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Dielectric Properties of Natural Rubber Latex at Frequencies from 200 MHz to 2500 MHz

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Experimental results for dielectric properties of natural rubber latex at 26°C over a frequency range of 200 MHz to 2500 MHz are presented. The study includes the variation of dielectric constant and dielectric loss factor with moisture content ranging from 40% to 100% (wet basis). A series of solution with various moisture contents were prepared from latex concentrate, diluted latex concentrate, freshly tapped latex and diluted fresh latex. Measurement of the dielectric properties was done by using open-ended co-axial line sensor and automated network analyser. Interesting results such as transition in the form of dielectric loss from conductive mechanism possibly due to interfacial polarisation to dipole orientation of water molecules at about 2 GHz were observed. A substantial conduction effect due to ammonia solution and conducting phases in the latex was also observed in the lower frequency region of the spectrum. However, the dielectric constant parameter showed a good relationship with moisture content and the effect of conducting phases and preservative is not detectable i.e. independent of the type of solutions. A suggestion for future design of moisture content sensor for Hevea *latex in this range of frequency is indicated.*

When electromagnetic waves pass through a non-magnetic dielectric material, the electric field interacts with the material and is quantified by relative complex permittivity $\varepsilon = \varepsilon' - j\varepsilon''$. The real part ε', which is known as dielectric constant or relative permittivity expresses the ability of the material to store energy and the imaginary part ε'', which is known as dielectric loss factor, is a measure of the energy absorbed from the applied field.

Information on the dielectric properties of materials can be used in industrial applications such as for indirect determination of moisture content which is an important parameter in the quality assessment, process control and microwave heating in the rubber industry.

The common technique used in the determination of moisture content is based on the electrical conductivity of the sample. The conductivity σ of the material is related to the dielectric loss factor by an expression[1] written as

$$\sigma = 2\pi f \varepsilon_o \varepsilon'' \qquad \ldots 1$$

where f is the frequency and ε_o is the absolute permittivity of free space.

Another technique is based on the relationship between moisture content and the attenuation and phase shift of electromagnetic waves passing through the sample or reflection coefficient at the surface of the sample.

The attenuation constant α, the phase constant β and voltage reflection coefficient Γ may be written as a function[2] of ε' and ε'' as

$$\alpha = 8.686 \frac{2\pi}{\lambda_o} \left[\frac{1}{2}\varepsilon'\{\sqrt{1+\tan^2\delta_l} - 1\}\right]^{1/2} \ldots 2$$

$$\beta = 8.686 \frac{2\pi}{\lambda_o} \left[\frac{1}{2}\varepsilon'\{\sqrt{1+\tan^2\delta_l} + 1\}\right]^{1/2} \ldots 3$$

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$$\Gamma = \frac{\sqrt{\varepsilon'} - 1}{\sqrt{\varepsilon'} + 1} \qquad \ldots 4$$

where λ_o is the free space wavelength and tan $\delta_l = \varepsilon''/\varepsilon'$.

The measurement of moisture content in *Hevea* latex based on transmission and reflection techniques has been successfully done by Khalid[3,4,5]. At an operating frequency of about 10 GHz, the technique is able to achieve an accuracy of about 1% compared with 0.02% accuracy with the standard laboratory method[6].

This paper presents the experimental results of the dielectric properties of *Hevea* latex at frequencies ranging from 0.2 GHz to 2.4 GHz as a function of moisture content. A suggestion for possible loss mechanism responsible for the dielectric loss is addressed. Finally, the aspects of measurement of moisture content in *Hevea* latex in this range of frequencies are also presented.

MATERIALS AND METHODS

A series of solutions of *Hevea* rubber latex with moisture contents ranging from 40% to 98% (wet basis) were prepared. The sample with the lowest moisture content was obtained from latex concentrate supplied by the Rubber Research Institute of Malaysia. Freshly tapped latex with moisture contents ranging from 25% to 45% were obtained from the university farm (RRIM 600 clone). The diluted samples were prepared by adding de-ionised distilled water to the latex concentrate or fresh latex.

Measurements of dielectric properties of *Hevea* latex in frequencies ranging from 200 MHz to 2500 MHz were done by using a 4 mm open-ended coaxial-line probe which was coupled to an automatic network analyser (HP 8720B) and a computer. In this well known method by Athey *et al.*[7], the probe was placed in contact with a latex sample and the dielectric permittivity was determined from input impedance at the interface of the probe/latex sample. With proper calibration procedures proposed by Kraszewski[8] involving short circuit, open circuit and distilled water, the accuracy of the measurement was found to be about $\pm 5\%$ for ε' and $\pm 3\%$ for ε''.

All measurements were done at room temperature (*i.e.* $26°C \pm 1°C$) and the actual moisture content of the sample was obtained by drying three 10 g samples at a temperature of 70°C. The averages of these results were recorded.

RESULTS

The spectrum of dielectric properties of *Hevea* rubber latex samples from latex concentrate, fresh latex, diluted fresh latex and de-ionised water is shown in *Figure 1*. For all samples, the dielectric constant parameters were almost constant throughout the frequency range and their magnitudes were found to be decreasing as percentages of moisture content in the sample decrease. The value of ε' for latex concentrate (38.5% moisture content) at 0.2 GHz was about 25. This value is very close to the extrapolated value measured by Laogun[9] which was done on latex concentrate (43.2% moisture content) with frequency ranging from 0.1 MHz to 100 MHz. The spectrum of loss factor ε'' demonstrates a sharp decrement as frequency increases as shown in *Figure 1* and after the minimum point at about 2 GHz, ε'' increases gently as frequency increases following the pattern of de-ionised water.

Figures 2a–g show the variation of ε' and ε'' with moisture content at specific frequencies. Throughout these figures, ε' demonstrates a linear relationship with moisture content and is almost unaffected by the type of solutions. However ε'' shows a spreading in its value which depends very much on the type of solution used. At 0.2 GHz *(Figure 2a)*; for the same value of moisture content, the magnitude of ε'' is found to be higher for the solution originated from latex concentrate compared to the solution from fresh latex or diluted fresh latex. Both types of solution almost

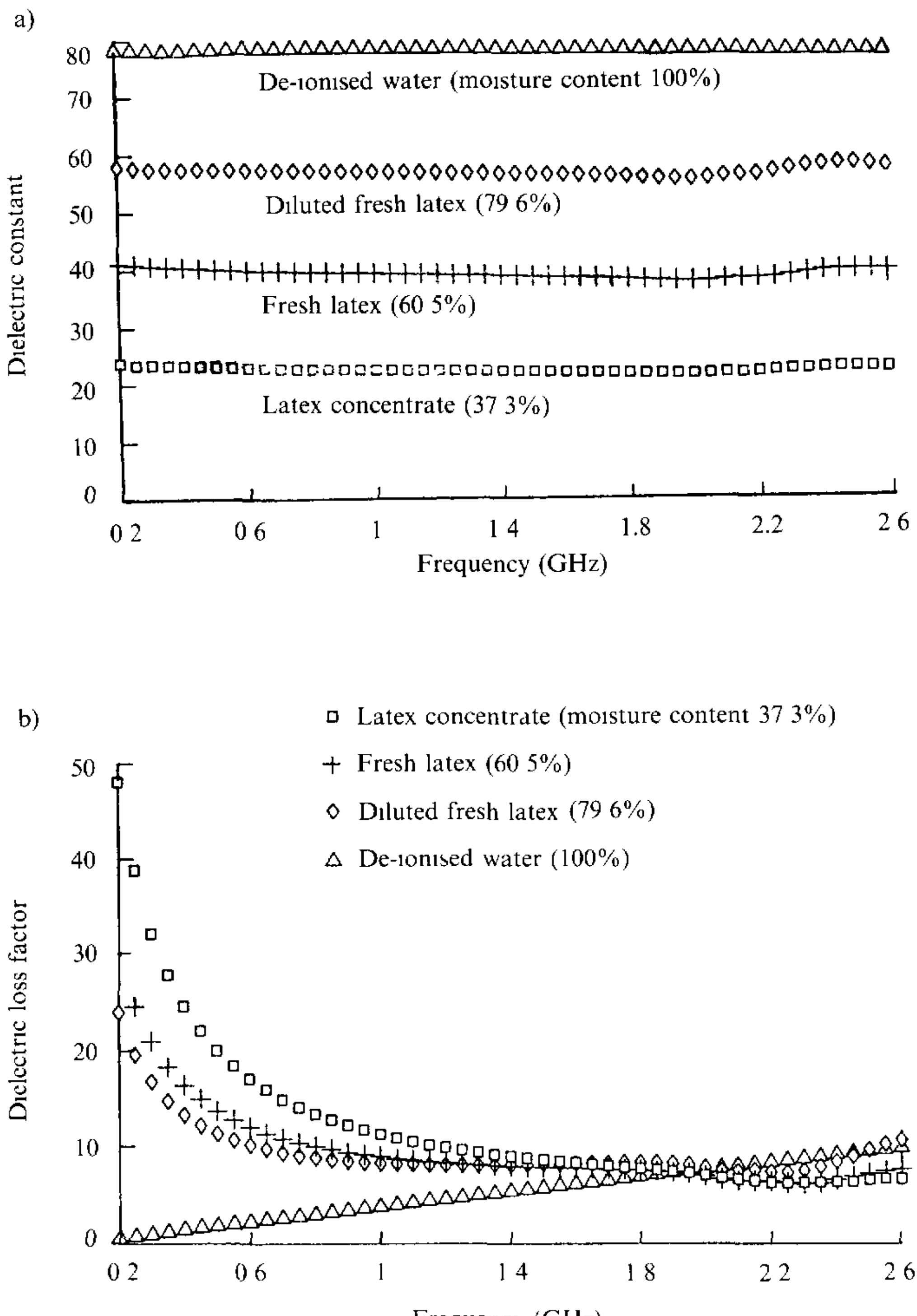


Figure 1 Dielectric properties of natural rubber latex at 26°C as a function of frequency

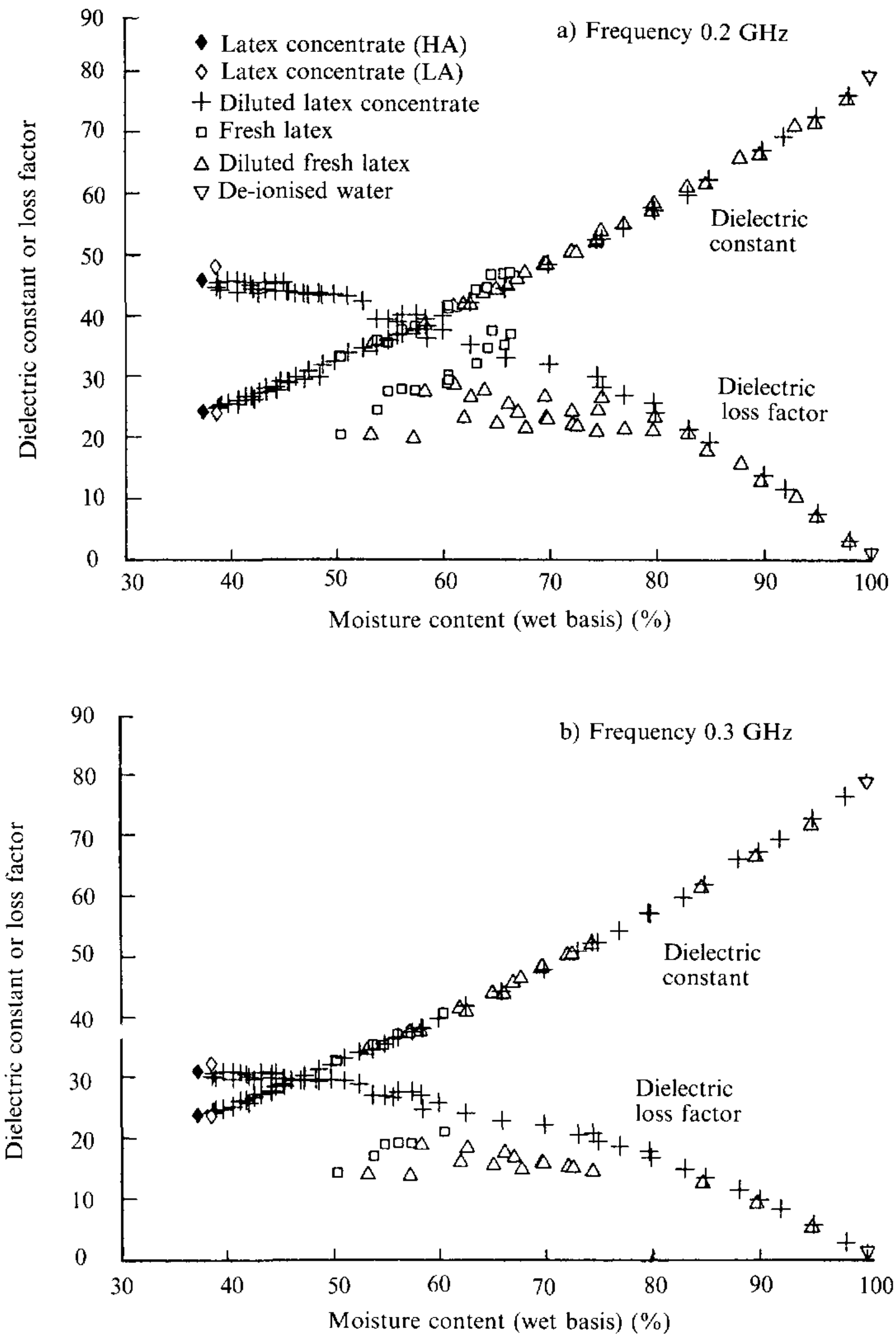


Figure 2. Dielectric properties of natural rubber latex as a function of moisture content (wet basis) at 26°C and specific frequencies of 0.2 GHz to 2.4 GHz.

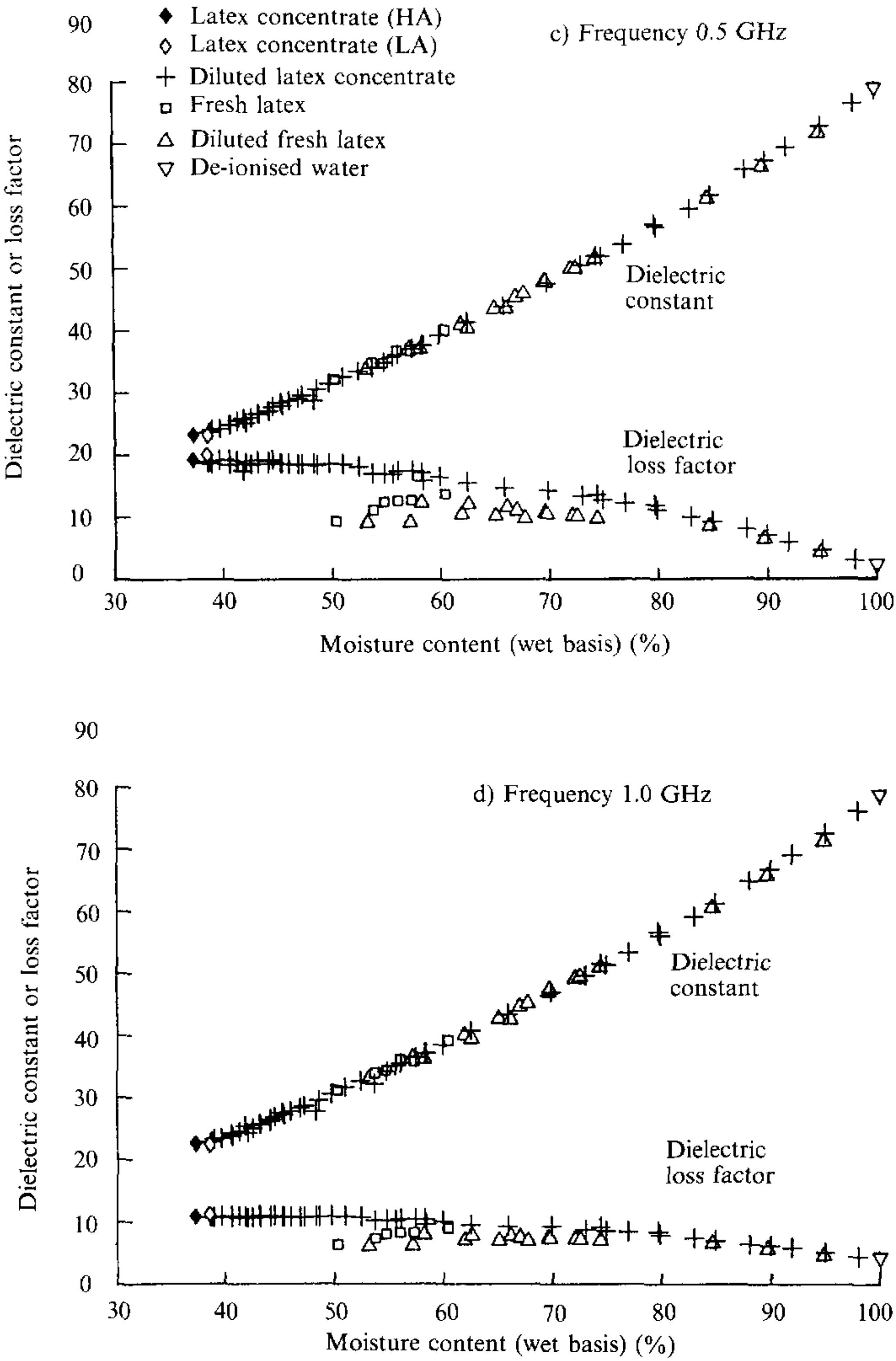
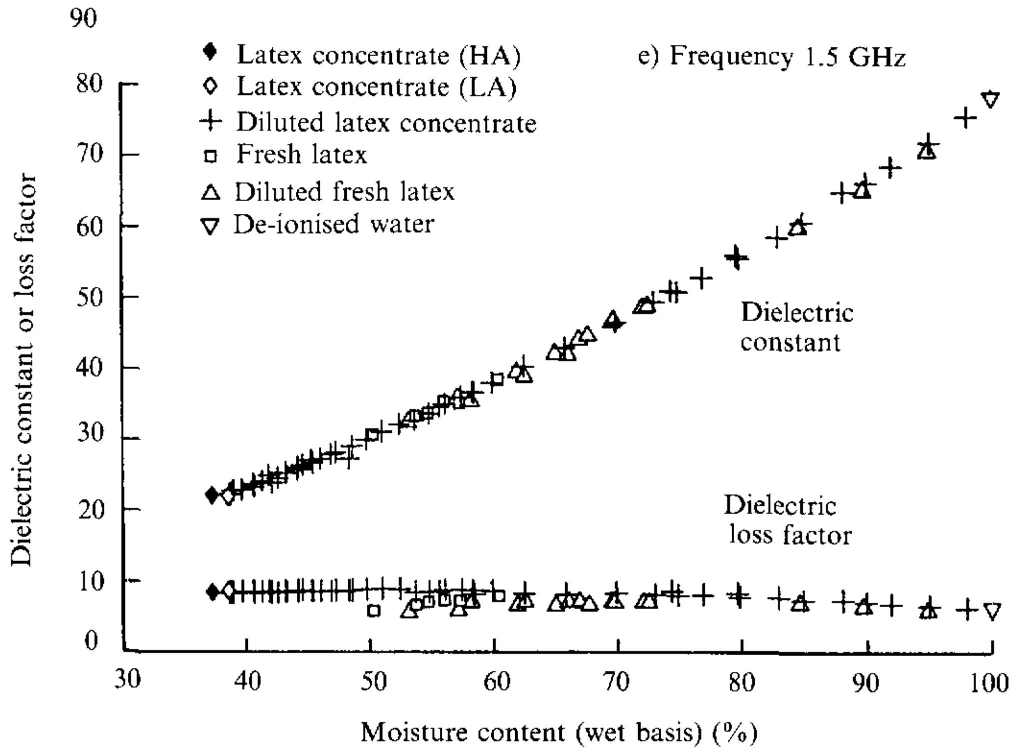
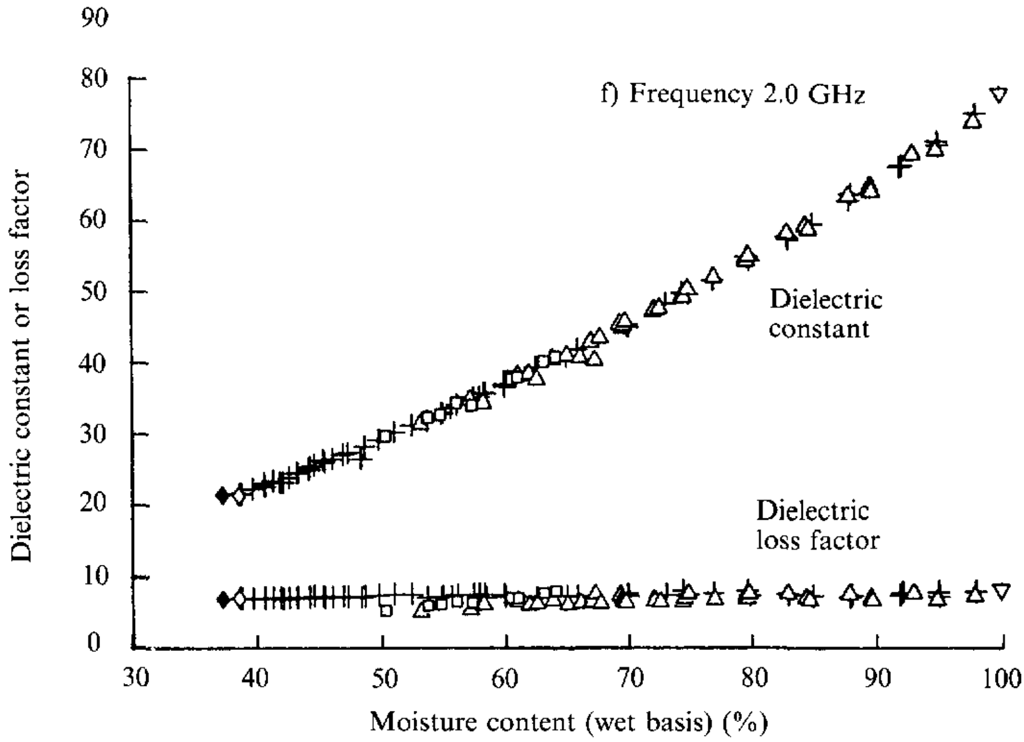


Figure 2. Dielectric properties of natural rubber latex as a function of moisture content (wet basis) at 26°C and specific frequencies of 0.2 GHz to 2.4 GHz (contd).





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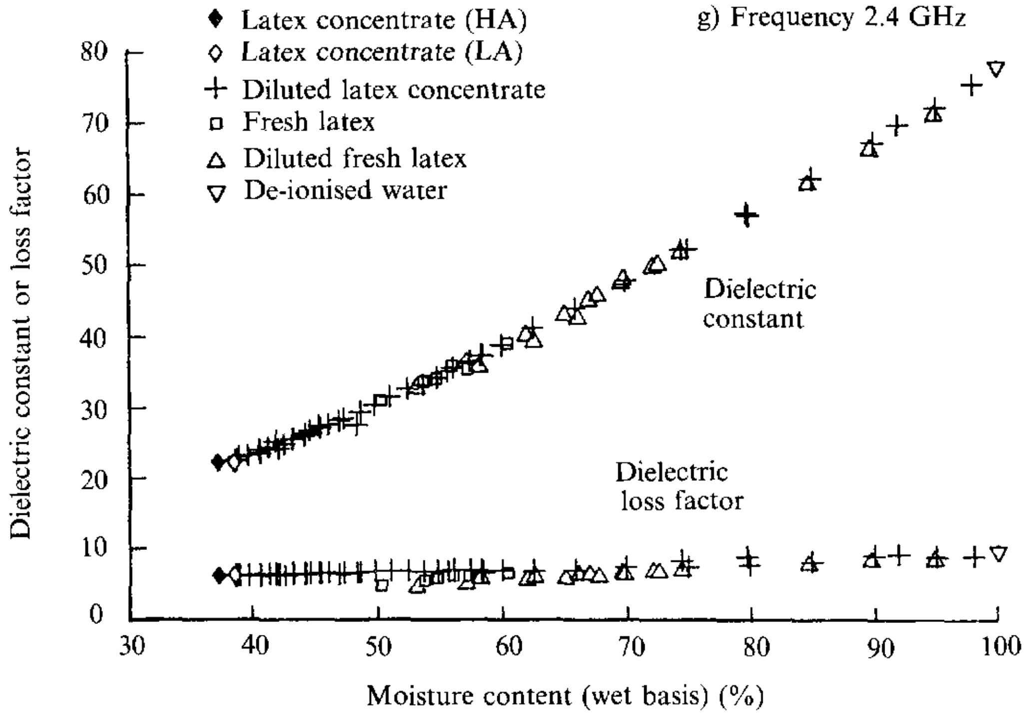

Figure 2. Dielectric properties of natural rubber latex as a function of moisture content (wet basis) at 26°C and specific frequencies of 0.2 GHz to 2.4 GHz (contd).

have the same value of ε″ at about 80% moisture content.

The difference of dielectric loss factor data between diluted latex concentrate samples and fresh latex samples with the same moisture content becomes smaller as frequency increases. This is clearly shown in *Figures 2 a–g.*

At 2.4 GHz, the ε″ values from different samples converge to a single line. *Table 1* gives the fitted dielectric constant data from various solutions and the dielectric loss factor data from diluted latex concentrate samples at selected frequencies.

DISCUSSION

In the frequency range of 0.2 GHz to 2.5 GHz, it is predicted that two types of dielectric loss occurred, namely the dipole loss ε''_d and the conductivity loss ε''_c which contribute additively to the total dielectric loss, *i.e.*

$$\varepsilon'' = \varepsilon''_d + \varepsilon''_c \qquad \ldots 5$$

Figure 1 illustrates the two forms of dielectric loss mechanisms in *Hevea* latex as a function of moisture content and frequency.

At frequencies higher than 2 GHz, the dielectric loss is mainly due to the dipolar orientation ε''_d of the water molecules while at lower frequencies, the conductivity loss ε''_c predominates. It is known that latex consists of 2% – 3% conducting phases which arise from proteins, fatty acid soaps, phospholipids and various types of ionic species[10]. They are normally related to the build-up of charge particles at interfaces in this heterogeneous dielectric and is known as interfacial polarisation.

TABLE 1. FITTED DIELECTRIC CONSTANT DATA FROM VARIOUS SOLUTIONS AND THE DIELECTRIC LOSS FACTOR DATA FROM DILUTED LATEX CONCENTRATE SAMPLES AT SELECTED FREQUENCIES

Moisture content (wet basis)(%)	Frequency (GHz) 0.2	0.3	0.5	1.0	1.5	2.0	2.4
Dielectric constant, ε′							
40	25.8	24.6	24.2	23.8	23.2	22.8	23.9
50	32.7	31.9	30.8	30.9	30.5	29.4	30.7
60	40.1	39.6	38.5	38.8	37.9	37.2	38.2
70	48.1	47.7	47.3	47.4	46.4	45.6	46.8
80	57.3	57.7	56.9	56.7	56.1	55.0	55.9
90	67.3	67.3	67.7	67.1	66.1	65.6	66.4
100	79.2	78.5	78.1	78.8	77.9	78.1	77.3
Dielectric loss factor, ε″							
40	45.0	30.9	19.1	10.8	10.9	6.9	6.3
50	42.7	28.4	17.8	10.4	10.5	7.2	6.5
60	37.5	25.3	16.1	9.7	9.8	7.3	6.9
70	31.4	21.6	13.9	8.9	8.9	7.5	7.3
80	23.6	16.6	10.9	8.8	7.8	7.6	7.9
90	13.6	9.8	7.0	6.3	6.3	7.7	8.6
100	1.1	1.3	1.9	3.9	3.8	7.8	9.3

The effect of conducting phases is clearly shown in *Figure 2*. At 0.2 GHz the dielectric loss spreads according to the strength of conducting phases in the sample. Dielectric loss factors for latex concentrate and diluted latex concentrate are higher than those of fresh latex and its diluted samples. This may be due to ammonium ions associated with ammonium added to the latex concentrate acting as preservative. However at frequencies higher than 2.4 GHz (*Figure 2g*), no spreading in dielectric loss was observed. This implies that the contribution from the conductivity loss or interfacial polarisation is small and the loss is dominated by the dipolar orientation of water molecules.

The above experimental results suggest that at frequencies of 2 GHz and above, both transmission and reflection techniques are suitable for measurements of moisture content in *Hevea* latex. At these frequencies, ε″ values are not much affected by the ammonia or conducting phases in the latex. The variations of ε′ and ε″ with moisture content at 2.4 GHz are about 0.95% and 0.05% moisture content respectively.

At frequencies less than 2 GHz, the conduction technique is more preferable (*Equation 1*) although this technique is bound to be affected by the conducting phases in latex or added preservative. However for diluted latex concentrate, there is an acceptable relationship between ε″ and the moisture content although its sensitivity decreases slowly with frequency.

CONCLUSION

In the frequency range of 0.2 GHz to 2.5 GHz, the dielectric properties of natural rubber latex can be divided into two regions. The first region is for frequencies approximately less than 2 0 GHz where the form of dielectric loss is probably due to interfacial polarisation while the second region, with frequencies greater than 2 GHz, the mechanism is dominated by the dipole orientation

From the results obtained, we found that both the transmission and the reflection techniques are the best methods for the determination of moisture content with operating frequencies greater than 2 0 GHz We found no specific relationship between the conductivity and moisture content in the region less than 2 0 GHz since it is affected by the conducting phase in the latex or added preservative in the latex

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