PRELIMINARY PROBE MEASUREMENTS OF DIELECTRIC PROPERTIES IN BIOLOGICAL TISSUES AT MICROWAVE FREQUENCIES

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I. INTRODUCTION

The measurement of the complex permittivity of biological tissues can be carried out by means of the non destructive open-ended coaxial technique presented here. It can present a great interest in application which require a rapid evaluation of properties in continuous quality control of industrial processes. Furthermore, this technique represents a useful diagnostic tool for detecting changes from a previous state or during process.

Measurements of the dielectric properties are an important part of the analysis of food products, as they provide valuable information in all stages of resource development ranging from evaluation to processing, process diagnostics and controls. Some research during the past several decades by investigators from many disciplinary fields shows that the primary determinants of electrical properties of food are frequency, temperature, chemical composition and physical structure. In some cases, it is not permissible to destroy any part of the material tested, especially in the monitoring of industrial processes. In order to provide a technique suitable to these applications, the study of reflection produced by some biological tissues in front of a open ended coaxial line aperture was initiated.

A processing system with accurate data acquisition and computation was also developed. We present a few typical preliminary measurements at ambient temperature on biological tissues which included muscle and fat.

II. MATERIALS AND METHODS

For complete dielectric characterisation of biological tissues, it is necessary that the dielectric properties be measured over a broad frequency band. It is also important to simulate in a laboratory the real conditions existing in an industrial environment. Based on these requirements, it is clear that in developing an adequate and versatile system for measuring the dielectric properties, attention should be focused on using an automatic broad band measuring system.

The key components of the measurement system are the probe and the network analyser which is a Hewlett-Packard model 8753C. The probe is an open-ended coaxial line. The geometry of the probe and a proposed equivalent circuit for the TEM mode in the coaxial line are shown in Fig. 1.

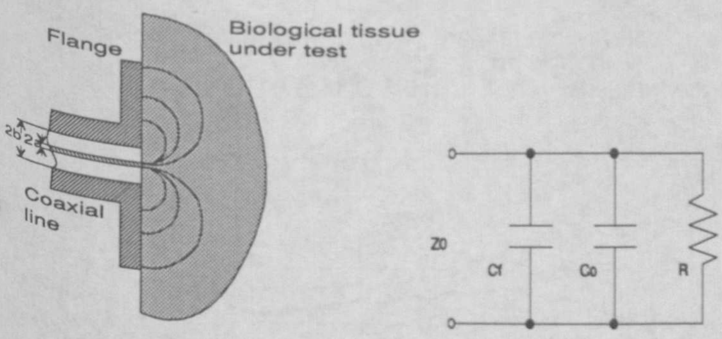


Fig.1 Geometry of the open-ended probe and an equivalent circuit

The capacitance C_t represents the electric field concentration inside the Teflon filled part of the coaxial line. The capacitance C_0 and the conductance R represent the fringing field concentration and radiation into the dielectric surrounding the sensor. The biological tissue under test is assumed to be homogeneous, isotropic, linear and non magnetic and of complex relative permittivity

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

Conduction losses are included in the term ε''.

The input reflection coefficient S_{11}^{*} of the sample is equal to $S_{11}^{*} = S_{11}e^{j\phi} = \dfrac{Z_l/Z_0 - 1}{Z_l/Z_0 + 1}$ where Z_l is the input impedance at the edge of the probe, and Z_0 is the characteristic impedance of the coaxial line.

The input reflection coefficient is equal to $$S^{*} = \frac{1 - j\omega Z_0[C_0 + C_f]}{1 + j\omega Z_0[C_0 + C_f]}.$$

and from this the relative dielectric constant ε′ the loss factor ε″ and the loss tangent tanδ are

$$\varepsilon' = \frac{2S_{11}\sin(-\phi)}{\omega Z_0 C_0\left(1 + 2S_{11}\cos\phi + S_{11}^2\right)} - \frac{C_f}{C_0} \qquad \varepsilon'' = \frac{1 - S_{11}^2}{\omega Z_0 C_0\left(1 + 2S_{11}\cos\phi + S_{11}^2\right)} \qquad \tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{1 - S_{11}^2}{2S_{11}\sin(-\phi)}$$

if C_f/C_0 is much smaller than ε′ which is always the case when the dimensions of the coaxial line are appropriately selected and for situations involving measurement of tissues with high dielectric constant.

The automatic network analyser HP8753C with the transmission test setup HP85047A is calibrated before measurements are made, and a one port calibration is performed using a conventional method with short-circuit, open circuit and a standard. In this case, we chose pure deionised water as standard because of high value of ε′. Fig.2 illustrates the measurement system employed to measure the dielectric constant of tissue samples. A computer collects the reflection coefficient S_{11} and phase angle ϕ from the network analyser and computes the complex permittivity of the biological tissue sample. We used the correcting model implemented by Hewlett-Packard on the network analyser. We used precision HP connectors and cables and errors due to directivity and source mismatch were corrected at each measurement.

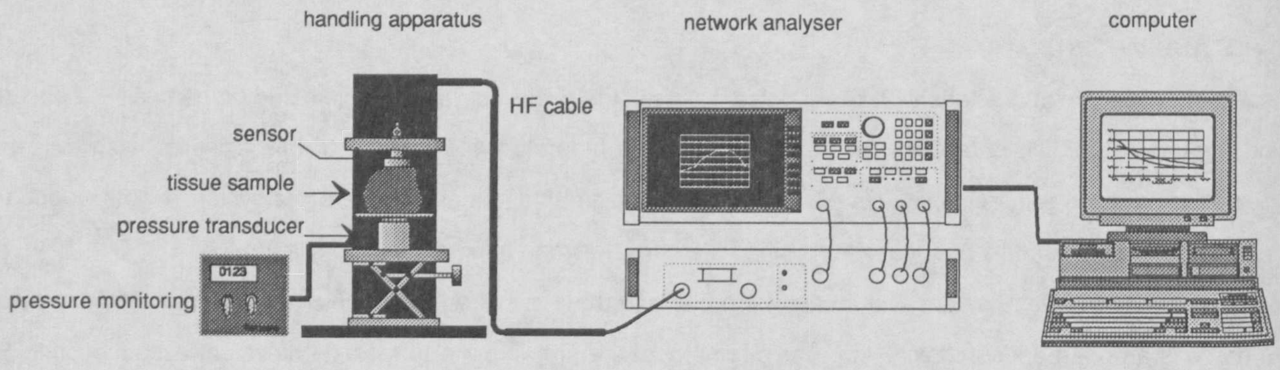


Fig.2 The dielectric measurement system

To check the accuracy of the procedure, the complex permittivity of standard material was measured. The obtained results are shown on Fig.3 and good accuracy is achieved in the frequency range from 0.5 GHz to 6 GHz.

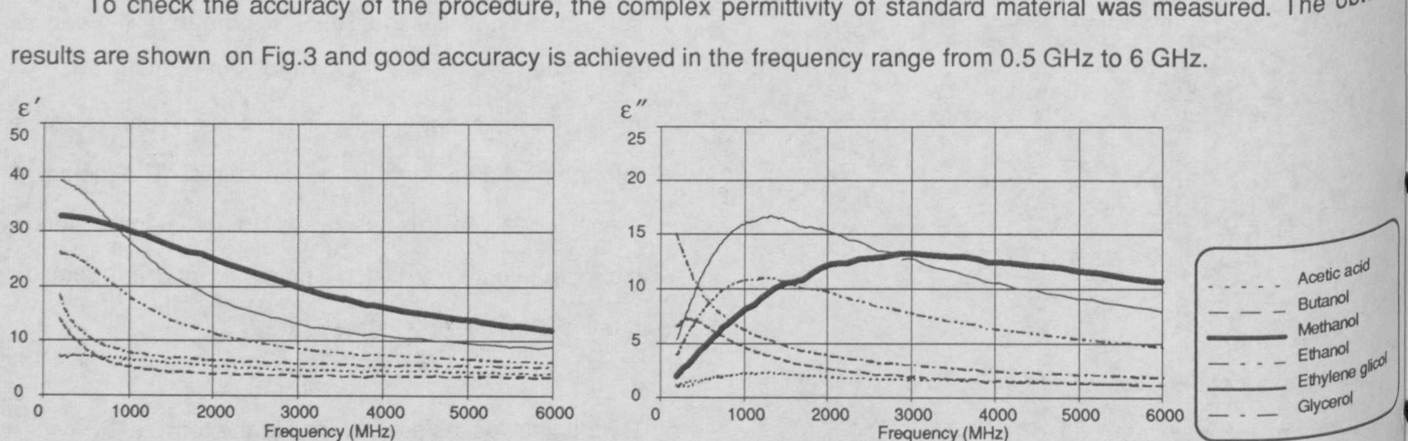


Fig.3 Complex permittivity and loss factor measured on some reference liquids.

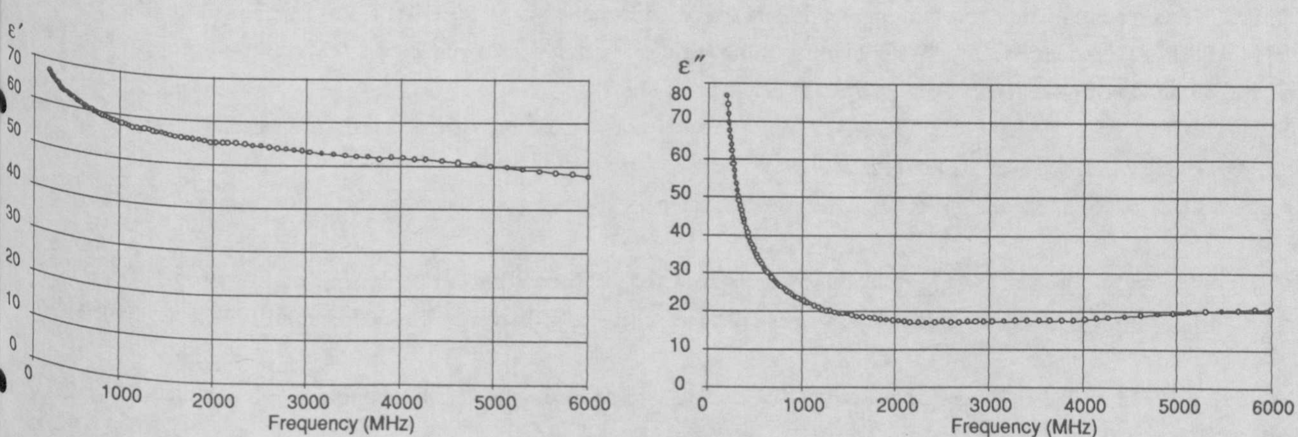
Our broad band measurements are in good concordance with the literature data. The range of variations of literature values of liquids with high dielectric loss we used as references is wide. Anyway we can compare our results and literature data for some of them for particular frequencies as shown on Table I.

Liquid	Measured		Literature		Reference
	ε′	ε″	ε′	ε″	
Acetic acid	4.5	1.5	5.1	0.79	P.O. RISMAN (1971)
Butanol	4	1.9	3.5	1.6	VON HIPPEL (1954)
Methanol	23	13.5	18.5 - 24	14 - 15.5	P.O. RISMAN (1971)
Ethanol	8	8	5.1 - 6.5	1.6 - 6	P.O. RISMAN (1971)
Ethylene glycol	13	13	12	12	VON HIPPEL (1954)
Glycerol	7	3	8.9	6.1	P.O. RISMAN (1971)

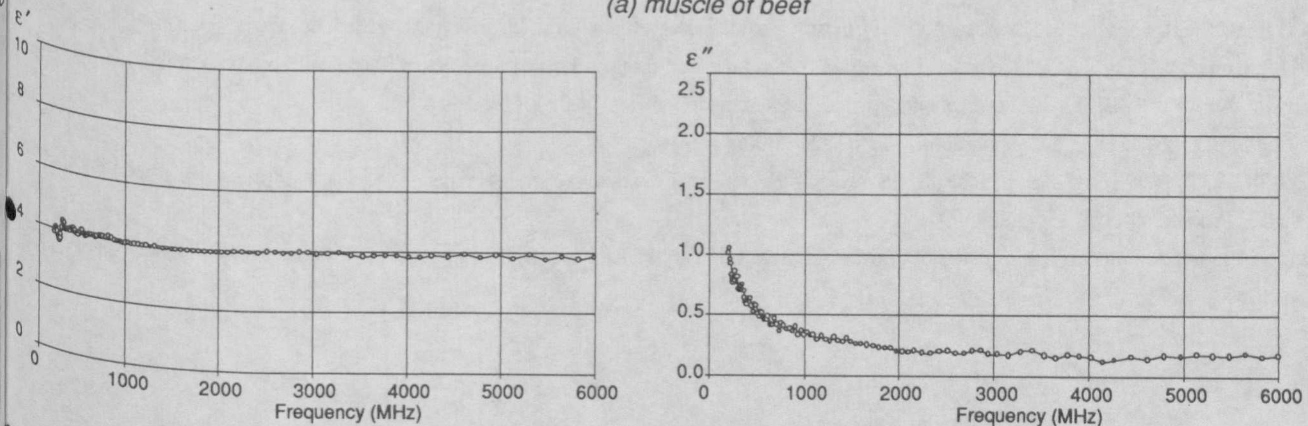
Table I . Comparison of the permittivity values measured and values from literature at 3 GHz and temperature about 20° C).

III. RESULTS AND DISCUSSION

In this section, we present a few typical results from preliminary measurements at ambient temperatures. The dielectric permittivity and dielectric loss factors for samples of meat and fat tissues are shown in Fig. 4. Tissue samples were obtained from freshly killed beefs. All measurements were taken after complete calibration of the network analyser.



(a) muscle of beef



(b) Fat tissue of beef

Fig. 4. Experimentally measured dielectric constant and loss factor of muscle (a) and fat tissue (b) of beef at room temperature.

It must be emphasized that the results values are not to be regarded as definitive as the purpose of these initi measurements was to test the probe and the method. Anyway we can compare our measurements with those obtained by S. RAY and J. BEHARI (1988): ε′ 49-52 for muscle at 1 GHz and 19°C, E.C. BURDETTE (1981): ε′ 46 and ε″ 12 for muscle ε′ 5.5 and ε″ 0.8 for fat tissue at 3 GHz and 20 C and to notice that we are in good agreement with reported values except the value of ε″ in fat tissue. The curves representing dielectric constant clearly show a great difference between behaviour muscle and fat tissue tested. It is evident from the data obtained here that the dielectric constant of muscle is slightly higher and this may be attributed to the higher water content.

IV. SUMMARY

Development of automation in industrial processes creates a growing need for improved sensors for process monitoring and control. A method has been demonstrated for measurement of the complex permittivity of biological tissues on a broad frequency band using an open ended coaxial line as probe sensor with an measuring system based on an automatic network analyser. Results of system performance evaluation via measurements of standard liquid dielectric are presented. Some preliminary results on biological tissues are reported showing a significant difference between the dielectric properties of muscle and fat tissue.

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