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Original Article

Electrical characteristics of pure and contaminated latex serum

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Abstract

This paper presents electrical characteristics of pure latex serum and latex serum contaminated with cassava and calcium carbonate ($CaCo_3$). The pure serum sample was prepared by centrifuging field latex samples where the contaminated samples were prepared by adding cassava flour and $CaCo_3$ at certain concentrations to the pure samples. Complex permittivity measurement at 1 GHz was performed with Agilent 8510E dielectric probe kit equipped with an automatic network analyzer. From the measured permittivity of pure and contaminated serum samples, we first calculated their conductivity, static permittivity, high-frequency permittivity, and relaxation time. These parameters are crucial for formulating a mathematical model for pure and contaminated latex which can be used for developing an algorithm to classify pure and contaminated latex samples.

Keywords: complex permittivity, contaminated latex, measurement, serum

1. Introduction

Natural rubber is one of the key economic plants. Nowadays, there are many kinds of products made from natural rubber such as toys, shoes, gloves, tires, to name a few. Recently more products made from rubber such as futsal ground or road surface were proposed (Tuntiworawit *et al.*, 2005). It is expected that the demand of rubber latex will rise progressively.

Natural rubber latex is obtained by tapping the bark of a rubber tree. It is a colloid, opaque, and white liquid (Marcia *et al.*, 2003). Basically fresh rubber latex consists of water, rubber content, and non-rubber content. Rubber latex generally contains 30-40% rubber and 60-70% water and non-rubber content (Jayanthy & Sankaranarayanan, 2005). The latex quality called dry rubber content (DRC) is measured from the amount of dry rubber in that latex. This quality indicator has been used for trading fresh latex. Rubber farmers, who are on the seller side, will gain more money if their field latex contains a high DRC. Both the sellers and buyers need a rapid and accurate method to determine the DRC for trading.

Recently, a low-cost and rapid DRC measurement technique based on measurement at a microwave frequency was proposed (Julrat *et al.*, 2012). The technique determines DRC of latex from its complex permittivity at 1 GHz. A six–port reflectrometer was adopted because of its low hardware complexity. This leads to a simple design, implementation, and maintenance.

The electrical characteristics of natural latex were thoroughly investigated and reported (Julrat *et al.*, 2014). The latex model was developed based on their study and a rapid method to determine DRC of latex was proposed. It was reported that the most commonly found irrelevant substances in fresh latex are cassava and calcium carbonate ($CaCo_3$) (Somwong *et al.*, 2015). It has been reported that some farmers intentionally added these substances to increase the weight. Since the previously proposed method was based on a microwave technique that is applicable to pure latex, a method to classify contaminated latex is required.

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It is crucial to investigate the electrical characteristics of latex contaminated with these substances. In a physical context, latex consists of serum (water and non-rubber content) and the rubber content. Several researchers proposed complex permittivity of rubber latex to determine the DRC. Based on the assumption that rubber latex consists of water and dry rubber, Khalid (1992) presented the dielectric mixture model. Three models were investigated: Weiner's upper bound model, Bruggemann's model, and Kraszewski's model. These models were validated by comparing their accuracy performances with the experiment. Later, Khalid *et al.* (1997) reported that the changes of complex permittivity significantly depended on temperatures and frequencies. For example, conductive loss was governed at frequencies below 2 GHz, and dipole orientation of water molecules was governed at frequencies above 2 GHz which corresponded to the appropriate frequencies for a latexometer design. Yahaya *et al.* (2014), measured the moisture content in rubber latex and utilized the determination of the content based on reflection measurement in order to predict the moisture content by the dielectric constant of rubber latex.

In general, natural rubber is composed of the rubber content and serum. The components of latex serum are specifically different from the components in the water. To understand the natural characteristics of latex serum would probably lead to the development of a dielectric model with more accuracy than the previous models. Consequently, we aim to study the characteristics of latex serum, both pure and contaminated. The electrical characteristics of pure serum contaminated with cassava flour and $CaCo_3$ were investigated. In this paper, the frequency range of 0.5-6.0 GHz was chosen to cover two mechanisms: conductive loss and dielectric orientation. In addition, this frequency range is recommended due to a large availability of off-the-shelf electronic components.

2. Materials and Methods

The method of this paper is shown in Figure 1. Several samples of fresh latex were from the Rubber Research Institute of Songkhla. The fresh latex samples were centrifuged at a speed of 25,000 rpm for 1.15 h with ultra-centrifuge equipment at the Faculty of Science, Prince of Songkla University, to separate the rubber content form the serum according to Yeang *et al.* (2002). The serum contaminated with cassava and $CaCo_3$ were prepared by adding these substances to the pure serum.

The complex permittivity measurement was set up with an Agilent 8510E dielectric probe kit. The probe kit was installed with an HP 8510B automatic vector network analyzer calibrated from 0.5-6.0 GHz at 25°C. Before measuring the dielectric of samples, the probe kit was carefully calibrated by a standard short circuit, air, and distilled water. During calibration, the temperature of the distilled water was recorded and used for the calibration software. The measured dielectric permittivity of distilled water and air were consistent with the theoretical results to examine the calibration data. The measured data were collected via General Purpose Interface Bus: GPIB) and analyzed with the probe kit software (Figure 2).

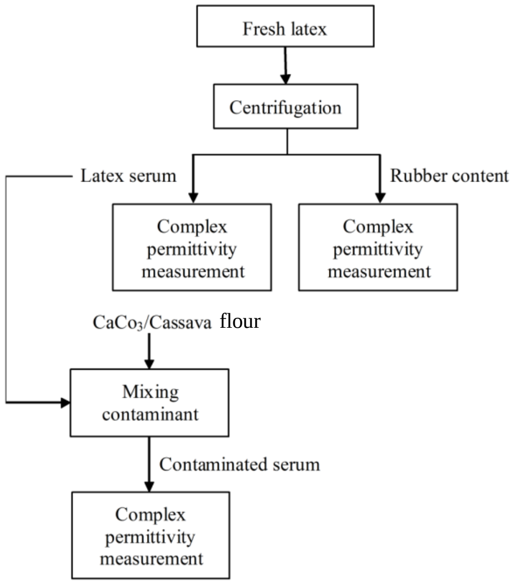


Figure 1. Dielectric permittivity measurement of method.

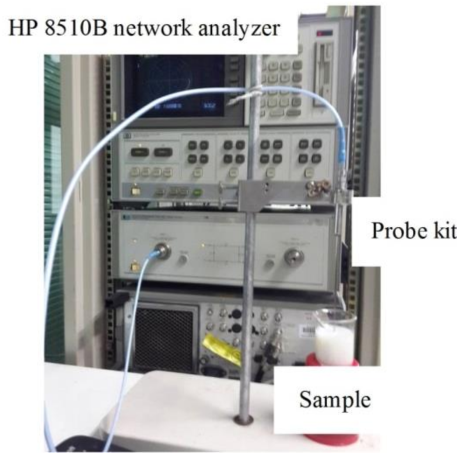
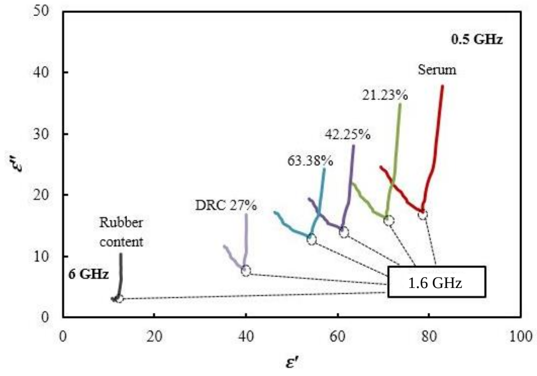


Figure 2. Measurement setup

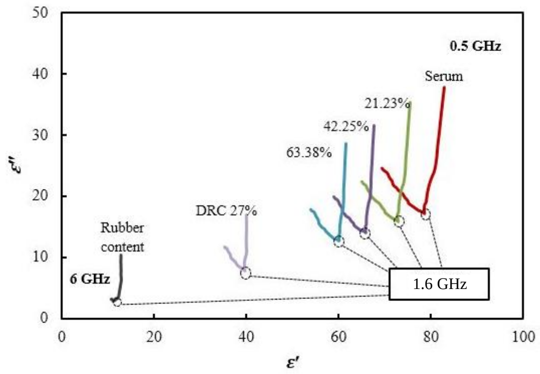
The pure serum was measured with the dielectric probe kit while six contaminated samples were prepared by mixing 15 mL pure serum with $CaCo_3$ and cassava powder to obtain 21.23%, 42.25%, and 63.85% contaminated solutions. Then, the complex permittivities were measured, collected, and compared.

3. Results and Discussion

The complex permittivity (ε' and ε'') of pure serum and six contaminated serum samples were measured at 25°C room temperature from 0.5-6.0 GHz. The results were plotted in the Cole-Cole format (Figure 3).



(a)



(b)

Figure 3. Cole–Cole plot (ε' and ε'') from 0.5-6 GHz at 25 °C of fresh latex, rubber content, latex serum, and contaminated serum. (a) with several flour concentrations and (b) with several $CaCo_3$ concentrations.

Figure 3(a) and 3(b) show the complex permittivity results of latex serum with several cassava concentrations and latex serum with several $CaCo_3$ concentrations, respectively. At the same frequency, the complex permittivity of the latex serum was generally higher than other samples of the investigation. The complex permittivity of the contaminated serum decreased as the contaminant increased (Figure 3). The dielectric constant of the contaminants was generally much lower than dielectric constant of the latex serum. For example, the dielectric constants at 1.6 GHz of cassava and $CaCo_3$ were 3 and 9, respectively (Deltacnt, 2016). On the other hand, the dielectric constant of the pure serum was approximately 80. The proportion of pure serum in the contaminated serum decreased, hence the dielectric constant decreased.

The Cole-Cole curves had a semi-elliptical shape. This comes from the frequency characteristics of ε'' which varied with the frequency at the rate faster than the characteristics of ε' . Especially at frequencies below 1.6 GHz, the rapid decrease of ε'' was expected from the ionic conductivity of the compound in fresh latex, rubber content, serum, and contaminants. The contaminants in the serum reduced both ε' and ε'' . The length of the elliptic axis decreased when the amount of contaminants increased because conductivity plays the dominant part in the low-frequency region.

The semi-elliptical Cole-Cole characteristic of ε' and ε'' can be mathematically described with the Debye equation, which is generally applied to water based solutions (Julrat *et al.*, 2014). The Debye model is defined according to Equations 1, 2, and 3.

$$\varepsilon^* = \varepsilon' - j(\varepsilon'' + \frac{\sigma}{\omega}) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} + \frac{\sigma}{\omega\varepsilon_0} \quad (1)$$

$$\varepsilon'' = \frac{\varepsilon_s - \varepsilon_\infty}{1 + \omega^2\tau^2}(\omega\tau) + \frac{\sigma}{\omega\varepsilon_0} \quad (2)$$

$$\varepsilon' = (-\tau)(\omega\varepsilon'' - \frac{\sigma}{\omega}) + \varepsilon_s \quad (3)$$

where ε^* is the complex permittivity, ε_s and ε_∞ are static and high-frequency dielectric permittivities, σ is the DC conductivity, $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m is the permittivity of free space, τ is the Debye relaxation time, and $j = \sqrt{-1}$.

The model in Equations 1-3 was applied with the measured results to determine the electrical parameters of pure serum and contaminated serum with cassava and $CaCo_3$ at 1 GHz frequency. This frequency was suggested from the pioneer work on DRC measurement (Julrat *et al.*, 2012). To determine the electrical parameters of pure and contaminated serum samples, the regression analysis with Equation 3 at 1 GHz was performed.

Table 1 lists τ , ε_s , ε_∞ , and σ with the correlation coefficients (R^2) range of 0.95-0.97. The conductivity decreased as the amount of contaminant (cassava or $CaCo_3$) increased. Though pure and contaminated serums provide different values of σ , no significant difference existed with the type of contaminant. The value of ε_s was clearly characterized with the content and type of contaminant. Hence, σ was suggested to detect the contaminant, and ε_s was applied to classify the contaminated serum samples.

Table 1. Electric parameters of latex serum and contaminated latex serum.

Samples	ε_s	ε_∞	τ (sec)	σ (S/m)
Serum	79.31	22.13	1.26×10^{-11}	1.27
Flour				
21.23%	71.15	20.98	1.26×10^{-11}	1.15
42.25%	61.05	18.03	1.25×10^{-11}	1.00
63.38%	53.66	17.33	1.57×10^{-11}	0.87
$CaCo_3$				
21.23%	73.31	22.76	1.25×10^{-11}	1.14
42.25%	66.21	21.05	1.19×10^{-11}	0.99
63.38%	60.52	19.65	1.18×10^{-11}	0.88

4. Conclusions

The analysis of the experimental results found that the complex permittivity of pure serum decreased as the amount of contaminants increased. At frequencies below 1.6 GHz, the characteristic of ε'' rapidly decreased. This is expected to come from the ionic conductivity of the compound in serum and contaminants. When applied at 1 GHz, the values of relaxation time (τ), static permittivity (ε_s), high-frequency permittivity (ε_∞) and conductivity (σ) decreased as the amount of contaminant increased. For the contaminated serum, the samples contaminated with $CaCo_3$ showed comparable σ with the cassava flour contaminated samples. The cassava decreased the σ with the content. It is highly possible to apply σ to classify the contaminated serum from the pure serum. The static permittivity is another electrical parameter that is highly possible to apply to distinguish pure latex from contaminated latex. In addition, it is also be used to classify the type of contaminant. The authors believe that the finding in this research will lead to a formation of a complete mathematical model to use with the DRC determination system based on a six-port reflectometer.

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