4.5 Effective relative permittivity of chicken

Once the relative permittivity of the meat constituents and the volume fraction of the blood are known, Maxwell Garnett formula can be used to calculate the effective relative permittivity of slgt and non slgt chicken. The variation of the effective relative permittivity of slgt and non slgt chicken for different blood volume fractions are shown in Figure 4.16. The effective permittivity of the non slgt chicken shows higher values compared to the effective permittivity of the slgt chicken. These results are in agreement with the results of the relative permittivities which show that the non slgt had a higher relative permittivities compared to the slgt chickens.

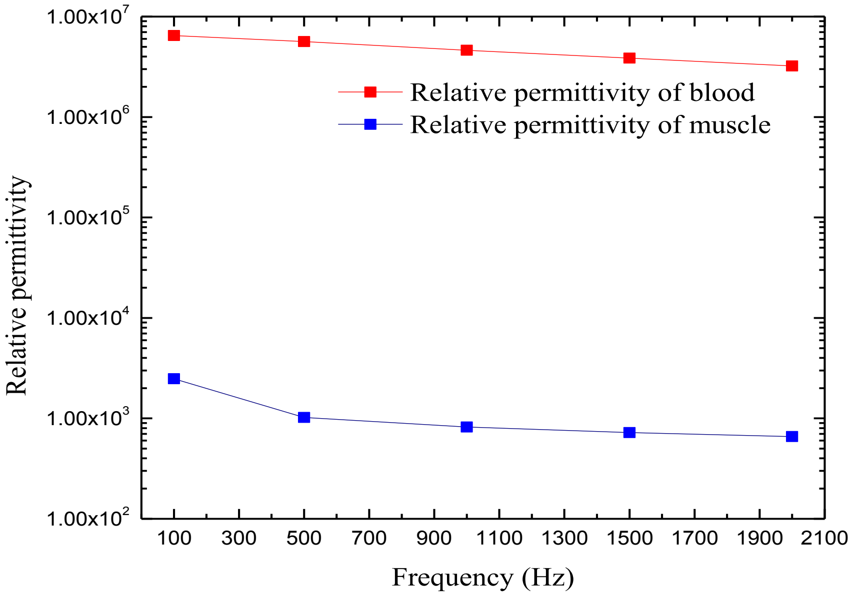


Figure 4.15: Relative permittivity of muscle and blood of chicken

This difference between slgt and non slgt is due to the difference in blood volume, as mentioned earlier. Of course, the values of the dielectric properties of the slgt and non slgt in experimental results are not identical with the theoretical results. As can be seen, there are differences in term of values between the relative permittivities and the effective relative permittivities at the respective frequencies in both cases; slgt and non slgt. This is believed to be due to the loss in the other constituents of the meat in the extraction process. The extraction process not only separates the blood from muscle, but, it removes all the other components which form the meat sample when the relative permittivity is measured. Muscle alone has shown very low relative permittivity because of the loss of water molecules, ions, proteins and so on. These low values of the muscle's relative permittivity have decreased the effective relative permittivity of meat.

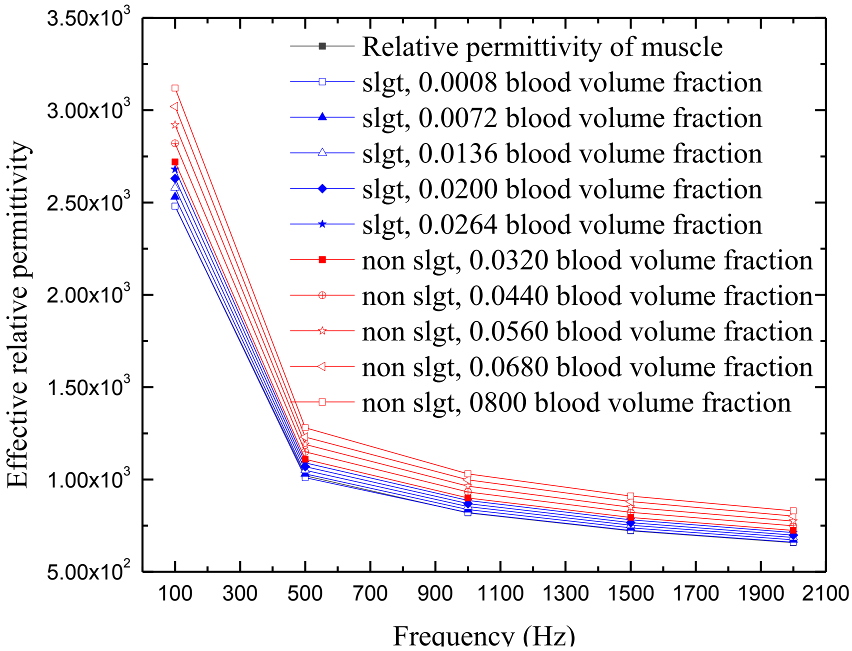


Figure 4.16: Effective relative permittivity of slgt and non slgt chicken

4.6 Meat colour

It is interesting to note that the colour of the non properly slaughtered chicken appears to be more reddish and has some small dots of blood in some areas like wings while properly slaughtered chicken is found to be bright red in color. This must be due to the residential blood which is believed to be higher in case of the non properly slaughtered chicken. Figure 4.17 shows the colour of slgt and non slgt chickens.

Figure 4.17: Color of slgt and non slgt chicken

4.7 Summary

Dielectric properties of non slgt chicken has shown higher values compared to the values obtained from slgt chicken. Blood volume has a significant impact on the meat and could change the dielectric properties. The dielectric properties of meat increase with the blood volume and hence giving rise to high values for non slgt chicken. Relative permittivity of both slgt and non slgt chicken decreases with increasing frequency for the whole measurements duration, meanwhile the dissipation factor decreases with the frequency after 3 hours of slaughter. Nevertheless, It changes its trend after 24 hours until the last day of the measurement. Determining the properties of perfect dielectric matreials is usful to validate the accuracy and the reliability of the technique being used. Measured dielectric constants of A4 paper and FR4 were shown close proximity to their standarad values.

The experimental data is validated by comparison with the theoretical calculations. Maxwell mixing rule is considered a suitable method to calculate the effective dielectric properties of two phase materials. It could be used to calculate the effective relative permittivity of meat when the studied meat is considered as a muscle and blood only, and by knowing the respective relative permittivities of pure muscle and blood.

CHAPTER 5

CONCLUSIONS, CONTRIBUTIONS AND RECOMMENDATIONS

5.1 Conclusions

Dielectric properties of biological tissues such as meat can be measured and used to study the characteristics of these tissues. Several techniques are available for the dielectric properties measurements, such as impedance analyzers, coaxial probe, resonance structure, LCR meters, waveguide, scalar and vector network analyzers and parallel plate capacitors. Parallel plate capacitor technique is simple, reliable and has good accuracy that make it suitable for such measurements. Platinum is resistive to oxidation and corrosion, so it is used to construct the parallel plate capacitor. LCR meter was used with the designed parallel plate capacitor to measure the relative permittivity and the dissipation factor of slgt and non slgt chicken.

Two dielectric properties of chicken namely relative permittivity and dissipation factor were measured. The values of the relative permittivities of the non properly slaughtered chicken (non slgt) were higher compared to the corresponding values of the properly slaughtered chicken (slgt). The dissipation factors for the non slgt chicken as well higher as the relative permittivities compared to the values of the slgt chicken. This is attributed to the blood volume which is higher in non slgt chicken compared to the slgt chicken.

Frequency has affected the dielectric properties of chicken (relative permittivity and dissipation factor). Relative permittivity decreases with increasing frequency for both slgt chicken and non slgt chicken for the whole period of the measurements (15 days). Dissipation factor for both slgt chicken and non slgt chicken decreased with increasing the frequency in the first measurement (3 hours after slaughtering) and after 24 hours the trend was changed for both and found to increase with increasing frequency until the end of the measurement days.

Postmortem time also influenced the dielectric properties of chicken. The relative permittivities of slgt chicken and non slgt chicken increased from day 0 (3 hours measurement) until day 2 (after 48 hours of slaughtering) and then it started to decrease up to day 4. After day 4 the values remained quite constant until the last day of the measurement (after 14 days of slaughtering). The dissipation factor of fresh chicken (3 hours measurement) was very high compared to the rest of the days. It decreased with time for both slgt chicken and non slgt chicken until day 6 after slaughtering and then it remained quite constant for the rest of the days until day 14.

The effective relative permittivities of the slgt chicken and non slgt chicken were calculated. Blood was totally extracted from the chicken's meat to get pure muscle. The relative permittivity of the pure muscle and the relative permittivity of the pure blood were applied using Maxwell Garnett formula to calculate the effective relative permittivity in order to validate the experimental results. It was found that there is a good agreement between the values of the relative permittivities and the effective relative permittivities. In both cases the non slgt chicken shows higher relative permittivity values. It may be concluded that the parallel platinum plate capcitor is a good tool to differentiate slgt chicken from non slgt chicken.

5.2 Contributions

Design a capacitive device which can differentiate properly slaughtered and non properly slaughtered chicken using parallel platinum plate capacitor .

Paving the way to differentiate properly slaughtered meat from non properly slaughtered meat for variety of animals.

5.3 Recommendations

This research paves way to differentiate properly slaughtered chicken from non properly slaughtered chicken. However, it has some limitations.

The measurements were only conducted at low frequencies (100-2000 Hz) which is within α-dispersion only. In the frequency range used, the relative permittivity and the dissipation factor of the non properly slaughtered chicken have higher values compared to the values of the properly slaughtered chicken. However, this may not be the case if a wide frequency range is used to include β, γ and δ dispersions.

In addition to the frequency range, this result is limited to chicken's breast only, other parts of the chickens were not included. Researches on the dielectric properties of human organs have revealed that different organs give different dielectric properties. As the chicken's flesh is a biological tissue like human organs, it is believed that different parts of the chickens flesh will give rise to different results, because the concentration of blood inside the chicken's flesh differs from organ to another.

Platinum is a very good material to be used as plates for the capacitor construction. Nevertheless, platinum is quite expensive; so it is recommended to identify other good materials with a high reliability and lower price to replace the platinum plates.

The results have shown that the relative permittivities and the dissipation factors of properly slaughtered and non properly slaughtered chickens can be used as a way of characterization only within 3 to 4 days of slaughter. Therefore, factors other than the relative permittivity and the dissipation factor, e.g. conductivity and pH, need to be included for better characterization for longer time.

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[2] Almur Abdelkreem Saeed Rabih, Mumtaj Begam Kasim, Taib bin Ibrahim, Zainal Arif bin Burhanudin "Effective Relative Permittivity of Properly Slaughtered and non Properly Slaughtered Chicken using Dielectric Mixing rules" National Postgraduate Conference (NPC)2011, 19-20 Sep 2011, Universiti Teknologi PETRONAS, Perak, Malaysia.

[3] Almur Abdelkreem Saeed Rabih, Mumtaj Begam Kasim, Taib bin Ibrahim, Zainal Arif bin Burhanudin "Characterization of properly slaughtered and non properly slaughtered Chicken" 2011 IEEE Colloquium on Humanities, Science and Engineering Research (CHUSER 2011) , 5-6 December 2011, Universiti Teknologi Mara, Penang, MALAYSIA.

[4] A bronze medal for Capacitive variations study of fish, cow and pig meat in Engineering Design Exhibition, EDX 25 (21st - 22nd April 2010), Universiti Teknologi PETRONAS

APPENDIX A

TABLES SUMMARIZING DIELECTRIC PROPERTIES

Table A- 1: Dielectric properties of slgt and non slgt chicken for 3 hours

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor(slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	2.08×10^{7}	3.40×10^{6}	2.75×10^{7}	4.84×10^{6}	5.3298	0.535342	6.2949	0.600933
500	4.71×10^{6}	9.06×10^{5}	1.35×10^{7}	8.46×10^{6}	5.1164	1.004966	6.580725	0.179101
1000	1.97×10^{6}	3.33×10^{5}	9.18×10^{6}	7.68×10^{6}	3.7256	0.833385	4.77635	0.006675
1500	1.16×10^{6}	1.82×10^{5}	7.01×10^{6}	6.58×10^{6}	3.1356	0.59253	3.806125	0.031519
2000	8.05×10^{5}	1.21×10^{5}	5.59×10^{6}	5.57×10^{6}	2.696	0.506861	3.21485	0.045239

Table A- 2: Dielectric properties of slgt and non slgt chicken after 24 hours

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor(slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.87×10^{7}	5.45×10^{6}	3.99×10^{7}	3.47×10^{6}	0.71704	0.100541	0.79856	0.114239
500	2.84×10^{7}	3.05×10^{6}	2.91×10^{7}	1.98×10^{6}	1.9768	0.224493	2.30586	0.398862
1000	2.45×10^{7}	4.10×10^{6}	2.61×10^{7}	2.02×10^{6}	3.40134	0.389419	3.99874	0.61728
1500	2.25×10^{7}	5.27×10^{6}	2.45×10^{7}	2.29×10^{6}	4.7536	0.54508	5.59794	0.844563
2000	2.13×10^{7}	6.26×10^{6}	2.32×10^{7}	2.46×10^{6}	6.05834	0.694479	6.9216	0.993897

Table A- 3: Dielectric properties of slgt and non slgt chicken, 48 hours of slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor(slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	4.04×10^{7}	2.65×10^{6}	4.23×10^{7}	1.52×10^{6}	0.64228	0.051693	0.680252	0.074714
500	3.00×10^{7}	1.80×10^{6}	3.13×10^{7}	9.31×10^{5}	1.8455	0.180298	2.0878	0.378785
1000	2.67×10^{7}	2.11×10^{6}	2.77×10^{7}	7.93×10^{5}	3.2646	0.444386	3.438	0.306429
1500	2.56×10^{7}	2.12×10^{6}	2.60×10^{7}	6.46×10^{5}	4.5392	0.531982	4.8028	0.414387
2000	2.45×10^{7}	1.78×10^{6}	2.50×10^{7}	5.84×10^{5}	5.7905	0.619872	6.1162	0.519577

Table A- 4: Dielectric properties of slgt and non slgt chicken, 72 hours of slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.85×107	1.42×10^{6}	4.03×10^{7}	3.62×10^{5}	0.64038	0.045787	0.64968	0.059989
500	2.85×107	1.17×10^{6}	2.98×10^{7}	5.19×10^{5}	1.8408	0.19483	1.8762	0.23413
1000	2.54×107	5.02×10^{5}	2.65×10^{7}	4.33×10^{5}	3.25	0.245938	3.2488	0.401452
1500	2.42×107	1.03×10^{6}	2.50×10^{7}	4.05×10^{5}	4.5082	0.374964	4.6578	0.496318
2000	2.33×107	1.00×10^{6}	2.40×10^{7}	3.61×10^{5}	5.7314	0.493728	5.7808	0.705247

Table A- 5: Dielectric properties of slgt and non slgt chicken, 4 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.87×10^7	2.55×10^5	3.95×10^7	4.34×10^5	0.64218	0.052395	0.64664	0.066257
500	2.90×10^7	2.94×10^5	2.97×10^7	5.32×10^5	1.8834	0.194297	1.884	0.225665
1000	2.58×10^7	1.81×10^5	2.72×10^7	1.29×10^6	3.2464	0.322755	3.3202	0.460267
1500	2.44×10^7	1.54×10^5	2.55×10^7	8.28×10^5	4.5284	0.43117	4.6252	0.601645
2000	2.35×10^7	1.31×10^5	2.45×10^7	7.18×10^5	5.76	0.52816	5.8776	0.749492

Table A- 6: Dielectric properties of slgt and non slgt chicken, 5 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	4.04×10^7	1.09×10^6	4.08×10^7	1.02×10^6	0.60518	0.032408	0.62964	0.040438
500	3.03×10^7	1.04×10^6	3.07×10^7	9.32×10^5	1.72314	0.106614	1.8038	0.131205
1000	2.71×10^7	7.28×10^5	2.72×10^7	7.56×10^5	3.0164	0.215212	3.0964	0.207399
1500	2.53×10^7	4.17×10^5	2.56×10^7	6.57×10^5	4.18826	0.266992	4.3142	0.273795
2000	2.44×10^7	3.09×10^5	2.46×10^7	6.26×10^5	5.32966	0.324689	5.4896	0.334058

Table A- 7: Dielectric properties of slgt and non slgt chicken, 6 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.98×10^{7}	7.59×10^{5}	4.03×10^{7}	4.31×10^{5}	0.61594	0.003345	0.60332	0.026667
500	2.98×10^{7}	6.25×10^{5}	3.03×10^{7}	3.21×10^{5}	1.756	0.016508	1.7238	0.079647
1000	2.65×10^{7}	6.59×10^{5}	2.70×10^{7}	3.64×10^{5}	3.0315	0.040196	3.035	0.17105
1500	2.50×10^{7}	6.14×10^{5}	2.57×10^{7}	4.21×10^{5}	4.2387	0.066081	4.2295	0.187764
2000	2.41×10^{7}	5.93×10^{5}	2.48×10^{7}	4.09×10^{5}	5.4967	0.051609	5.3789	0.242935

Table A- 8: Dielectric properties of slgt and non slgt chicken, 7 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.87×10^{7}	8.36×10^{5}	3.93×10^{7}	8.45×10^{5}	0.61792	0.01834	0.61454	0.02732
500	2.89×10^{7}	5.47×10^{5}	2.95×10^{7}	7.80×10^{5}	1.80636	0.065141	1.7938	0.091756
1000	2.57×10^{7}	5.42×10^{5}	2.63×10^{7}	6.67×10^{5}	3.1298	0.115081	3.1076	0.149529
1500	2.42×10^{7}	5.24×10^{5}	2.49×10^{7}	5.78×10^{5}	4.37674	0.159868	4.3524	0.190661
2000	2.33×10^{7}	5.19×10^{5}	2.40×10^{7}	6.00×10^{5}	5.5764	0.19952	5.54214	0.239609

Table A- 9: Dielectric properties of slgt and non slgt chicken, 8 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.85×10^{7}	6.48×10^{5}	3.86×10^{7}	1.14×10^{6}	0.60946	0.022974	0.60896	0.037839
500	2.90×10^{7}	4.47×10^{5}	2.89×10^{7}	1.21×10^{6}	1.7824	0.095788	1.7584	0.150553
1000	2.58×10^{7}	5.03×10^{5}	2.59×10^{7}	9.45×10^{5}	3.0934	0.17013	3.1054	0.321753
1500	2.45×10^{7}	4.59×10^{5}	2.45×10^{7}	8.64×10^{5}	4.3326	0.238884	4.2952	0.345436
2000	2.36×10^{7}	4.41×10^{5}	2.37×10^{7}	8.42×10^{5}	5.533	0.301949	5.4836	0.426499

Table A- 10: Dielectric properties of slgt and non slgt chicken, 9 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.85×10^{7}	1.13×10^{6}	3.94×10^{7}	5.63×10^{5}	0.5971	0.024261	0.6076	0.016819
500	2.91×10^{7}	6.84×10^{5}	2.96×10^{7}	4.36×10^{5}	1.7258	0.107083	1.7654	0.08299
1000	2.60×10^{7}	7.28×10^{5}	2.67×10^{7}	1.11×10^{6}	2.984	0.187999	3.1076	0.159687
1500	2.44×10^{7}	8.33×10^{5}	2.52×10^{7}	7.98×10^{5}	4.1776	0.267133	4.343	0.218006
2000	2.35×10^{7}	8.35×10^{5}	2.43×10^{7}	6.83×10^{5}	5.3294	0.340278	5.538	0.276895

Table A- 11: Dielectric properties of slgt and non slgt chicken, 10 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.83×10^{7}	9.70×10^{5}	3.95×10^{7}	1.00×10^{6}	0.5911	0.037948	0.60567	0.026322
500	2.84×10^{7}	1.01×10^{6}	2.96×10^{7}	8.74×10^{5}	1.6788	0.144205	1.7469	0.107641
1000	2.55×10^{7}	7.46×10^{5}	2.67×10^{7}	6.34×10^{5}	2.9405	0.258585	3.0307	0.187442
1500	2.41×10^{7}	7.22×10^{5}	2.50×10^{7}	4.64×10^{5}	4.0905	0.362194	4.2449	0.258975
2000	2.32×10^{7}	7.24×10^{5}	2.41×10^{7}	4.65×10^{5}	5.2157	0.458853	5.4174	0.326695

Table A- 12: Dielectric properties of slgt and non slgt chicken,11 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.86×10^{7}	7.40×10^{5}	3.89×10^{7}	4.17×10^{5}	0.599666	0.016473	0.60435	0.030022
500	2.88×10^{7}	7.81×10^{5}	2.90×10^{7}	4.34×10^{5}	1.7152	0.084934	1.7342	0.126452
1000	2.57×10^{7}	9.64×10^{5}	2.60×10^{7}	6.54×10^{5}	2.9526	0.15703	3.0019	0.219246
1500	2.45×10^{7}	1.25×10^{6}	2.46×10^{7}	3.10×10^{5}	4.1828	0.277013	4.2024	0.300049
2000	2.33×10^{7}	8.53×10^{5}	2.36×10^{7}	3.86×10^{5}	5.3136	0.33108	5.3616	0.372727

Table A- 13: Dielectric properties of slgt and non slgt chicken,12 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.91×10^7	6.82×10^5	3.96×10^7	1.21×10^6	0.60278	0.031799	0.63164	0.036623
500	2.91×10^7	4.80×10^5	2.93×10^7	9.69×10^5	1.7078	0.110205	1.7902	0.110208
1000	2.62×10^7	1.80×10^6	2.68×10^7	1.89×10^6	3.0086	0.294721	3.1901	0.248389
1500	2.48×10^7	2.05×10^6	2.49×10^7	1.34×10^6	4.2356	0.463103	4.397	0.321846
2000	2.38×10^7	1.45×10^6	2.41×10^7	1.20×10^6	5.3648	0.516433	5.5796	0.402718

Table A- 14: Dielectric properties of slgt and non slgt chicken, 13 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.78×10^7	1.53×10^6	3.83×10^7	1.15×10^6	0.5787	0.039671	0.59282	0.045763
500	2.80×10^7	5.43×10^5	2.84×10^7	8.06×10^5	1.605	0.129184	1.6418	0.175666
1000	2.48×10^7	5.64×10^5	2.50×10^7	7.27×10^5	2.768	0.23843	2.8164	0.314519
1500	2.34×10^7	5.36×10^5	2.36×10^7	6.60×10^5	3.872	0.337432	3.9238	0.447752
2000	2.26×10^7	5.14×10^5	2.27×10^7	6.02×10^5	4.9424	0.425955	4.9948	0.573208

Table A- 15: Dielectric properties of slgt and non slgt chicken, 14 days after slaughtering

Frequency(Hz)	Relative permittivity(slgt)		Relative permittivity(non slgt)		Dissipation factor (slgt)		Dissipation factor(non slgt)	
	Average value	STDEV	Average value	STDEV	Average value	STDEV	Average value	STDEV
100	3.75×10^7	9.88×10^5	3.80×10^7	1.10×10^6	0.5929	0.026715	0.59644	0.036479
500	2.78×10^7	4.92×10^5	2.82×10^7	9.52×10^5	1.658	0.100322	1.6644	0.125323
1000	2.46×10^7	6.60×10^5	2.50×10^7	8.07×10^5	2.85	0.188	2.8784	0.242634
1500	2.32×10^7	7.14×10^5	2.37×10^7	7.69×10^5	3.9772	0.269597	4.0257	0.352043
2000	2.24×10^7	7.45×10^5	2.29×10^7	7.55×10^5	5.0644	0.349801	5.1428	0.464571

Table A- 16: Dielectric properties of slgt and non slgt chicken, 100 Hz

Time(days)	Relative permittivity		Dissipation factor	
	slgt	non slgt	slgt	non slgt
0	2.08×10^7	2.75×10^7	5.3298	6.2949
1	3.87×10^7	3.99×10^7	0.71704	0.79856
2	4.04×10^7	4.23×10^7	0.64228	0.680252
3	3.85×10^7	4.03×10^7	0.64038	0.64968
4	3.87×10^7	3.95×10^7	0.64218	0.64664
5	4.04×10^7	4.08×10^7	0.60518	0.62964
6	3.98×10^7	4.03×10^7	0.61594	0.60332
7	3.87×10^7	3.93×10^7	0.61792	0.61454
8	3.85×10^7	3.86×10^7	0.60946	0.60896
9	3.85×10^7	3.94×10^7	0.5971	0.6076
10	3.83×10^7	3.95×10^7	0.5911	0.60567
11	3.86×10^7	3.89×10^7	0.599666	0.60435
12	3.91×10^7	3.96×10^7	0.60278	0.63164
13	3.78×10^7	3.83×10^7	0.5787	0.59282
14	3.75×10^7	3.80×10^7	0.5929	0.59644

Table A- 17: Dielectric properties of slgt and non slgt chicken, 500 Hz

Time(days)	Relative permittivity		Dissipation factor	
	slgt	non slgt	slgt	non slgt
0	4.71×10^{6}	1.35×10^{7}	5.1164	6.580725
1	2.84×10^{7}	2.91×10^{7}	1.9768	2.30586
2	3.00×10^{7}	3.13×10^{7}	1.8455	2.0878
3	2.85×10^{7}	2.98×10^{7}	1.8408	1.8762
4	2.90×10^{7}	2.97×10^{7}	1.8834	1.884
5	3.03×10^{7}	3.07×10^{7}	1.72314	1.8038
6	2.98×10^{7}	3.03×10^{7}	1.756	1.7238
7	2.89×10^{7}	2.95×10^{7}	1.80636	1.7938
8	2.90×10^{7}	2.89×10^{7}	1.7824	1.7584
9	2.91×10^{7}	2.96×10^{7}	1.7258	1.7654
10	2.84×10^{7}	2.96×10^{7}	1.6788	1.7469
11	2.88×10^{7}	2.90×10^{7}	1.7152	1.7342
12	2.91×10^{7}	2.93×10^{7}	1.7078	1.7902
13	2.80×10^{7}	2.84×10^{7}	1.605	1.6418
14	2.78×10^{7}	2.82×10^{7}	1.658	1.6644

Table A- 18: Dielectric properties of slgt and non slgt chicken, 1 kHz

Time(days)	Relative permittivity		Dissipation factor	
	slgt	non slgt	slgt	non slgt
0	1.97×10^{6}	9.18×10^{6}	3.7256	4.77635
1	2.45×10^{7}	2.61×10^{7}	3.40134	3.99874
2	2.67×10^{7}	2.77×10^{7}	3.2646	3.438
3	2.54×10^{7}	2.65×10^{7}	3.25	3.2488
4	2.58×10^{7}	2.72×10^{7}	3.2464	3.3202
5	2.71×10^{7}	2.72×10^{7}	3.0164	3.0964
6	2.65×10^{7}	2.70×10^{7}	3.0315	3.035
7	2.57×10^{7}	2.63×10^{7}	3.1298	3.1076
8	2.58×10^{7}	2.59×10^{7}	3.0934	3.1054
9	2.60×10^{7}	2.67×10^{7}	2.984	3.1076
10	2.55×10^{7}	2.67×10^{7}	2.9405	3.0307
11	2.57×10^{7}	2.60×10^{7}	2.9526	3.0019
12	2.62×10^{7}	2.68×10^{7}	3.0086	3.1901
13	2.48×10^{7}	2.50×10^{7}	2.768	2.8164
14	2.46×10^{7}	2.50×10^{7}	2.85	2.8784

Table A- 19: Dielectric properties of slgt and non slgt chicken, 1.5 kHz

Time(days)	Relative permittivity		Dissipation factor	
	slgt	non slgt	slgt	non slgt
0	1.16×10^{6}	7.01×10^{6}	3.1356	3.806125
1	2.25×10^{7}	2.45×10^{7}	4.7536	5.59794
2	2.56×10^{7}	2.60×10^{7}	4.5392	4.8028
3	2.42×10^{7}	2.50×10^{7}	4.5082	4.6578
4	2.44×10^{7}	2.55×10^{7}	4.5284	4.6252
5	2.53×10^{7}	2.56×10^{7}	4.18826	4.3142
6	2.50×10^{7}	2.57×10^{7}	4.2387	4.2295
7	2.42×10^{7}	2.49×10^{7}	4.37674	4.3524
8	2.45×10^{7}	2.45×10^{7}	4.3326	4.2952
9	2.44×10^{7}	2.52×10^{7}	4.1776	4.343
10	2.41×10^{7}	2.50×10^{7}	4.0905	4.2449
11	2.45×10^{7}	2.46×10^{7}	4.1828	4.2024
12	2.48×10^{7}	2.49×10^{7}	4.2356	4.397
13	2.34×10^{7}	2.36×10^{7}	3.872	3.9238
14	2.32×10^{7}	2.37×10^{7}	3.9772	4.0257

Table A- 20: Dielectric properties of slgt and non slgt chicken, 2 kHz

Time(days)	Relative permittivity		Dissipation factor	
	slgt	non slgt	slgt	non slgt
0	8.05×10^{5}	5.59×10^{6}	2.696	3.21485
1	2.13×10^{7}	2.32×10^{7}	6.05834	6.9216
2	2.45×10^{7}	2.50×10^{7}	5.7905	6.1162
3	2.33×10^{7}	2.40×10^{7}	5.7314	5.7808
4	2.35×10^{7}	2.45×10^{7}	5.76	5.8776
5	2.44×10^{7}	2.46×10^{7}	5.32966	5.4896
6	2.41×10^{7}	2.48×10^{7}	5.4967	5.3789
7	2.33×10^{7}	2.40×10^{7}	5.5764	5.54214
8	2.36×10^{7}	2.37×10^{7}	5.533	5.4836
9	2.35×10^{7}	2.43×10^{7}	5.3294	5.538
10	2.32×10^{7}	2.41×10^{7}	5.2157	5.4174
11	2.33×10^{7}	2.36×10^{7}	5.3136	5.3616
12	2.38×10^{7}	2.41×10^{7}	5.3648	5.5796
13	2.26×10^{7}	2.27×10^{7}	4.9424	4.9948
14	2.24×10^{7}	2.29×10^{7}	5.0644	5.1428

Table A- 21: Volume fractions of blood in slgt and non slgt chicken

Volume fraction of blood in slgt chicken	Volume fraction of blood in non slgt chicken
0.0008	0.0320
0.0072	0.0440
0.0136	0.5600
0.0200	0.0680
0.0264	0.0800

Table A- 22: Relative permittivity of blood and muscle of chicken

Frequency(Hz)	Chicken's blood	Chicken's muscle
100	6.48×10^6	2.48×10^3
500	5.64×10^6	1.02×10^3
1000	4.62×10^6	8.19×10^2
1500	3.85×10^6	7.22×10^2
2000	3.22×10^6	6.58×10^2

Table A- 23: Effective relative permittivty of slgt chicken

Frequency(Hz)	Volume fraction of blood				
	0.0008	0.0072	0.0136	0.0200	0.0264
100	2.48×10^3	2.53×10^3	2.58×10^3	2.63×10^3	2.68×10^3
500	1.01×10^3	1.03×10^3	1.05×10^3	1.07×10^3	1.09×10^3
1000	8.21×10^2	8.37×10^2	8.53×10^2	8.69×10^2	8.86×10^2
1500	7.24×10^2	7.38×10^2	7.52×10^2	7.66×10^2	7.81×10^2
2000	6.60×10^2	6.73×10^2	6.86×10^2	6.99×10^2	7.12×10^2

Table A- 24: Efferctive relative permittvity of non slgt chicken

Frequency(Hz)	Volume fraction of blood				
	0.0320	0.0440	0.0560	0.0680	0.0800
100	2.72×10^2	2.82×10^2	2.92×10^2	3.02×10^2	3.12×10^2
500	1.11×10^2	1.15×10^2	1.19×10^2	1.23×10^2	1.28×10^2
1000	9.00×10^2	9.32×10^2	9.64×10^2	9.98×10^2	1.03×10^2
1500	7.94×10^2	8.22×10^2	8.50×10^2	8.80×10^2	9.10×10^2
2000	7.24×10^2	7.49×10^2	7.75×10^2	8.02×10^2	8.30×10^2

APPENDIX B

FIGURES OF DIELECTRIC PROPERTIES VERSUS FREQUENCY

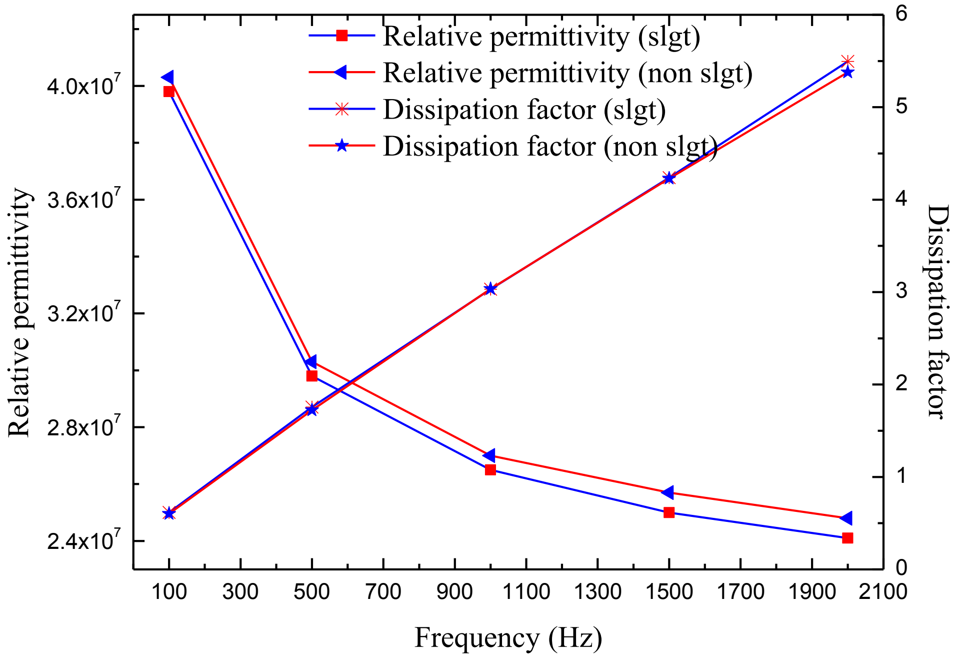

Figure B- 1:Dielectric properties versus frequency, 6 days after slaughter

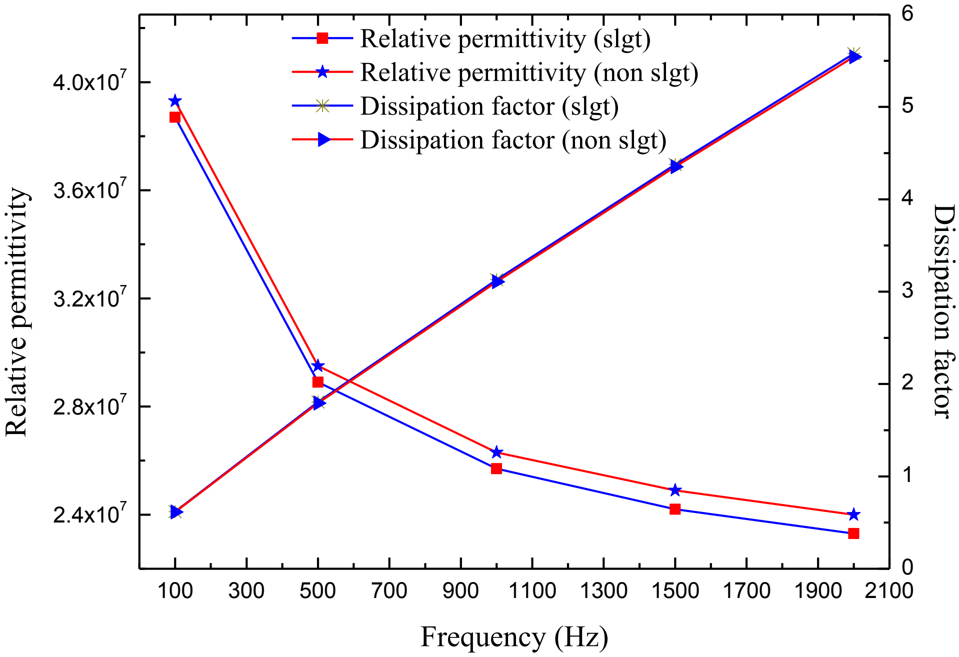

Figure B- 2: Dielectric properties versus frequency, 7 days after slaughter

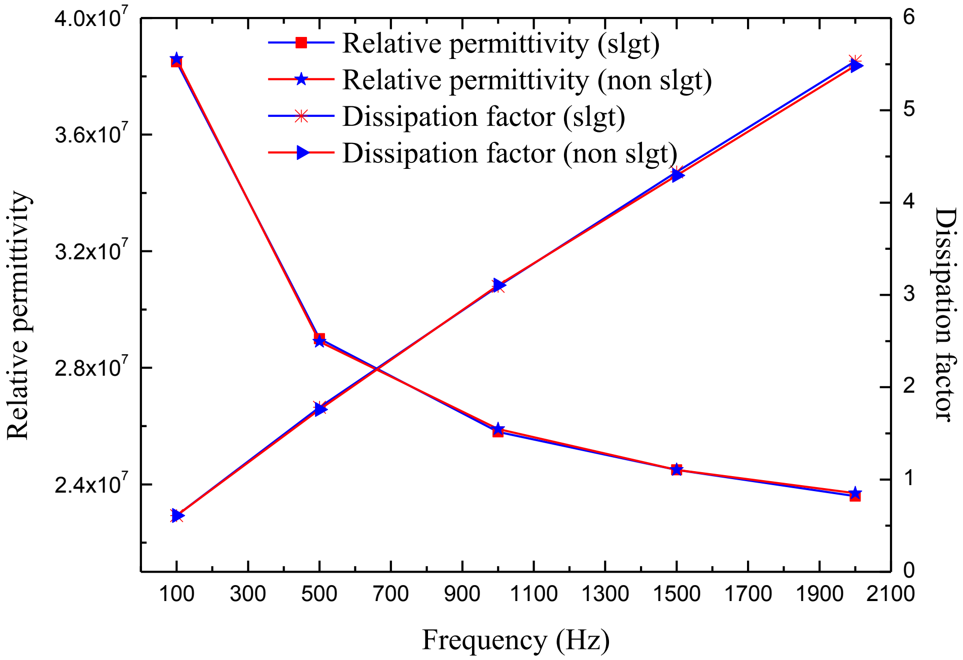

Figure B- 3: Dielectric properties versus frequency, 8 days after slaughter

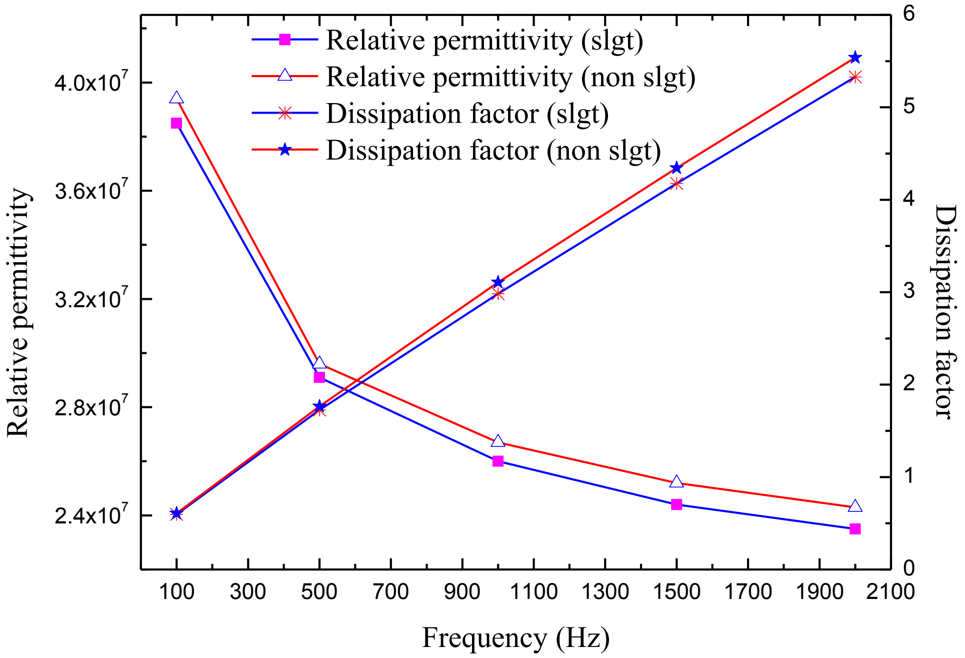

Figure B- 4: Dielectric properties versus frequency, 9 days after slaughter

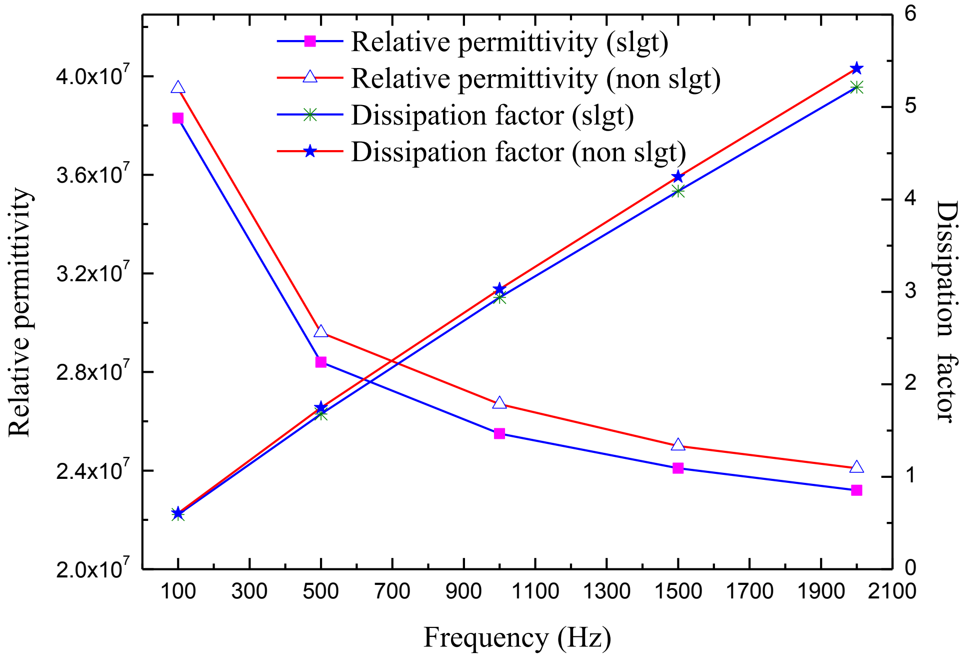

Figure B- 5: Dielectric properties versus frequency, 10 days after slaughter

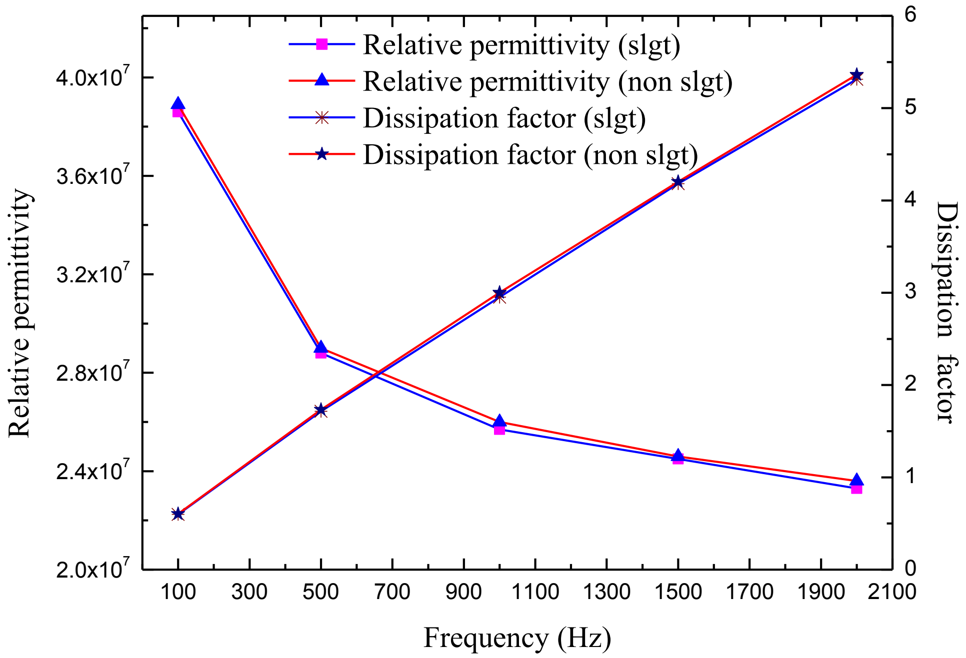

Figure B- 6: Dielectric properties versus frequency, 11 days after slaughter

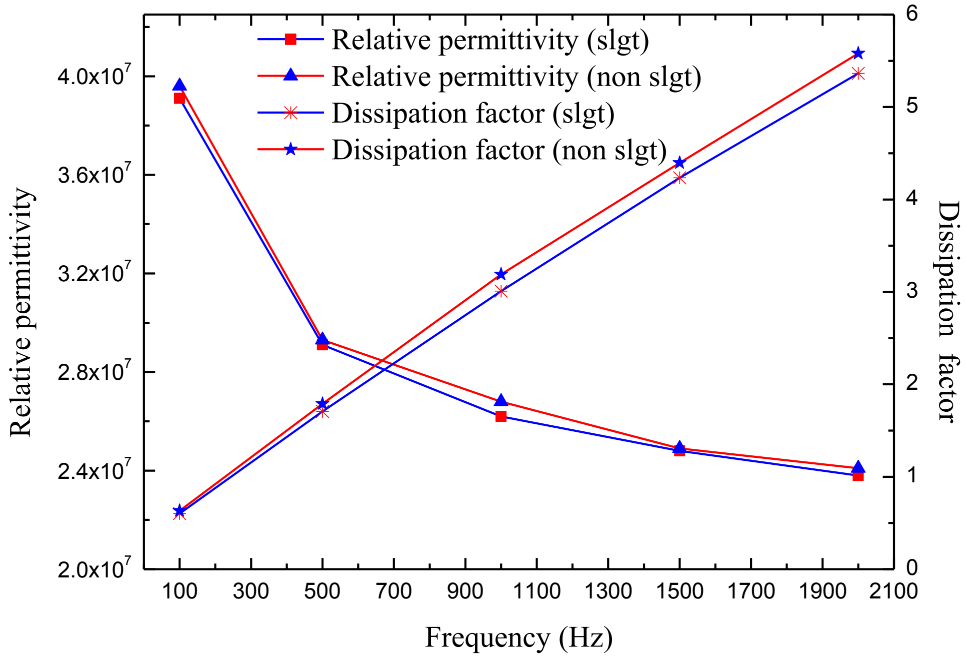

Figure B- 7: Dielectric properties versus frequency, 12 days after slaughter

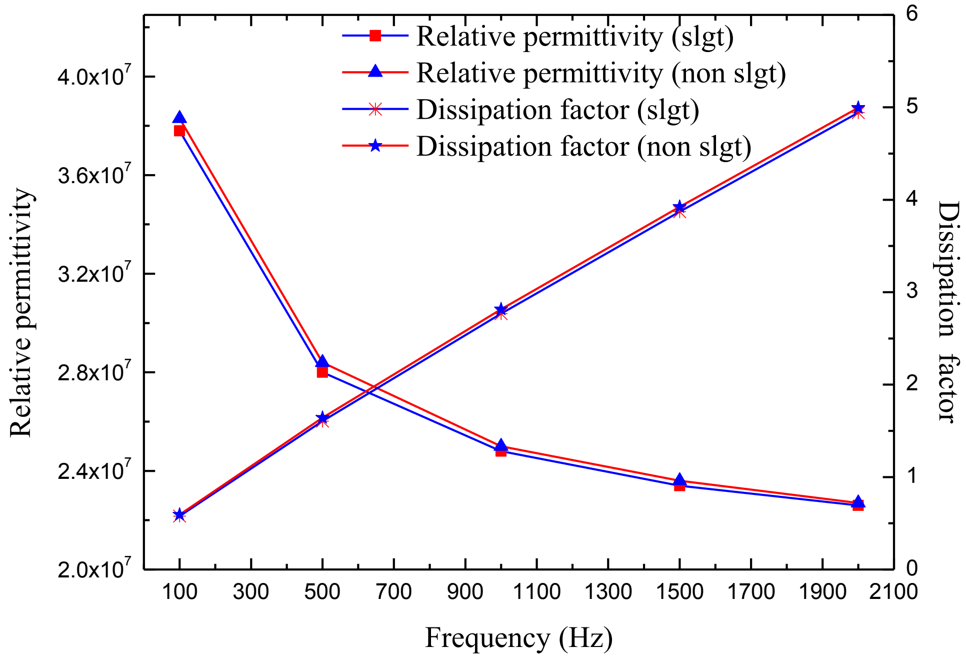

Figure B- 8: Dielectric properties versus frequency, 13 days after slaughter

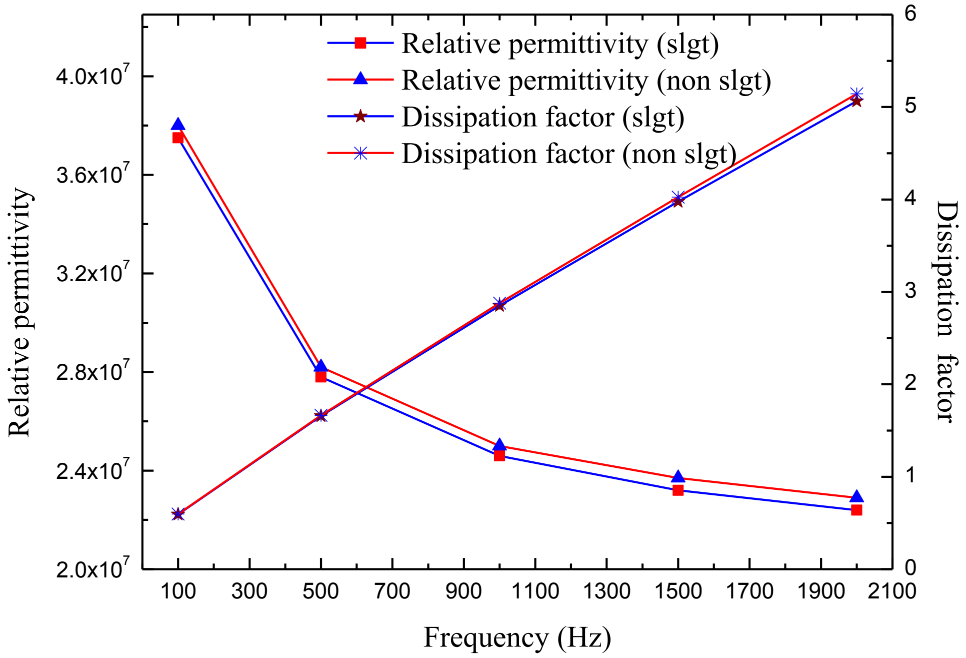

Figure B- 9: Dielectric properties versus frequency, 14 days after slaughter