J. Rubb. Res., 6(2), 65–72

Transition of Complex Permittivity Losses in Hevea *Rubber Latex from Conductivity Losses to Dipolar Losses at 2.6 GHz*

J. HASSAN*#, K. KHALID* AND W. M. D. WAN YUSOFF*

Dielectric properties of Hevea *rubber latex with moisture content 38%–98% were measured using the open-ended coaxial line sensor coupled to the Automated Network Analyser. Measurements were made at frequencies 0.2 GHz–20 GHz and at selected temperatures –30°C to 50°C. Complex permittivity losses or dielectric loss factor showed a very interesting phenomena at 0.2 GHz to 2.6 GHz where a transition occured from conductivity losses to dipolar losses. Below 2.6 GHz, the losses were due to the conducting phases in the* Hevea *latex arising from proteins, fatty acid soaps, phospholipids and various types of ohmic species. Higher losses were achieved from latex concentrate due to the addition of ammonia as preservative. Above 2.6 GHz the losses were governed by orientation of the water molecules. The transition was clearly observed in the plots of dielectric losses* versus *temperature at 0.2, 0.6, 1.0, 1.4, 1.8, 2.2 and 2.6 GHz for latex concentrate, fresh latex, diluted fresh latex and deionised water at moisture contents 38%, 56%, 89% and 100%, respectively.*

Key words: *Hevea brasiliensis;* dielectric; properties; latex; moisture content; permittivity; loss; conductivity, dipolar; transition; temperature

Hevea rubber latex is a complex biological product from *Hevea brasiliensis* containing 55%–80% water, 15%–45% rubber hydrocarbon and approximately 2%–4% non-rubber constituents which consist of proteins, lipids, quebrachitol, sugars, carotenoids, enzymes and inorganic salts (0.5%). The inorganic salts include potassium ions, phosphate ions and traces of copper, iron, sodium, calcium and magnesium which constitute the conducting phases in the latex[1,2]. Most of the lipids and part of the protein were adsorbed to the surface of the rubber particles in the form of a protective layer which maintained the stability of the latex particles.

The dielectric properties considered are the relative complex permittivity, $\varepsilon^* = \varepsilon' - j\varepsilon''$ where the real part is the real relative permittivity also known as the dielectric constant and the imaginary part as the complex permittivity losses or the dielectric loss factor.

* Department of Physics, Faculty of Science and Environmental Studies, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

Corresponding author (e-mail: jumiah@fsas.upm.edu.my)

The dielectric constant is the ability of the material to store energy while the loss factor is the ability to dissipate energy as heat.

Dielectric properties of *Hevea* rubber latex at various moisture contents and temperatures have been reported over the frequency range of 0.2 GHz–20 GHz[3]. An interesting phenomena was observed in the transition of the dielectric loss factor from conductivity losses at 0.2 GHz to dipolar losses at 2.6 GHz. The period of transition occurred between 0.2 GHz to 2.6 GHz where complete transition to dipolar losses was observed.

These properties are important in the electrical aspect of latex where energy losses are very much affected by moisture, temperature and frequency. The transition of the loss mechanism clearly reflects its crucial dependence on frequency, especially from 0.2 GHz–20 GHz. The detailed results obtained for energy loss has applications in high power microwaves.

MATERIALS AND METHOD

The samples consist of a series of *Hevea* rubber latex solutions prepared from latex concentrate and freshly tapped latex diluted with deionised water with a difference in moisture content of about 2%–3% between each sample. A total of about 40 samples were used with moisture content ranging from 40%–98%. Latex concentrate which had been preserved with 0.025% tetramethyl-thiuram disulphide zinc oxide and 0.2%–0.3% ammonia[8] was supplied by the Rubber Research Institute of Malaysia (RRIM). Freshly tapped latex was obtained from the University Research Park of Universiti Putra Malaysia (UPM).

Measurement of the dielectric properties of *Hevea* latex was done using the open-ended coaxial line sensor with Automated Network Analyser and computer. With proper calibration[9,10], the probe was immersed in the sample and the dielectric permittivity was determined from the input impedance at the interface. Two water baths were used for variation in temperature as already reported[5]. The accuracy of the samples was ±5% for ε' and ±3% for ε'. The actual moisture content of the samples was obtained using the conventional method by drying three 1.5 g–2.5 g of the samples at 70°C and the average results recorded.

RESULTS AND DISCUSSION

The transition of complex permittivity losses from conductivity losses to dipolar losses are beautifully illustrated in *Figures 1–7*[5,10] at temperatures –30°C to 50°C and various moisture content. The selected samples shown include latex concentrate, fresh latex, diluted fresh latex and deionised water with moisture contents 38%, 56%, 89% and 100% respectively. At 0.2 GHz to 2.6 GHz in the solid (frozen) state region over the temperature range of –30°C to –3°C, the lines coincided at about –30°C with ε' ~0.4 after which it shows a spreading which was due to the different degree of concentration of dissolved ions in the samples. In the transition region between –3°C to 3°C, as the phase of latex was changing from solid to liquid, ε'' showed a steep increase. This was due to the change in the physical state of water in latex from bound water to free water. All values for ε'' at 0.2 GHz and 2.6 GHz are tabulated in *Table 1*.

The transition in the losses occurred in the liquid state (2°C–50°C) from conductive to dipole losses. At 0.2 GHz–0.6 GHz (*Figures 1* and *2*), the loss factor of latex concentrate showed the highest conductivity losses of about 24.9 GHz at 0.2 GHz and 2°C and increases

TABLE 1 FITTED DIELECTRIC LOSS FACTOR DATA FROM –30°C TO 50°C AT 0 2 GHz AND 2 6 GHz FOR LATEX CONCENTRATE (38%), FRESH LATEX (56%), DILUTED FRESH LATEX (89%) AND DEIONISED WATER (100%)[5]

Temperature (°C)	Moisture Content % (wet basis)							
	0 2 GHz				2 6 GHz			
	38% ε''	56% ε''	89% ε''	100% ε''	38% ε''	56% ε''	89% ε''	100% ε''
–30	0 2	0 2	0 1	0 4	0 2	0 1	0 1	0 2
–20	0 8	0 5	0 2	0 4	0 6	0 3	0 4	0 2
–10	3 0	0 9	0 6	0 4	1 6	0 5	0 7	0 2
2	24 9	16 8	9 1	1 9	7 3	11 2	19 3	21 8
10	28 3	20 0	9 7	1 3	6 5	9 4	14 6	16 0
20	34 1	25 1	13 0	0 9	5 9	7 8	10 6	11 2
30	39 4	29 9	17 5	0 8	5 6	6 8	8 3	8 4
40	42 7	33 0	21 3	0 7	5 4	6 0	7 0	6 6
50	42 1	32 9	22 5	0 4	4 9	5 2	6 1	5 1

with increasing temperature followed by fresh latex and diluted fresh latex but inversely proportional to its moisture content In this region conductivity losses dominated and this was shown in the results where latex concentrate had the highest dielectric losses due to the ammonium ions (ammonia) added as preservative plus the conducting phases already present in the latex with minimum moisture The conducting phases include proteins, lipids, quebrachitol, sugars, carotenoids, enzymes, potassium ions, phosphate ions and traces of copper, iron, sodium, calcium and magnesium Elevations in temperature also raise the mobility of ions in the solution thus increasing ε'' as already reported[5] Deionised water has the minimum losses due to the fact that it did not have any conducting phases or accountable ionic species but only water molecules (dipoles) This could be seen in the dielectric loss of water which had a negative temperature dependence At 0 6 GHz (*Figure 2*) the losses of latex concentrate decreased to 10 at ~ 2°C but the losses of the deionised water increased slowly At this frequency, signs of transition of the losses occurred slowly The losses of all the curves decreased to below 10 at ~ 2°C except for deionised water which slowly increased showing the emergence of dipolar losses due to the polarisation of the water molecules

At 1 0 GHz, 1 4 GHz, 1 8 GHz, 2 2 GHz and 2 6 GHz (*Figures 3–7*), the curves intersect at ~ 6°C, 15°C, 26°C, 38°C and 50°C, respectively showing transition of the losses and all the loss factors decreased with increasing temperature The shape of the latex curves show a depression as compared with the deionised water which might be due to water binding by dissolved ions The above phenomenon is almost similar to the temperature for a few food products at 2 8 GHz and temperatures from –20°C to 60°C reported earlier[11] The variation of ε'' at 10 GHz[5,10] is almost similar to ε'' obtained at 1 0 GHz–2 6 GHz but with less depression as the effect of ionic conductivity became less ineffective

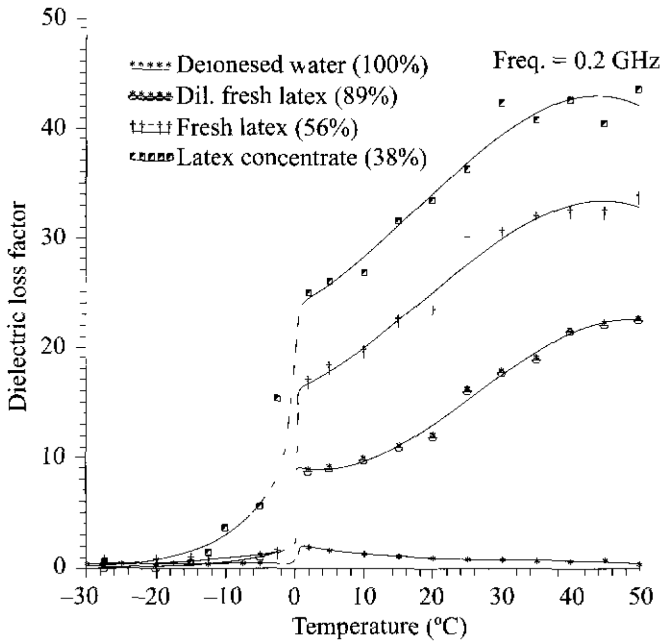

Figure 1 Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 0 2 GHz*[5]

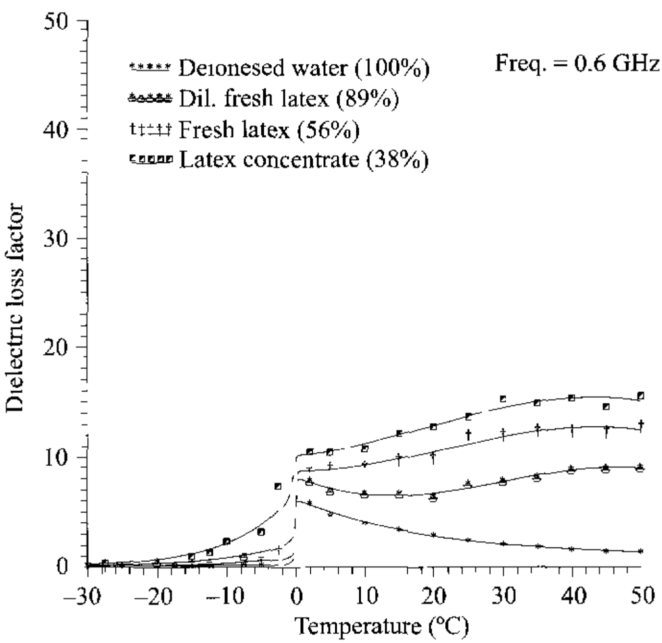

Figure 2 Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 0 6 GHz.*

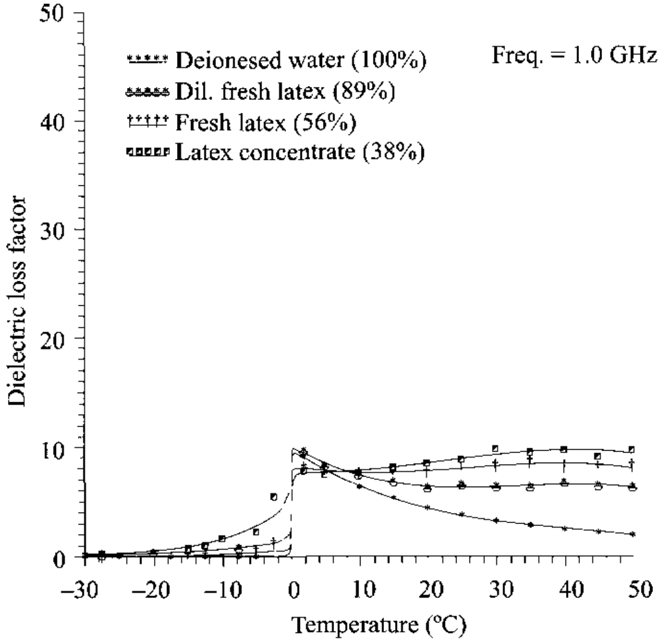

Figure 3. Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 1.0 GHz.*

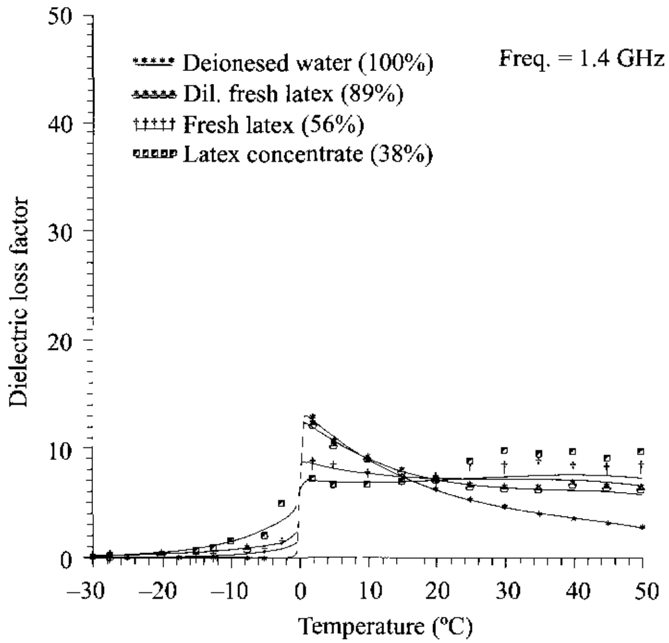

Figure 4. Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 1.4 GHz.*

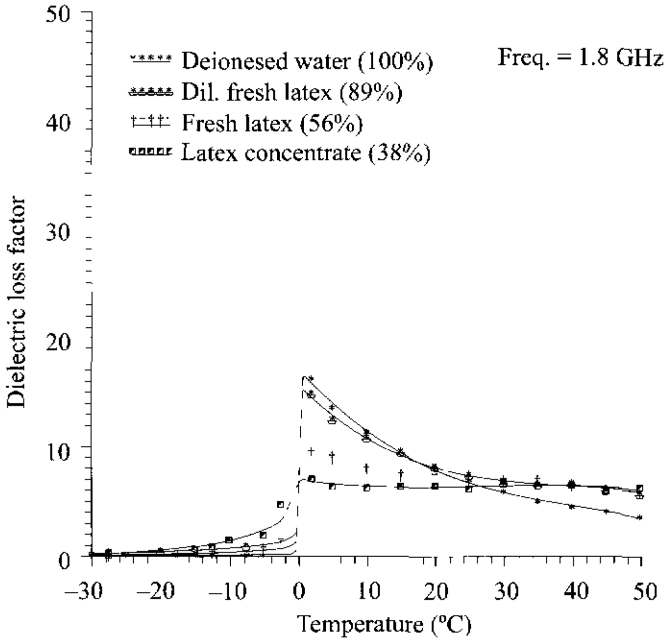

Figure 5. Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 1.8 GHz.*

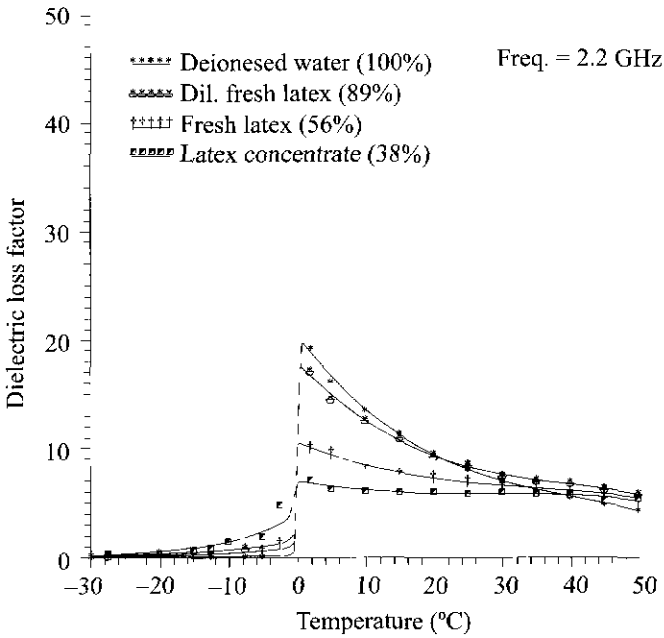

Figure 6. Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 2.2 GHz.*

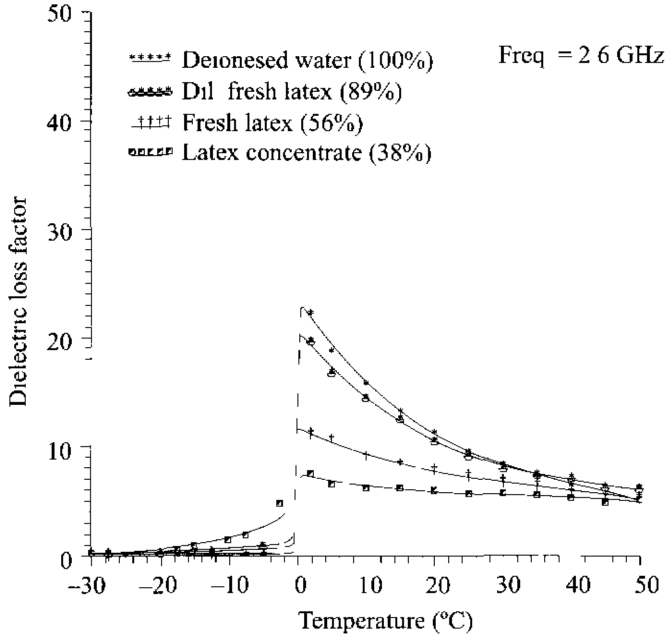

Figure 7 Dielectric loss factor of Hevea *rubber latex at selected moisture content with respect to temperature at 2 6 GHz*

CONCLUSION

The transition of the losses from conductive to dipolar losses occurred in the liquid state from 2°C–50°C and frequencies 0 2 GHz–2 6 GHz. At 0 2 GHz the losses were conductive due to the conducting phases in the latex, including ammonium ions added as preservative in latex concentrate Above 0 2 GHz and below 2 6 GHz was a region of transition between two losses, conductive and dipolar where the influence of conductive losses began to diminish especially in latex concentrate and dipolar losses began to dominate in samples having high moisture content At 2 6 GHz the losses were mostly due to the orientation of the water molecules or dipolar losses

ACKNOWLEDGEMENTS

This work was supported by the UPM research grant (50205-93-14) The authors wish to thank the technical staff, Roslim Mohd of Applied Electromagnetic Laboratory, Department of Physics, for his invaluable help The authors would also like to thank RRIM and the University Research Park of UPM for supplying the latex.

Date of receipt September 2002
Date of acceptance June 2003

REFERENCES

1 CHIN. H C (1979) Methods for Measuring the Dry Rubber Content of Field Latex

Traming Manual on Analytical Chemistrv Kuala Lumpur Rubber Research Institute of Malaysia

2 CHEN S F (1979) Composition of *Hevea* Latex *Traming Manual on Analytical Chemistry* Kuala Lumpur Rubber Research Institute of Malaysia, pp 44

3 KHALID, K AND WAN YUSOFF, W M D (1992) Dielectric Properties of Natural Rubber Latex at Frequencies from 200 MHz to 2500 MHz *J nat Rubb Res*, **7(4)**, 281–289

4 KHALID, K, HASSAN, J AND WAN YUSOFF W M D (1994) Dielectric Properties of *Hevea* Latex at Various Moisture Contents *J nat Rubb Res*, **9(3)**, 172–189

5 HASSAN, J, KHALID, K AND WAN YUSOFF W M D (1997) Microwave Dielectric Properties of *Hevea* Rubber Latex in the Temperature Range of –30°C to 50°C *Pertanika J Sci and Technol* **5(2)**, 179–190

6 LAOGUN, A A (1986) Beta Dielectric Dispersion in Natural Rubber Latex *J Appl Polym Sci* 32, 5085

7 KHALID K, HASSAN, J AND WAN YUSOFF, W M D (1996) The Effect of Ionic Conductivity and Dipole Orientation on Dielectric Loss of *Hevea* Rubber Latex *Proc EM Wave Interaction with Water and Moist Substances Workshop IEEE-MTTS Int Microwave Symposium, San Francisco USA*, 23–26

8 JOHN, C K, WONG N P CHIN, H C, KARIM, M Z AND ONG, C T (1982) LA-TZ latex Concentrate *RRIM Technology Bulletin* 6 Kuala Lumpur Rubber Research Institute of Malaysia

9 ATHEY, T W, STUCHLY, M A AND STUCHLY, S S (1982) Measurement of RF Permittivity of Biological Tissues with an Open-ended Coaxial Line *IEEE Trans*, **MTT-30**, 82

10 KRASZEWSKI, A, STUCHLY, M A AND STUCHLY, S S (1983) ANA Calibration Method for Measurements of Dielectric Properties *IEEE Trans Im-32*, **2**, 385

11 BENGTSSON, N E AND RISMAN, P O (1971) Dielectric Properties of Food at 3 GHz as Determined by Cavity Perturbation Technique II Measurements of Food Materials *J Microwave Power*, **6**, 107