Microwave Dielectric Measurement of Liquids by using Waveguide Plunger Technique

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Abstract

This paper describes a using the microwave bench test to obtained dielectric constant ($\varepsilon'$) and the dielectric loss ($\varepsilon''$) of liquids by using waveguide plunger technique. Measurements were made with some non-polar and polar liquid. The non-polar liquids are benzene and carbon tetrachloride. The dielectric constant and the dielectric loss of dilute solutions of bromobenzene in benzene have been measured. All of solutions measured at 10.5 GHz and temperature 25. This method is suitable for the accurate determination of the dielectric parameters of non polar or weakly polar or of dilute polar liquids in non-polar solvents.

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Keywords: Microwave dielectric; Dielectric constant; Dielectric loss; Waveguide plunger technique, Relaxation time

1. Introduction

Electromagnetic properties of each material are the permittivity, permeability and conductivity. For dielectric materials either lossy or lossless, the most identifying parameter is the dielectric constant or permittivity. Dielectric properties are intrinsic characteristics of the materials explaining the behavior and degree of the wave-mater interaction when exposed to microwave field. These properties are very important in microwave heating, microwave sensing, process design and application. For example, there are many researchers who have used dielectric properties to measured moisture content of material and agro-food. A number of methods for measuring the microwave dielectric constant and dielectric loss of liquids have been proposed by different research groups and the classic paper on the method of measurement is that of Roberts and Von Hippel in 1946[1], [2]. The measurement of dielectric properties of liquid materials at microwave frequencies can be used to determine some physical properties and evaluation of biological effects in biological molecules [3]-[5]. In this paper, the permittivity of lossless
dielectric, benzene and carbon tetrachloride, low loss dielectric, bromobenzene, at X-band frequency have been studied and compared to the published values in the literature.

2. Materials and Theory

In this paper, the permittivity of standard non-polar liquid, benzene and carbon tetrachloride and dilute solutions of polar liquids, bromobenzene in benzene have been measured at 10.5 GHz for mode and temperature 25\(^\circ\)C by using waveguide plunger technique. An X-band microwave bench was used to measure the guide wavelength, wavelength in dielectric, and a standing wave ratio. The schematic diagram and photograph of experimental set up are shown in Fig.1 and 2.

When microwave is traveling through medium 1 (air) and strikes normally to the surface of medium 2 (dielectric material), which one part of the energy is reflected, another part is transmitted through the surface and the rest of it is absorbed. The proportions of energy which fall into these three categories have been defined in term of the dielectric properties. The complex relative permittivity of the material is expressed as
Where:
- \( \varepsilon' \) is the dielectric constant
- \( \varepsilon'' \) is the dielectric loss

A standing wave pattern is thus produced in medium 1 (air). The input impedance \( Z(0) \) at the boundary is given by

\[
Z(0) = Z_1 \left[ \frac{E_{\text{min}} - j\tan\left(\frac{2\pi x_0}{\lambda_g}\right)}{E_{\text{max}}} \right] \left(1 - j\frac{E_{\text{min}}}{E_{\text{max}}} \tan\left(\frac{2\pi x_0}{\lambda_g}\right)\right)
\]

Where \( x_0 \) is the distance from a surface of dielectric material to the adjacent minimum of standing wave in medium 1 (air) as shown in Fig. 3 and \( Z_1 \) is the impedance of medium 1.

![Diagram with labels](image)

Fig. 3 The distance of the first minimum for the interface (\( x_0 \)).

If medium 2 (dielectric under test) terminated in a short circuit, the input impedance of the interface is

\[
Z(0) = Z_2 \tanh \gamma_d d
\]

Where \( Z_2, \gamma_d \) and \( d \) are the characteristic impedance, propagation constant, and the length of the medium 2, respectively.

If we take liquid sample of length equal to the integral multiplier of \( \lambda_g / 2 \) place in contact with the short circuit plate, then the distance of the first minimum for the interface (\( x_0 \)) is zero. Hence \( Z_1 = 1 \), so that equation (2) become...
The attenuation, \( \Delta \gamma \), get from slope of graph between \( E_{\text{min}} \) and \( E_{\text{max}} \), where \( n \) is the number of half wavelengths in the dielectric as shown in Fig.4.

Fig.4 wavelength in dielectric \( \gamma_d = 2(d_2 \cdot d_1) \)
The relaxation time, \( t \) can be determined by

\[
\frac{\varepsilon' \varepsilon_0}{\varepsilon''} = \frac{\omega t}{\beta} = 2\pi f
\]

Where, \( n_r \) is the refractive index of dielectric and \( \beta = 2\pi f \)

Results and discussion

The results are given in Table 1 along with the values published in the literature.

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Experimental values</th>
<th>Literature values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \varepsilon' )</td>
<td>( \varepsilon'' )</td>
</tr>
<tr>
<td>Benzene</td>
<td>2.248</td>
<td>-</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>2.183</td>
<td>-</td>
</tr>
<tr>
<td>Bromobenzene</td>
<td>4.444</td>
<td>1.748</td>
</tr>
</tbody>
</table>

The results obtained in this method were in good agreement with publication results in the literature [6-7]. The difference value of dielectric constant of benzene and carbon tetrachloride could be due to the frequency of measurement, in this paper gives value at 10.52 GHz whereas literature is measured at lower frequency. For bromobenzene, the difference value of dielectric constant and dielectric loss could be due to the measurement of VSWR and the different in determination of relaxation time could come from the value of refractive index.

Conclusions

This work demonstrates that a simple set up equipment and plunger waveguide method enables a quick determination of complex permittivity of loss-less and low loss dielectric liquids. However, this method can be used for the high loss liquid dielectric by dilute in non-polar solvent.

Acknowledgements

The authors would like to thank, Department of Physics and Department of Chemistry, Faculty of Science and Technology, Thammasat University, Rangsit center, for provided facility and some chemical liquid.

References