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Research Paper

Contamination detection in fresh natural rubber latex by a dry rubber content measurement system using microwave reflectometer

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This paper proposes a classifier for contamination detection in fresh latex. It relates to a dry rubber content (DRC) measurement system implemented with a 1 GHz microwave reflectometer (MWR), which behaves anomalously when fresh latex field samples are contaminated with cassava flour or $CaCO_3$ by 10% by mass or more. The relative permittivity (ε_r) of non-contaminated and contaminated samples were investigated and an algorithm for detecting contaminants is proposed. The performance of this algorithm was tested experimentally and practically significant contamination levels were diagnosed with high accuracy.

1. Introduction

Field Fresh Latex (FFL) is natural product which is extracted from rubber trees. FFL is generally used as the primary product to produce several rubber products (concentrated latex and dry rubber, such as raw rubber, smoked rubber sheets, rubber cup lumps etc.). Several consumer products such as tyres, hand gloves, condoms, and dampers are produced from FFL. New applications of FFL have been emerging continuously, e.g. in concrete mixtures for driveways or roads, and in sub-base materials (Siddique & Naik, 2004).

In the rubber trade, the price of FFL is normally determined by its dry rubber content (DRC). Three methods for determining the DRC of FFL are well known. The first one is based on specific gravity with an available commercial device (Metrolac). It has been widely used as a low-cost tool for quick DRC estimates (Tillekeratne, Karunanayake, Sarath Kumara, & Weeraman, 1988).

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Nomenclature

$\varepsilon_R, \varepsilon_w$	relative permittivity of dry rubber and water
ε_{eff}	effective permittivity of latex
ε_r	relative permittivity
$\varepsilon'_r, \varepsilon''_r$	dielectric constant and dielectric loss factor
υ	parameter of polarisation in the dielectric mixer model
f	volume fraction of dry rubber
D_S, D_w	densities of solid rubber and water, $g \cdot cm^{-3}$
A_i, B_i	parameters of a six-port reflectometer
P_i	power value reading from port i of a six-port reflectometer
b_2	reflection wave at port 2 of a six-port reflectometer
Γ	reflection coefficient
θ	phase angle of reflection coefficient, degree
$\lvert\overline{\Gamma_F}\rvert, \lvert\overline{\Gamma_A}\rvert, \lvert\overline{\Gamma_B}\rvert$	Average magnitude of reflection coefficient of field fresh latex, contaminated field fresh latex with type A and type B contaminants, respectively
Ω	angular frequency, rad s^{-1}
C_0, C_f	capacitances representing the electric fields confined in the air and dielectric material of the sensor probe, fF
Z_0	matching impedance, Ω
$\Delta_{\lvert\Gamma\rvert}$	the distance from the centre line of $\lvert\overline{\Gamma_F}\rvert$
$\sigma_{\lvert\Gamma\rvert}$	the standard deviation of $\lvert\overline{\Gamma_F}\rvert$
PPV, NPV	positive and negative predictive values of the contamination detection algorithm, %
D_{Se}, D_{Sp}	sensitivity and specificity values of the contamination detection algorithm, %
LR^+, LR^-	positive and negative likelihood ratios of the contamination detection algorithm
Eff	total efficiency of the contamination detection algorithm, %

Abbreviations

type A	calcium carbonate and cassava flour
type B	27% ammonia solution
DRC	dry rubber content, %
FFL	field fresh latex
N-FFL	non-contaminated field fresh latex
C-FFL	contaminated field fresh latex
$CaCO_3$	calcium carbonate
ZnO	zinc oxide
NH_3	Ammonia
TMTD	tetramethylthiuram disulfide
ANA	automatic network analyser
GPIB	general purpose interface bus
MAE	mean absolute error
STD	standard oven method
TSC	total solid content method
MWR	microwave reflectometer
SMA	subminiature version A
PCB	printed circuit board
ADC	analogue digital converter
MCU	microcontroller unit

The second method is based on measuring the Total Solids Content (TSC) in FFL by evaporating the water from the sample. Common microwave ovens are nowadays used for quick drying (Hamza, Dilfi, Muralidharan, & Kurian, 2008; Jayanthy, Sankaranarayanan, 2005; Khalid, 1991), leaving dry rubber and other solids in the dried sample. Initial and dry mass are measured, and TSC is subsequently calculated as their ratio. The results from this method contain errors caused by non-rubber content, so it is not appropriate if the FFL sample is contaminated (Khalid, Wahab, & Rahman Kasmani, 1988).

The third method is the currently standardised oven method (STD), ASM D 1076-80. There are a few standards that have been well established and are widely accepted in the rubber industry, for example ISO 126:1972, BS 1672: part 1:1950, ASM D 1076-80. These methods require well-trained users in a well-equipped laboratory, and a determination takes about half a day. Hence the STD is inappropriate for use in trade of FFL, being too slow and not suitable for field use.

While several approaches are currently being researched, none of them is yet suitable for use in a market trade, where contaminated FFL (C-FFL) is commonly found. Some farmers deliberately add specific contaminants to FFL to gain certain benefits in the market trade. When C-FFL samples are used to make rubber products, they tend to degrade flexibility, wear resistance, tensile strength, viscosity, and heat accumulation characteristics. Most common contaminants that have been found are white solids, since these are difficult to distinguish by human eye, thus increasing the solid content of the C-FFL samples and thereby the price. Nowadays, commonly found contaminants are cassava flour, calcium-carbonate ($CaCO_3$), and gypsum. NH_3 solution, Tetramethylthiuram disulfide (TMTD), or Zinc oxide (ZnO) are other chemical substances intentionally added to preserve FFL (Langner, 1996), as well. The quantity of these preservative substances should be rigorously controlled to less than 0.2% by volume. Such latex samples are here labelled as N-FFL.

Recently, a simple microwave reflectometer (MWR) equipped with a dielectric probe sensor was proposed for DRC determination (Julrat et al., 2012), where the one-port reflectometer measurement was combined with a six-port circuit. Sinusoidal 2.5 GHz waves are emitted from an open-ended coaxial probe and incident radiation is reflected back from the FFL sample. This design provides a portable and low-cost solution for determining the DRC although the accuracy of this technique in the case of C-FFL has not been addressed in prior work, as it is expected that the DRC results in such cases will be biased. For use in a market trade, a detection algorithm for contaminated samples would be necessary.

This paper describes our use of MWR to determine contamination in latex. The algorithm developed for contamination detection seeks to develop a screening method prior to DRC measurement in the MWR system. Development of the MWR and the algorithm for determining relative permittivity are presented in Section 2. Section 3 presents the limitation of the MWR and TSC when measuring DRC of contaminated latex. The ε_{eff} of latex contaminated with various contaminant contents were studied using an automatic network analyser (ANA). The algorithm for classifying non-contaminated and contaminated latex was developed and is reported in Section 3. The conclusions of paper are explained in Section 4.