J. Rubb. Res., **10(1)**, 17–25

Measurement of Dry Rubber Content of Natural Rubber Latex with a Capacitive Transducer

R. REJI KUMAR*#, S. NAJAMUL HUSSAIN* AND J. PHILIP**

A new method to determine the dry rubber content (DRC) of natural rubber latex using a capacitive transducer is presented. The capacitance of a capacitor is directly proportional to the area of the plates, permittivity of the medium and inversely proportional to the separation between the plates. If the area of the plates and the separation between them are kept constant, the capacitance is directly proportional to the permittivity of the medium. Based on this physical principle, a capacitive transducer was specially designed and fabricated. The capacitance of the capacitor with latex samples as the dielectric was measured with a high impedance LCR meter. Simultaneously, the DRC of the same latex samples was determined following standard laboratory procedures. Statistical analysis of the results showed that there was a good correlation between the capacitance with Hevea *latex as the dielectric and the corresponding DRC values. Related parameters such as dissipation factor, electrical resistivity, impedance and susceptibility were found to be proportional to the DRC values of latex.*

Key words: dry rubber content; natural rubber latex; capacitance; permittivity; dissipation factor; electrical resistivity; impedance; *Hevea*

Hevea latex is a natural biological liquid of very complex composition. Besides rubber hydrocarbons, it contains many proteinous and resinous substances, carbohydrates, inorganic matter, water, and others[1]. The dry rubber content (DRC) of *Hevea* latex is a very familiar term in the rubber industry. Ever since the commencement of commercial exploitation of *Hevea* trees, it is probably one of the few properties of latex first recognised and widely used for trade and processing. It has been the basis for incentive payments to tappers who being in yields more than the daily agreed poundage of latex rubber. It is an important parameter in rubber and latex processing, wherein the DRC of bulk latex and the quantity of chemical additives required for the production of rubber and latex products are determined. The importance of DRC cannot be over-emphasized[2] when it comes to industries based on latex/rubber processing.

NR latex has a DRC varying from about 20% to 40%, and is a colloidal dispersion of rubber particles in an aqueous serum. In addition, it contains 2% – 4% of non-rubber substances. The most accurate method for the determination of DRC is by the standard

**Rubber Research Institute of India, Rubber Board P.O., Kottayam-686 009, Kerala, India
**Sophisticated Test and Instrumentation Center, Cochin University of Science and Technology, Cochin – 682 022, Kerala, India
Corresponding author (e-mail: rejikumar1965@yahoo.com)

laboratory drying method which has been subjected to several modifications over the years to reduce the estimation time, the most prominent being the 'Chee' method[1,3].

Several methods have been cited in literature for the measurement of DRC of latex, of which the hydrometer method[5] is probably the most rapid one, even though its accuracy is limited by a wide range of measurement conditions encountered in practice which include biodeterioration, adulteration, dilution, aeration and warming. For latex, the average error of the hydrometer method is about 4% of the value estimated by the standard procedure which compares the oven dry weight of a rubber sample coagulated from 10 g of latex. The 'Spot Method' is popular in many laboratories which uses an accurate weighing balance to weigh the coagulum from a 0.3 g sample dried in a steam bath oven and expressed as a percentage of the original mass. The measurement time[4] is about 30 min, with an error of about 1%.

Other methods that have been reported for the determination of DRC include latex film dialysis[6], titration method[7], microwave attenuation mesurement[8], low resolution pulsed NMR technique[9], spin-eco technique[10] and dielectric measurement[13]. The short comings of these methods are that they are either labour intensive, time consuming, difficult to use or expensive. Another drawback with most of these methods is that the measurements can be done only in a laboratory, and not in the field.

In this paper we report a method to determine the DRC of rubber latex, which measures the variation of the capacitance of a specially designed capacitive transducer with the latex as the dielectric. The method is found to be accurate, fast, inexpensive, user-friendly and adaptable to varying environmental conditions. The correlation of capacitance variation with DRC to related electrical properties such as a.c. conductivity, impedance, loss factor *etc*. are established and discussed.

Principle of the Method

An elementary parallel plate capacitor consists of two conducting plates, electrically isolated from one another by an insulating medium. The capacitance (C) of this elementary capacitor is proportional to (i) the cross - sectional area A of the plates, (ii) the permittivity (or dielectric constant K) of the insulating medium and (iii) the reciprocal of the separation, t, between the plates. The relation is given by[12]:

$$C = \frac{\mathrm{K}A}{t} \qquad \ldots 1$$

If the area of the plates and the separation between them are kept constant, the capacitance of the capacitor is directly proportional to the dielectric constant or permittivity of the medium. If there is a direct relation between the DRC and dielectric constant of latex, then the same relationship holds good for the capacitance and DRC of rubber latex, if used as the dielectric. A capacitor, when connected to a sinusoidal voltage source, responds to it sinusoidally with definite impedance following the relation:

$$V = V_{\mathrm{o}}\, e^{j\omega t} \qquad \ldots 2$$

where,
V is the instantaneous voltage
V_{o} is the peak value of voltage
ω is the signal angular frequency
t is the time.

When filled with a dielectric medium of permitivity ε', the capacitance value gets modified as:

$$C = C_o\, \varepsilon'/\varepsilon_{\mathrm{o}} = C_o K' \qquad \ldots 3$$

where,

C_o is the capacitance with air or vacuum as the dielectric

ε_o is the permittivity of free space

K' is the dielectric constant of the medium.

A dielectric material with higher relative permittivity enhances the storage capacity of a capacitor by neutralising the charges at the electrode surfaces which otherwise would have contributed to the applied external field. The impedance of a capacitor is not a pure reactance, but is modified by the series resistance of the lead and plates, losses in the dielectric, parallel resistance of the plates and leakage effects. One way to handle this complex situation is to combine all these effects into an equivalent series resistance (Rs), measured directly with an impedance bridge or indirectly with instruments such as the Q meter. The overall impedance of the system is given by:

$$Z = R + jX \qquad \ldots 4$$

where, X is the reactance of the capacitor. The impedance, Z, is the inverse of admittance, Y,

$$\text{or , } Y = 1/Z \qquad \ldots 5$$

or

$$Y = G + jB \qquad \ldots 6$$

where,

$G = 1/R$ and

$B = \omega\, C_p$.

Here G is the conductance, C_p is the parallel plate capacitance and B is the susceptibility of the medium;

$\omega = 2\pi f$, f being the test frequency.

The dissipation factor, D can be expressed as:

$$D = 1/Q \qquad \ldots 7$$

where, Q is the quality factor. The equivalent resistance, (R) of the capacitor is given by:

$$R = |Z| \cos \theta \qquad \ldots 8$$

where $|Z| = \sqrt{(R^2 + X^2)}$, and $\theta = \tan^{-1} (X/R)$, θ being the phase lag due to capacitive reactance.

EXPERIMENTAL METHOD

Experimental set up consisted of a specially designed capacitive transducer and an LCR (inductance, capacitance and resistance) meter. The capacitive transducer comprised four concentric cylinders with increasing diameters, insulated from each other and firmly fixed. Each cylinder acted as the plate of a capacitor with the alternate cylinders connected externally in parallel to increase the effective capacitance of the combination. The equivalent diagrams of the capacitor combination and the assembled capacitive transducer are shown in *Figures 1* and *2*, respectively. The block diagram of the experimental set up used for measurements is shown in *Figure 3*. The effective capacitance of the capacitive transducer is C, and is given by:

$$C = C_1 + C_2 + C_3 + C_4 \qquad \ldots 9$$

This capacitive transducer was immersed in a beaker containing a constant volume of latex (400 mL), whose capacitance was measured. The terminals A and B of the assembled capacitive transducer (*Figure 2*) were connected to an LCR meter (Agilent Technologies Model 4263 B) for measuring the capacitance with NR latex as the dielectric medium. The capacitance, as well as other parameters were measured at a frequency of 100 Hz under standard laboratory conditions. All measurements were carried out within 4 h after collecting the samples from the collection centre. Other parameters such

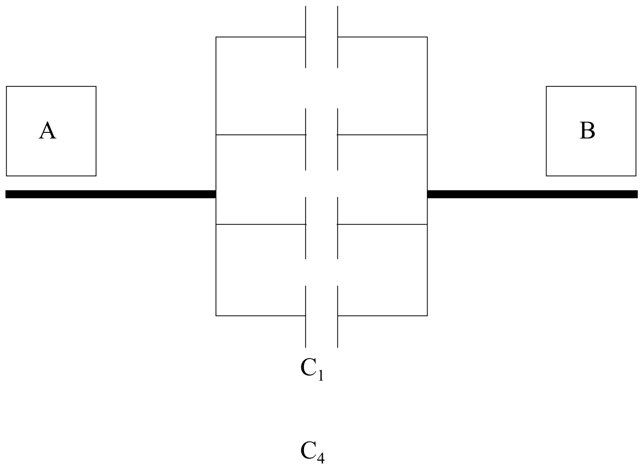
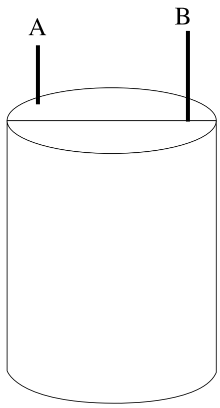


Figure 1. Schematic diagram of the capacitive transducer (Parallel configuration).



A and B are terminals.

Figure 2. Assembled capacitive transducer.

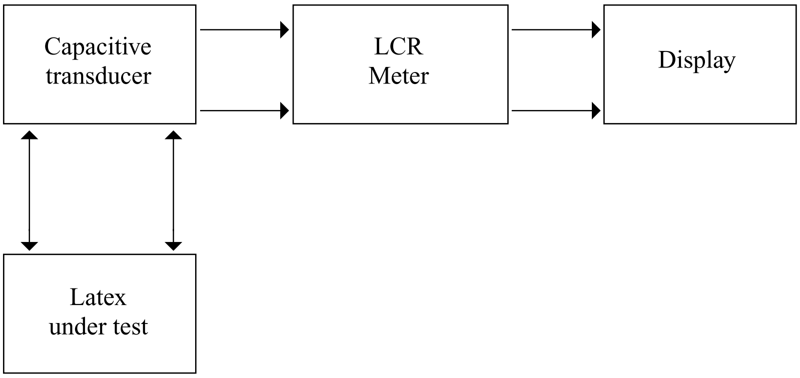


Figure 3. Block diagram of experimental set up.

as resistance (*R*), dissipation factor (*D*), impedance (*Z*) and susceptibility (*G*) were measured with the same LCR meter. All these parameters for different samples with various DRC values were measured under the same physical and environmental conditions for direct comparison.

The latex samples for all the experiments described in this work were collected from the Factory Management Division of the Rubber Research Institute of India. This Division collects latex from smallholders as well as the Rubber Research Institute of India experimental farm to make value-added latex products. For the work reported in this paper, latex samples (Clone: RRII 105, Year of planting: 1989–1993, D3 tapping system) with wide variations in DRC were collected. The latex samples were collected after filtration and an anticoagulant was added to each sample to preserve it. The amount of anticoagulant (Ammonia) added to each sample was kept constant to ensure that the effect of the anticoagulant was the same in all measurements. After the preparation of latex samples by adding anticoagulant, 10 mL – 15 mL of each sample was collected in separate containers to determine their DRC values following standard laboratory procedures and another 400 mL of latex for capacitance measurement, as outlined above.

RESULTS AND DISCUSSION

The data collected in a series of the measurements on different sets of samples are presented in *Table 1*. *Figures 4* and *5* show the variations of series as well as parallel capacitances of the capacitive transducer with DRC of the latex. The results obtained were analysed using standard statistical techniques. The parallel and series capacitances exhibit high negative correlations (–0.84 and –0.86, respectively), whereas dissipation factor (*D*) and resistance (*R*) exhibited high positive correlations (0.76 and 0.79, respectively). Impedance (*Z*) showed a medium correlation (0.59). The uncertainties indicated in the figures take into account all the uncertainties involved in the measurements of DRC and capacitance values. It was evident that both series and parallel capacitances of the capacitor were inversely proportional to the DRC of the latex. The proportionality constants obtained were 0.123nF/%DRC and 0.117nF/%DRC, respectively.

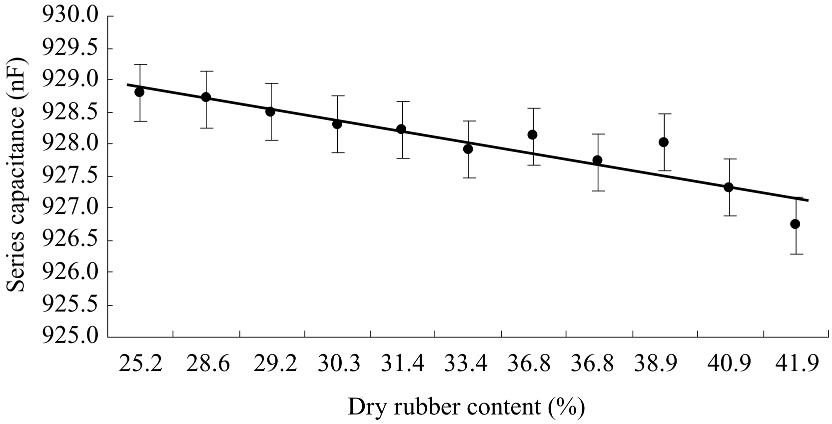


Figure 4. Variation of series capacitance with DRC of latex.

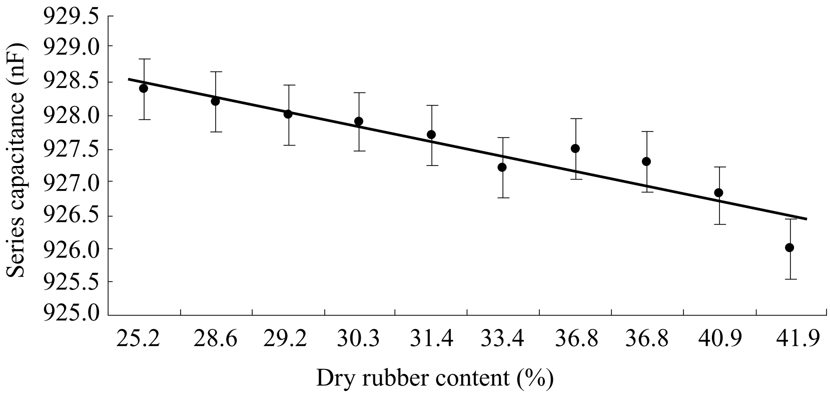


Figure 5. Variation of parallel capacitance with DRC of latex.

TABLE 1. VARIATION OF CAPACITANCE AND OTHER PHYSICAL PARAMETERS WITH DRC

No	DRC (%)	Cp (nF)	Cs (nF)	D	R (Ω)	Z (Ω)
1	25.2	928.4	928.8	0.0234	40.75	1.7167
2	28.6	928.2	928.7	0.0241	42.33	1.7145
3	29.2	928.0	928.5	0.0248	43.54	1.7147
4	30.3	927.9	928.3	0.0244	42.91	1.7152
5	31.4	927.7	928.2	0.0246	43.50	1.7155
6	33.4	927.2	927.9	0.0251	44.38	1.7165
7	34.9	926.7	927.2	0.0251	44.26	1.7176
8	36.8	927.5	928.1	0.0249	44.19	1.7157
9	36.8	927.3	927.7	0.0247	43.37	1.7164
10	38.9	927.6	928.0	0.0241	42.62	1.7160
11	40.9	926.8	927.3	0.0262	45.79	1.7169
12	41.9	926.0	926.7	0.0264	47.35	1.7222
Mean	34.025	927.44	927.95	0.02481	43.75	1.716492
SD	5.2307	0.6894	0.6332	0.00084	1.68	0.002016
± SEM	1.5	0.2	0.2	0.00029	0.49	0.0006

Note: Cp = Parallel capacitance; Cs = Series capacitance; D = Dissipation factor; R = Resistance; Z = Impedance; nF = Nano Farad; Ω = ohm; SD = Standard deviation; SEM = Standard error of the mean.

The purpose of this study was to ascertain whether a relationship between the DRC of rubber latex with its electrical properties could be established. With a proper design of the present capacitive transducer, it was evident that capacitance was inversely proportional to DRC and it could be measured with sufficient sensitivity and accuracy. The other electrical / dielectric properties naturally followed the dielectric constant or permittivity of the medium. For the design of a practical measuring instrument one need not measure all the parameters presented in *Table 1*. It was noticeable that the series capacitance of the measuring capacitor was most sensitive to DRC compared to other measured parameters. While designing a practical DRC meter following this scheme, one needs to provide provision to measure just the series capacitance accurately. We think that such an instrument can be made at a comparatively low cost and the measurements can be done in the field with a battery-operated instrument. Since the DRC measurements need to be recorded by non-technical personnel working at latex collection centers, it is important that the instrument be made user-friendly and the measurements done in a short period of time. The design and fabrication of such an instrument is in progress.

CONCLUSION

A good correlation between DRC and dielectric/electrical properties of natural rubber latex samples was established by the study. DRC was sensitive to the capacitance of the specially designed capacitor which could be used to design a practical instrument based on the above mentioned principles. Even though the study established the relationship between DRC and dielectric/electrical properties of rubber latex, we have not attempted to bring out the microscopic phenomena responsible for the observed effects. Further, the influence of non-rubber constituents and adulterants in these measurements were not investigated. Interpretation of the results in terms of the molecular polarisability of the medium would be very informative to understand the electrochemical processes relevant to this complex medium. It was estimated that a practical measurement system following this method would have measurement uncertainties up to ± 2% due to various factors. However, the measurement uncertainties could be reduced considerably by optimising the transducer design and measurement procedures.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Dr. N.M. Mathew, former Director, Rubber Research Institute of India, for all the help and support.

Date of receipt: September 2006
Date of acceptance: May 2007

REFERENCES

1. RUBBER RESEARCH INSTITUTE OF MALAYSIA (1973) Methods for Measuring the Dry Rubber Content of Field Latex. *Plrs'Bull. Rubb. Res. Inst. Malaysia*, **124**, 4–13.

2. RUBBER RESEARCH INSTITUTE OF MALAYSIA (1980) Determination of Dry Rubber Content of *Hevea* Field Latex. *Plrs' Bull. Rubb. Res. Inst. Malaysia*, **163**, 56–59.

3. CHIN HONG CHEAW (1981) Metrication and Changes to the 'Chee' Method of Determining the Dry Rubber Content of Field Latex. *Plrs' Bull. Rubb. Res. Inst. Malaysia*, **169**, 136–149.

4. HARRIS E.M. (1985) Measurement of Dry Rubber Content of Natural Rubber Latex and Wet Crepe Using Specific Heat. *Proc. Inter. Rubb. Conf. Kuala Lumpur, Malaysia*, 271–285.

5. NADARAJAH, M. AND MUTHUKUDA, S. (1963) The Determination of Dry Rubber Content of Natural Rubber Latex by the Use of the Metrolac. *Quart. J. Rubb. Res. Inst. Ceylon*, **39**, 85–93.

6. SUMARNO KARTOWARDOJO (1969) Determination of Dry Rubber Content of *Hevea Brasiliensis* by Latex Film Dialysis. *J. Rubb. Res. Inst. Malaysia*, **22(4)**, 389–398.

7. ROSAMMA ALEX, PREMALATHA, C.K., BABY KURIAKOSE AND RAMESH, B. NAIR (2003) Measurement of Dry Rubber Content of Fresh Natural Rubber Latex by a Titration Method. *J. Rubb. Res.*, **6(4)**, 221–230.

8. KAIDA BIN KHALID, YAHYA MAT HASSAN AND ABD RAHMAN RAMLI (1989) Measurement of Dry Rubber Content and Total Solid Content of *Hevea* Latex by Microwave Techniques. *Proc. Rubber Growers' Conference, Malacca*, 493–504.

9. GAMBHIR, P.N., JOSHI, D.K., TIWARI, P.N. AND MANI, J. (1993) Quick Determination of Dry Rubber Content of Natural Rubber Latex by Low-Resolution Pulsed NMR Technique. *J. nat. Rubb. Res.*, **8(3)**, 208–212

10. GAMBHIR, P.N., JOSHI, D.K., TIWARI, P.N. AND MANI, J. (1993) Rapid Determination of Dry Rubber Content of Natural Rubber Latex by Spin-eco Technique. *13th International Conference on Magnetic*

Resonance in Biological Systems, *14-19 August 1988, University of Wisconsin, USA*.

11. KAIDA BIN KHALID AND MOHAMMAD DAUD (1994) Dielectric Properties of Natural Rubber Latex at Frequencies from 200 MHz to 2500 MHz. *J. Rubb. Res. Inst. Malaysia*, **7(4)**, 281–289

12. NAIR, K.K. AND SIVARAMAKRISHNANAN, N.H. (1970-1971) Correlation of Metrolac DRC with Actual DRC of Latex. *Rubber Board Bulletin*, **11(1)**, 17–24.

13. EDGAR RHODES AND H. FAIRFIELD SMITH (1939) The Viscosity of Preserved and Concentrated Latex. Part I, *J. Rubb. Res. Inst. Malaysia*, *Communication*, **241**, 171–188.

14. ROYCE J. NOBLE (1953) Latex in Industry. *Rubber Age, N.Y.*, 58–83.

15. CALVERT, J.M. AND Mc CAUSLAND, M.A.H. (1978) *Text Book of Electronics*. New York: John Wiley and Sons, pp. 12–19.