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# Application of electrical admittance measurements to the quality control of milk

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**Abstract**

The method of electrical admittance spectroscopy has been used to study the water and fat content of milk. Over the frequency range 5 Hz to 1 MHz, the electrical circuit was dominated by a single time constant. To eliminate the effect of electrode polarisation, the conductance of the milk was measured at high frequencies where it showed a saturation value. The characteristics at 100 kHz and 8 °C for all milk samples revealed a linear decrease in conductance with increasing water content. Admittance data for full fat, semi-skimmed and skimmed milk showed an increase in milk conductance with decreasing fat content. 

*Keywords:* Electrical admittance; Milk

## 1. Introduction

Valuable information about the electrical conduction behaviour of solid or liquid materials may be obtained by performing electrical admittance measurements over a wide range of frequencies. Admittance spectroscopy can also be used for gas and vapour sensing [1,2] and for quality control of a variety of foodstuffs [3,4]. The electrical conductivity of dairy products has been studied for more than 40 years to provide accurate values of the fat and protein content [5–7]. Recently, adulteration has led to considerable problems in the milk industry and it has become necessary to develop new and improved instrumentation for the rapid and reliable detection of fraud. Several standard methods can be used to detect the concentration of water or fat content in milk. These techniques are based on the changes in freezing point of the milk (cryoscopic method) or on changes in refraction of light of the whey component of milk after the removal of the fat components. Here, we apply the technique of admittance spectroscopy to investigate the fat and water content in different types of milk.

## 2. Experimental details

The sensing devices consisted of two gold electrodes (L shaped) $15\,mm \times 6\,mm$ with a separation of 1 mm. The electrodes were deposited by thermal evaporation under high vacuum conditions ($10^{-6}$ mbar) onto clean glass microscope slides. Complex admittance measurements, in the frequency range of 5 Hz to 13 MHz, were performed using a HP 4192A impedance analyser. A schematic diagram of the measurement system is shown in Fig. 1. A four terminal configuration was used to connect the device electrodes to the impedance analyser. The analyser measures the real and imaginary parts of the impedance from the in-phase current and $90^{\circ}$ out-of-phase current with respect to the applied voltage. Calibration measurements on the leads connecting the device to the impedance analyser were also made to take into account the effect of any parasitic elements. Values of the conductance and capacitance of the leads were automatically eliminated from those values measured with the device connected. The RMS amplitude of the ac voltage was 700 mV, no significant changes in the sensing properties of the device were observed at lower voltages. Measurements consisted of 90 points equally spaced on a logarithmic scale in the measured frequency range.

The conductivity of milk as a function of fat and water content was determined using samples (full fat, skimmed and semi-skimmed) obtained from different local supermarkets. Milk samples were prepared by adding ultra pure water to the original milk to achieve the required volume percent water. These samples were carefully stirred to mix the water with the milk to avoid the generation of air bubbles that would have reduced the conductivity.

Samples of 25 ml were introduced into the measurement system, which was then placed in a refrigerator to keep the

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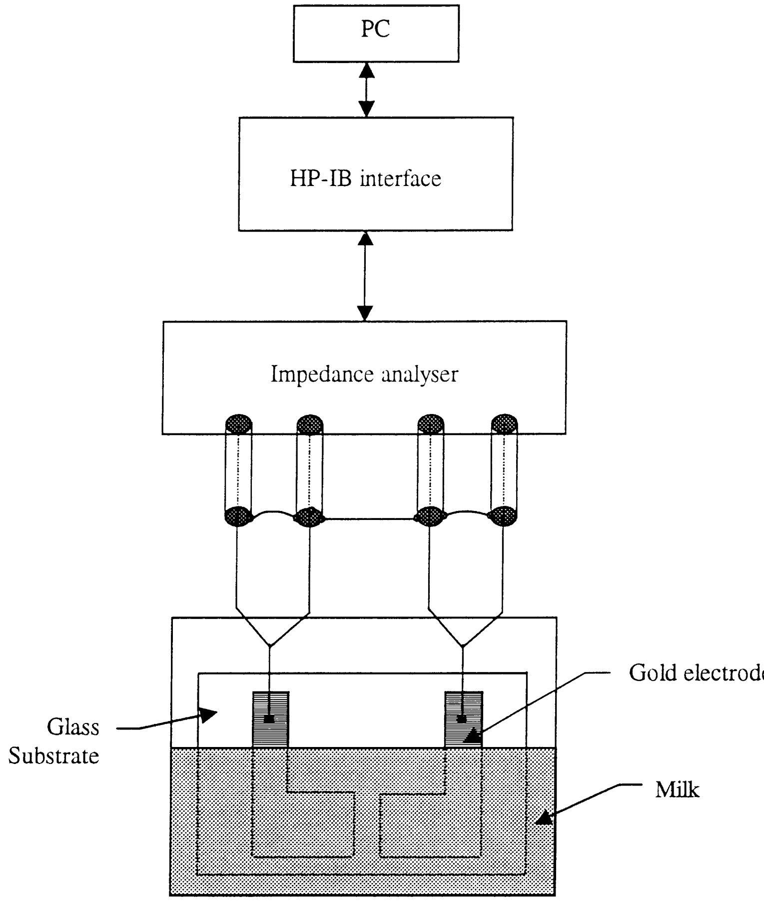


Fig. 1. Schematic diagram of the impedance analyser system.

sample's temperature between 2 and 8 °C, measured by a Fluke 2170A digital thermometer. Careful control was very important as the conductivity of milk was found to change significantly with temperature. Before each experiment, the sensor was washed in a diluted detergent and rinsed with ultra pure water for at least 5 min and dried by exposure to a flow of dry nitrogen gas.

## 3. Results and discussion

The admittance measurements were obtained from the instrumentation in the form of a capacitance $C_m$ in parallel with a conductance $G_m$. Fig. 2 shows the frequency dependencies of $G_m$ for a mixture of full fat milk and pure water as a function of water content at 8 °C. The variation of the measured conductance with frequency for pure water is also shown for comparison. For all the milk samples, the conductivity exhibits a rapid variation with frequency below 10 kHz, but remains constant above this value. The high frequency saturation value decreases approximately linearly as the concentration of water in the milk increases, indicating that it is a property of the milk solution. The measured capacitance $C_m$ versus frequency as a function of the water content in milk is shown in Fig. 3. For all the samples, $C_m$ decreases monotonically with frequency and saturates at high frequencies at a value of about 20 pF. The measured capacitance data are presented in a different form in Fig. 4, which shows the variation of the measured susceptance ($B_m = \omega C_m$) with frequency.

The behaviour of conductance and capacitance together with the peak in the frequency dependence of the susceptance, shown in Fig. 4, indicate the presence of dielectric dispersion associated with the electrode polarisation [6]. The frequency at which the susceptance reaches a maximum represents the relaxation frequency of the electrode polarisation. From Figs. 2 and 4 it can be seen that gold electrodes exhibit a polarisation at around 250 Hz (for full fat milk), which decreases with increasing water content.

The electrical admittance between two electrodes immersed in an electrolyte can be modelled using series and parallel combinations of capacitors and resistors. An insight into the equivalent circuit can be obtained by plotting the real part of the complex admittance against its imaginary component [8]. The complex admittance data for two milk samples (50:50 water:full fat milk and 67:33 water:full fat milk) as a function of frequency are shown in this form ($B_m$ versus $G_m$) in Fig. 5. The data approximate to semicircles, indicating that the equivalent circuit of the measurement