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Microwave Attenuation of Fresh Hevea *Latex*

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The relationship between microwave attenuated power and dry rubber content of fresh Hevea *latex is derived. This calculation is based on a model of water suspension by Wiener. Calculation shows that the dry rubber content of* Hevea *latex can be determined from conveniently measured parameters such as microwave attenuation, density of latex and thickness of latex layer. The experimental results on attenuation as a function of dry rubber content agree with data calculated from the theory within experimental uncertainty.*

Performance of the d.r.c. meter based on microwave attenuation has been discussed in detail by the author[1,2]. It has been shown that this technique is simple to operate, cheap, portable and with coefficient of deviation of about 1% compared with the Standard Laboratory Method.

It is important to develop the theoretical aspect of microwave attenuation of fresh *Hevea* latex and relate d.r.c. with easily measured parameters. This calculation is very important especially for the selection of optimum conditions for measurement and design purposes.

The main components of the complex composition of fresh *Hevea* latex are rubber solids[3]. Introducing the designa-
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tion W_1 and W_r for the weight of latex and dry rubber or rubber hydrocarbon, respectively, the definition of d.r.c. in the fractional weight is:

$$\text{D.r.c.} = W_r/W_1 \qquad \ldots 1$$

The relationship between total solid content, TSC and d.r.c. is:

$$\text{D.r.c.} = \text{TSC} - \text{NRS} \qquad \ldots 2$$

where NRS is the fractional weight of the non-rubber solid.

Microwave aquametry or measurement of the water content in solids and liquids by the microwave technique is a well known method. In this method, the relationship between electromagnetic wave attenuation and material moisture content is determined. Since the fractional weight of the total solid content of the material equals to unity minus fractional weight of moisture content, knowledge of the amount of moisture can be used to determine TSC or d.r.c. of the latex.

This work utilises the model of water suspension derived from Wiener's dielectric mixture theory. Experimental results for milk and clay-sand slurry are in good agreement with results predicted by theory[4].

In this paper the relationship between d.r.c. and TSC of fresh *Hevea* latex with various parameters such as microwave attenuation, density and thickness of the latex layer is derived. The derivations based on this theory are compared with

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experimental data and they are found to be in good agreement.

ATTENUATION LATEX

Based on the model of water suspension, Kraszewski[4] showed that the attenuation coefficient of a plane electromagnetic wave passing through a flat layer of a mixture can be expressed as

$$\alpha_m = V_i\,\alpha_i + (1-V_i)\,\alpha_H \qquad \ldots 3$$

where α_i and α_H denote the individual attenuation coefficients due to inclusions and the host medium (water).

V_i is the volume filling factor of inclusions.

Similarly, we consider the latex to consist of two components of suspension, *i.e.* solid material (rubber + non-rubber solids) and water. From *Equation 3,*

$$\alpha_1 = V_s\alpha_s + V_w\,\alpha_w \qquad \ldots 4$$

where subscripts 1, s and w denote latex, solid material and water.

The volume fraction V_i can be calculated as:

$$V_s = \rho_l/\rho_s\ \mathrm{TSC}$$
$$V_w = \rho_l/\rho_w\ (1-\mathrm{TSC}) \qquad \ldots 5$$

where ρ_l, ρ_s and ρ_w are the bulk densities of latex, solid material and water, respectively, and *Equation 4* becomes:

$$\alpha_1 = \rho_l/\rho_s\ \mathrm{TSC}\ \alpha_s + \rho_l/\rho_w\ (1-\mathrm{TSC})\,\alpha_w \qquad \ldots 6$$

The above model assumes that the suspension layer of thickness t may be considered as consisting of two separate layers: the layer of host medium (water) of thickness t_1 and that of dry inclusions of thickness t_2, where $t_1 + t_2 = t$, as shown in *Figure 1.*

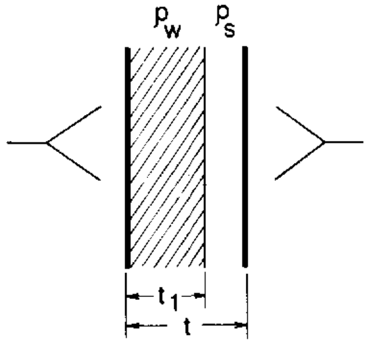

Figure 1. A model of suspension layer of thickness, t.

Hence, *Equation 3* may be rewritten as:

$$\alpha_1 t = (t-t_1)\,\alpha_s + t_1\,\alpha_w \qquad \ldots 7$$

Comparing *Equations 6* and *7*, the thickness of the water layer t_1, is given as:

$$t_1 = (1-\mathrm{TSC})\,(\rho_l/\rho_w)\,t \qquad \ldots 8$$

Substituting *Equation 8* into *Equation 7:*

$$\alpha_1 t = [t-(1-\mathrm{TSC})\,\rho_l/\rho_w\ t\,]\,\alpha_s + (1-\mathrm{TSC})\,\rho_l/\rho_w\ \alpha_w\ t \qquad \ldots 9$$

Denoting $\alpha_1 t$, $\alpha_s t$, $\alpha_w t$, by A_l, A_s and A_w, *Equation 9* becomes:

$$A_l = A_s(1-\rho_l/\rho_w) - \mathrm{TSC}\,\rho_l/\rho_w\,(A_w-A_s) + A_w\,\rho_l/\rho_w \qquad \ldots 10$$

where A refers to the attenuation in decibels.

From *Equation 10:*

$$\mathrm{TSC} = \left(\frac{A_w}{A_w-A_s}\right) + \frac{A_s(1-\rho_l/\rho_w)}{\rho_l/\rho_w\,(A_w-A_s)} - \frac{A_l}{\rho_l/\rho_w\,(A_w-A_s)} \qquad \ldots 11$$

The properties of a dielectric material may be expressed explicitly in terms of relative permittivity $\epsilon = \epsilon' - j\,\epsilon''$ where ϵ' is the dielectric constant and ϵ'' is the loss factor. When the plane wave is incident normally to the dielectric plate of thickness t the transmission coefficient neglecting the multiple reflections in the dielectric is given by Von Hipple[5] as

$$A = 8.686 \frac{2\pi t}{\gamma_0} \left[\tfrac{1}{2}\epsilon' \left(\sqrt{1 + \tan^2\delta} - 1\right)\right]^{\frac{1}{2}} \quad \ldots 12$$

where $\tan\delta = \epsilon''/\epsilon'$ is the loss tangent

λ_0 is the wavelength in vacuum.

The permittivity of water measured at T = 25°C at 10GHz is equal to:

$\epsilon_w = 55 - j\,31.9$

and that for *Hevea*[6] is

$\epsilon_r = 2.2 - j0.08$

Applying these quantities to *Equation 12*, $A_s \ll A_w$ and *Equation 11* reduces to

$$\mathrm{TSC} = 1 - \frac{A_l}{\gamma_l A_w} \quad \ldots 13$$

where $\gamma_l = \rho_l/\rho_w$ is the relative density of the latex.

From *Equation 2*,

$$\text{D.r.c.} = (1 - A_l/\gamma_l A_w) - \text{NRS} \quad \ldots 14$$

According to Cook and Sekhar[7] the NRS in latex is about 0.04 depending on the clone, environment and season.

We can show graphically the variation between attenuation A_l and d.r.c. from *Equation 13*, if we know: the variation of relative density of the latex with d.r.c. and the attenuation of water, A_w for a layer of thickness t at the particular frequency and temperature.

The relationship between relative density of the fresh latex and d.r.c. is obtained from the fitted equation based on de Varies[8] data;

$$\gamma_{l_{27}}^{27} = 1.0202 - 0.1204\,X' \quad \ldots 15$$

where $\gamma_{l_t}^{t}$ is the relative density relative to water at the same temperature as the observed substance

$t = 29°C$

X' is the weight of the dry rubber in 1 ml of latex at the temperature of observation. The conversion formula between X' and d.r.c. at 27°C–29°C from the findings of Fairfield-Smith[9] i

$$\text{D.r.c.} = \frac{X'}{1.018 - 0.1231\,X'} \quad \ldots 16$$

Equations 15 and *16* may be used to determine the variation of relative density of the fresh latex with d.r.c. *Figure 2* shows the variation of weight of dry rubber in 1 ml of latex and the relative density of latex with d.r.c.

The value of A_w can be determined by using *Equation 12*. The data for dielectric constant for water, $\epsilon = \epsilon' + j\,\epsilon''$ at a particular frequency and temperature can be obtained from the Cole-cole plot *(Figure 3)* based on data from Cook[10] and Grant *et al.*[11] A_w can also be determined directly from attenuation measurements of distilled water at the same thickness.

EXPERIMENTAL ARRANGEMENT AND RESULTS

A block diagram of the set-up is shown in *Figure 4*. The sample holder with a total thickness of about 3 mm is made from perspex sheet to minimise the phase shift and attenuation introduced by the holder.

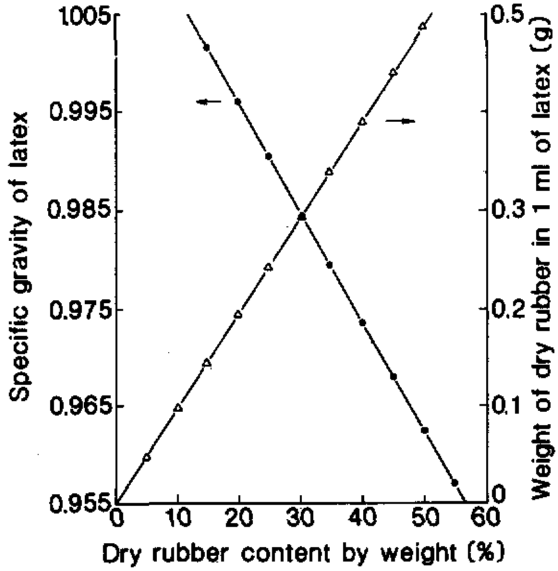

Figure 2. Variation of weight of dry rubber per millilitre and dry rubber content of fresh Hevea *latex at 27°C–29°C. (after de Varies*[7] *and Fairfield Smith*[8] *).*

The microwave source is a Gunn oscillator (HP 8620) operating at 10.17 Ghz with a power level of the order of 10 mW. Two-horn antennas are aligned facing each other, separated by a distance of 79 mm. The microwave signal is modulated in amplitude with frequency of 1 kHz. The output of the point contact detector (HP 432 A) is connected to the lock-in amplifier (ORTEC-5205) which provides a d.c. output proportional to the a.c. signal under investigation. The lock-in amplifier responds to the signal of interest and suppresses the effect of noise or other interfering components. Since the detector is operated in the 'square law region' the output voltage is proportional to the input power.

Investigations were carried out for d.r.c. of the latex from 0% to 50% and at four different thicknesses, over a range of room temperatures between 27°C and 29°C. The true d.r.c. of *Hevea* latex for each sample was obtained by using the

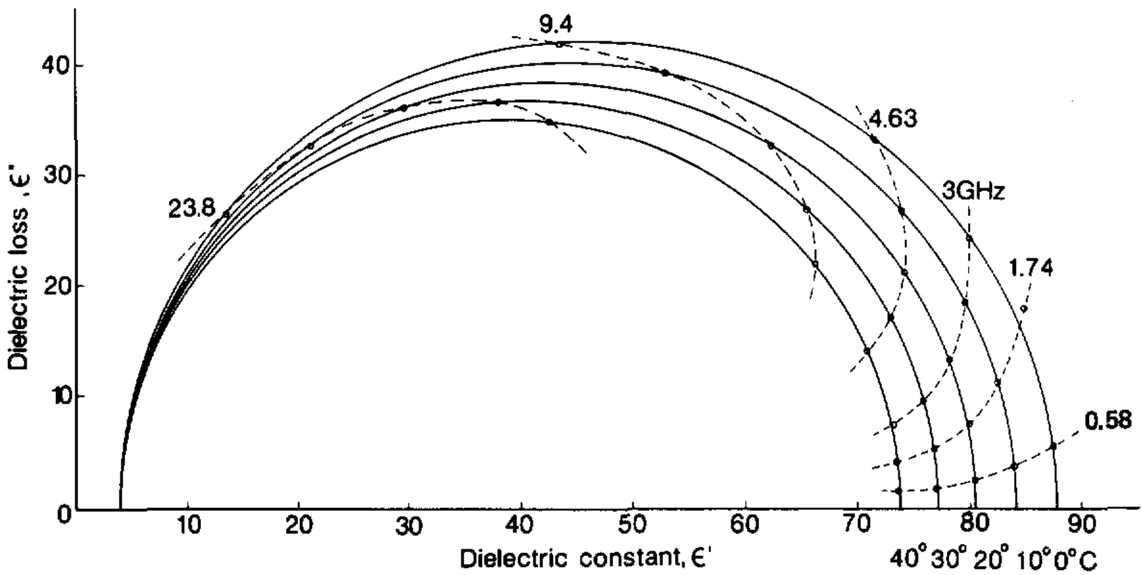

Figure 3. Cole-cole representation ϵ' (ϵ") of data for water at different temperature (°C) and frequencies (GHz) after: Cook (1952) and Grant et al. *(1957).*

Standard Laboratory Method (MS:3:35: 1975)[12]. The accuracy of this method is within ± 0.2%. Results of the attenuation measurements for various thicknesses of the latex sample at the average temperature of 29°C are shown in *Figure 5.* The uncertainty of the measurement is about ±0.5 dB. The experimental results on attenuation as a function of d.r.c. agree with the data calculated from *Equation 14,* within experimental uncertainty. In spite of this uncertainty, the capability of the instrument is fair. The standard deviation of the difference between d.r.c. measured by the Standard Laboratory Method and that measured by the microwave method is 0.7%, which is quite satisfactory for practical use[1,2].

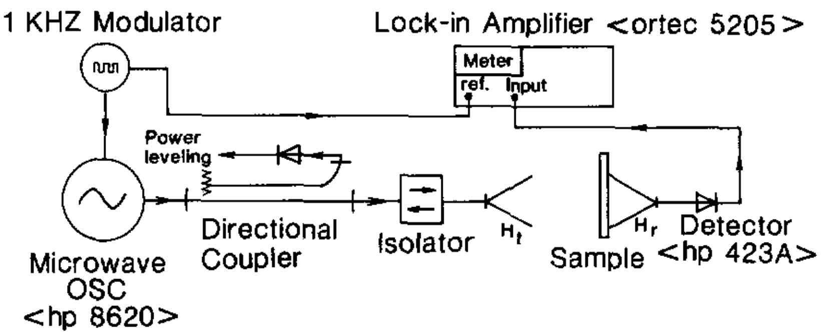

Figure 4. Basic experimental arrangement for attenuation measurement.

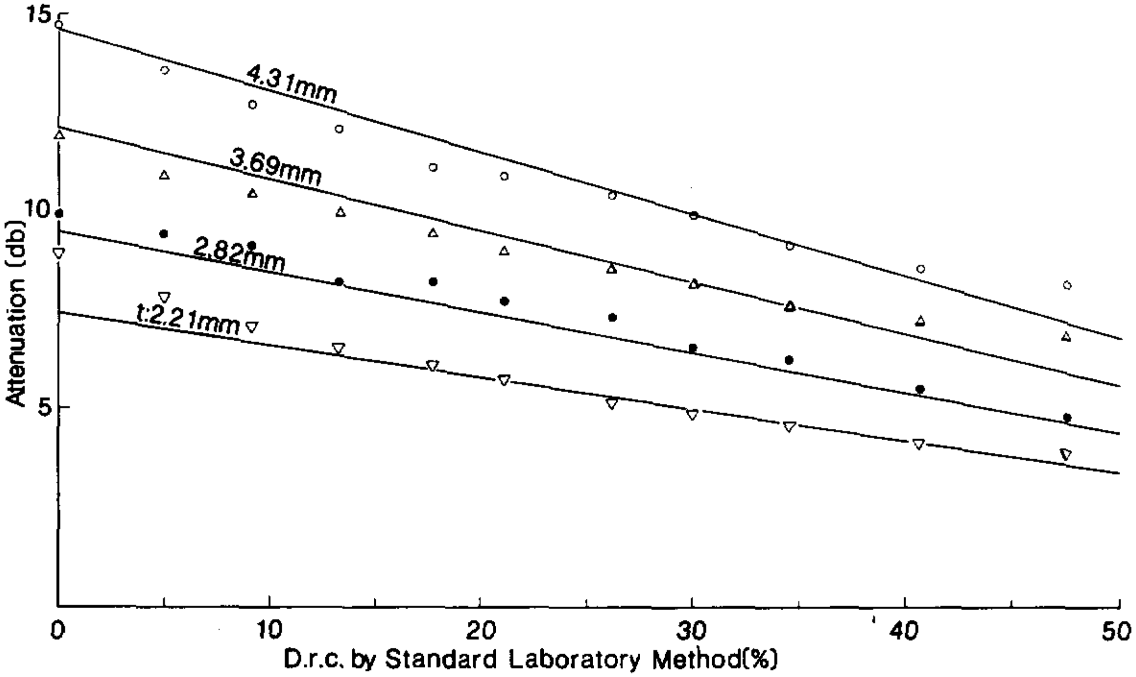

Figure 5. Attenuation versus *dry rubber content of fresh* Hevea *latex at four different thicknesses. Solid lines represent calculated values from* Equation 14.

CONCLUSION

Experimental measurements confirm that the model of water suspension may be used for the calculation of d.r.c. of fresh *Hevea* latex. Despite the complexity of the physical structure of the material, there exists a simple linear relationship between d.r.c. and attenuation of microwave signal.

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