Bio Impedance Spectroscopy For The Assessment Of Quality Of Fruits By Constructing The Equivalent Circuit.

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Abstract

A computer based virtual instrument is developed based on impedance spectroscopy technique to analyse the electrical properties of fruits and there by investigating the relationship of impedance spectroscopy nyquist plot and the quality of fruits. The instrument is developed with a application specific software developed using LabView and the electrical equivalent circuit parameters like Rp, Cp, r, R1, C1, R2 etc are calculated.

Keyword: Bio-impedance spectroscopy

1. Introduction

Impedance Spectroscopy (EIS) or AC impedance methods have seen tremendous increase in popularity in recent years. EIS studies the system response to the application of a periodic small amplitude ac signal. These measurements are carried out at different ac frequencies and, thus, the name impedance spectroscopy was later adopted. Analysis of the system response contains information about the interface, its structure and reactions taking place there

When used to study Biological systems, Impedance analysis is based upon relating the measured electrical values of a subject to their physiologic equivalents as determined when the subject is the only unknown part of a safe and controlled electrical circuit. The properties of the circuit are well-defined and don't change over time. The method is precise, sensitive and specific in its ability to illustrate the changes inherent in the biological subject.

The resistance (R) of a length of homogeneous conductive material of uniform cross sectional area is proportional to its length (L) and inversely proportional to its cross sectional area (A). Although the body is not a uniform cylinder and its conductivity is not constant, an empirical relationship can be established between the impedance quotient (L2/R) and the volume of the water, which contains electrolyte that conduct the electrical current through the body. Hence the measurement of impedance can be used for the characterization of biological subjects. This is the basic principle behind the bio-impedance spectroscopy.

1.1 Bio cells

All living things are made of cells. Cells are membrane bounded compartments filled with a concentrated solution of chemicals and salts. Groups of cells perform specialized functions and are linked by an intricate communications system. The cell membrane maintains an ion concentration gradient between the intracellular and extracellular spaces. This gradient creates an electrical potential difference across the membrane which is essential for cell survival. Electrical gradients are necessary to support movement of oxygen, carbon dioxide, and nutrients. Therefore, the cell membrane has electrically insulating qualities to maintain an electrical gradient. Damage to the cell membrane, and its functions, is as lethal to the cell as direct damage to the nucleus itself.

In the healthy living body, the cell membrane consists of a layer of non-conductive lipid material sandwiched between two layers of conductive protein molecules. Biologically, the cell membrane functions as a permeable barrier separating the intracellular (cytoplasm) and extracellular components. The lipid membrane is transversed by proteins, which are

soluble in water thus making pores through which water; ions and other chemicals can enter and exit the cell. Controlling the flow of these materials is essential to life. The cell membrane protects the interior of the cell while allowing passage of some materials to which it is permeable. The cell membrane is composed mostly of a double layer of phospholipids, arranged tail to tail along the width of the cell membrane. This structure is called the lipid bi-layer and is an electrical insulator (dielectric) as all fats and oils are. The head of the phospholipids are polar (carry a charge) and the tails are non-polar. The heads interact with water, where the tail is repulsed by water aligning them tail to tail with the heads facing the outside and inside of the cell. Fig.1 shows equivalent circuit of a biological cell.

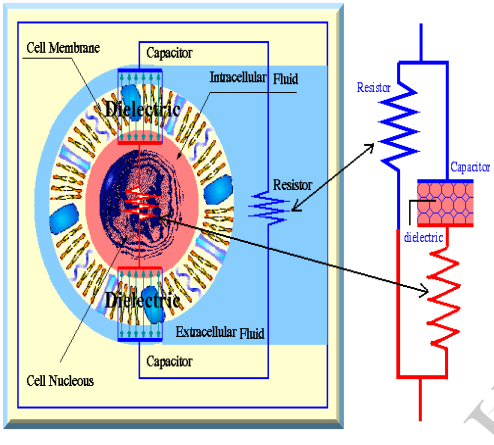

Fig.1 The equivalent circuit model of a biological samples

2. INSTRUMENTATION

The technology called virtual instrumentation is used for the realization of the impedance analyzer instrument. In order to realize the above said feature, LabVIEW 8.2 (from M/s National Instruments) software is used for developing the application specific software and National Instruments cards like NI 6281 or NI 6115 (data acquisition card) and NI 5401 (function generator card) are used for acquiring data and generating input signals.

The block diagram of the Universal Impedance Analyzer is shown in Fig.2. This consists of a Data acquisition card, a Function generator card, power amplifier, and a constant current source.

A function generator card (NI 5401) used to generate small amplitude input AC waveform of varying frequency along with required DC bias voltage to the DUT. This is a single channel 12 bit resolution programmable function generator card. It can generate an AC waveform from 1Hz to 16MHz with a frequency resolution of 9.31mHz and the output voltage ranges from +/-5V into a 50Ω load or +/-10V into a high impedance load with an accuracy of +/-0.01dB. Hence this card is used to generate an AC signal with a voltage of 0.4V to 5V with a variable frequency (in the same range), which is fed to a Howland constant current source for biological subjects as DUTs.

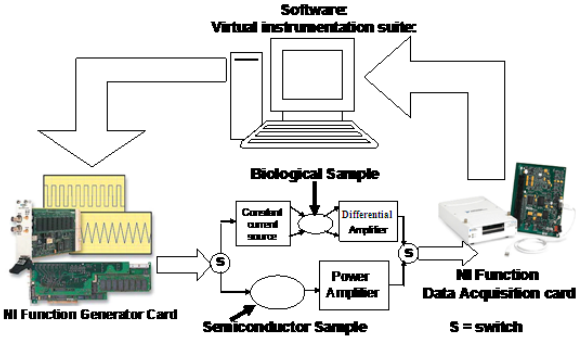

Fig.2: Block diagram of Universal Impedance Analyzer

A programmable data acquisition card is used to measure the voltage across the DUT and also to measure the current through the DUT. The data acquisition card used here is NI 6281. This card is having 16 input channel with resolution of 18 bits (can scan at a rate of 625ksamples/sec), two output channel with 16 bit resolution and 24 digital I/O ports. The digital I/O channels can be used to switch the relay. But for better accuracy one should read at least 10 times the input frequency. This data acquisition card reads only a signal with maximum 60 kHz frequency. So it is recommended to use another data acquisition card which is having high scan rate, say NI 6115.

A howland current source is used for generating constant current which is used in biological application. An Application specific software is developed using LabVIEW 8.2 software for automating the instrument and plotting and finally for calculating the equivalent circuit.

3. EXPERIMENTATION

The impedance spectroscopy experiments are conducted on some biological samples to produce the equivalent circuit models of these samples and also to monitor the changes with time. Here the sample used

is banana. The experiment is carried out by keeping banana as DUT. The test is conducted by applying a sine wave current of amplitude 2mAp-p, with a starting frequency 1Hz and ending frequency 10 kHz and number of point between start to end frequency are 100. The experiment is repeated for three times with an interval of 1 hour. The obtained results are shown in Fig.3 to Fig.11. Nyquist plot and capacitance plot for fresh sample of banana before and after fitting are shown in Fig.3 and Fig.4. The equivalent circuit models are shown in Fig. 5 along with their values.

Nyquist plot and capacitance plot of banana sample (after 1 hour) are shown in Fig.6 and Fig.7 and the equivalent circuit models are shown in Fig.8 along with their values.

Nyquist plot and capacitance plot of banana sample (after 2 hour) shown in Fig.9 and Fig.10. The equivalent circuit models are shown in Fig.11 along with their values.

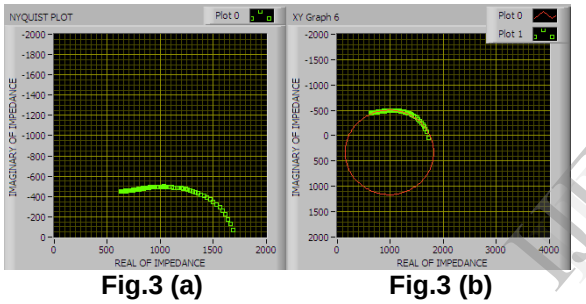

Fig.3 (a) Fig.3 (b)

Nyquist plot with measured data and fitted data

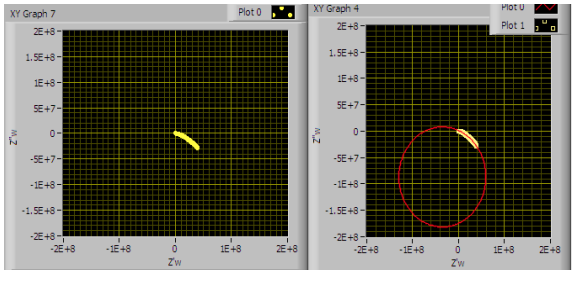

Fig.4(a) Fig.4(b)

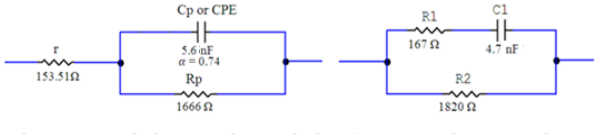

Fig.5: Model 1 and Model 2 for Fresh sample of Banana

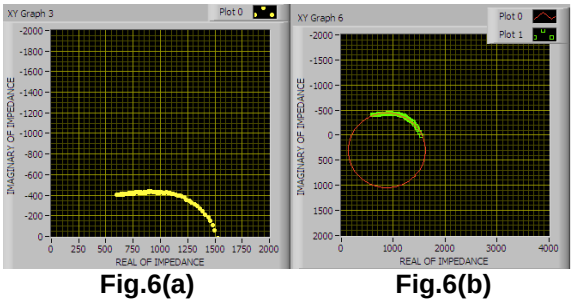

Fig.6(a) Fig.6(b)

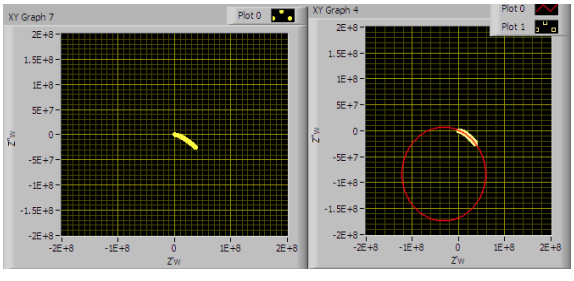

Fig.7(a) Fig.7(b)

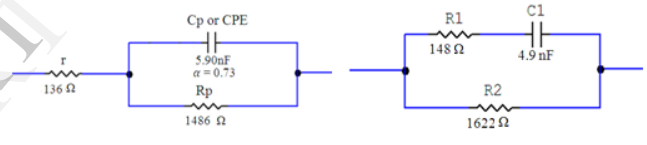

Fig.8. Model 1 and Model 2 for Banana sample after one hour

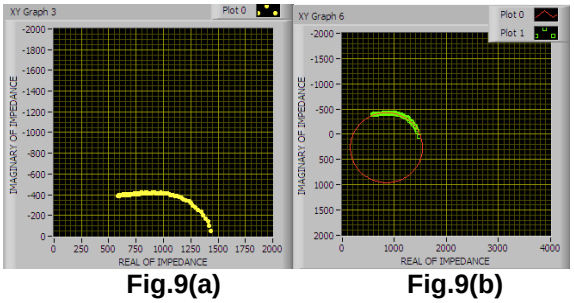

Fig.9(a) Fig.9(b)

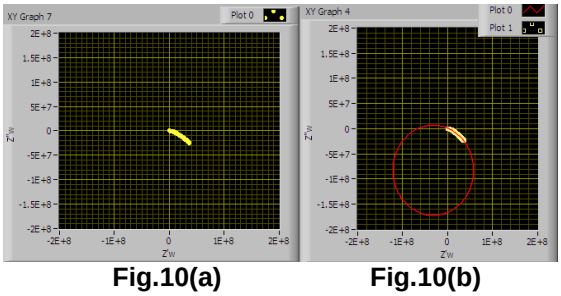

Fig.10(a) Fig.10(b)

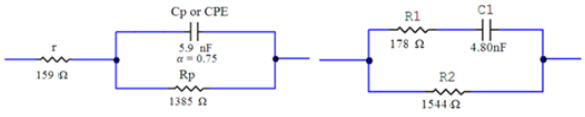

Fig.11: Model 1 and Model 2 for Banana sample after two hour

The variation in electrical parameters of banana with time is shown in Table 1.

	Electrical parameters	Fresh banana sample	Banana sample after 1 h	Banana sample after 2 h
Model 1	r	153Ω	136Ω	159Ω
	Rp	1666Ω	1486Ω	1385Ω
	Cp	5.6nF	5.9nF	5.9nF
	CPE (α)	0.74	0.73	0.74
Model 2	R1	167 Ω	148Ω	178Ω
	C1	4.7nF	4.9nF	4.7nF
	R2	1820 Ω	1622Ω	1544Ω

Table 1: Electrical parameters of Banana

4. CONCLUSION

The above results showed that Rp (in model 1) and R2 (in model 2) decrease drastically with time. R2 value in model 2 is realized as the extracellular resistance and it decreases with time. But the value of r and R1 decreases first and then increases. A detail study has to be conducted to get the exact behavior of these parameters. The above results also showed that the α value of CPE, Cp and C1 values remain almost constant with time. Here CPE (α) value is not equal to one which indicates that Nyquist plot spectrum contains more than one time constant.

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