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Measurement of Dielectric Properties of Liquids Using Microwave Reflectometry Technique

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ABSTRACT: We present detailed experimental technique for the determination of dielectric constant (ϵ') and the dielectric loss (ϵ'') for low loss liquids using microwave bench with plunger and coupler. The basic principle is the reflectometric analysis. The study presented here includes non-polar liquids are benzene and carbon tetrachloride. The dielectric constant and the dielectric loss of few selected liquids have been measured using microwave frequency 9.8 GHz and findings presented.

KEYWORDS: Microwave, Dielectric Constant, Dielectric Loss, Wave Guide Plunger, Reflectometry.

I. INTRODUCTION

In relation to dielectric properties, the electromagnetic properties of material of interest to scientists and engineers include the permittivity, permeability and conductivity. For dielectric materials both for lossy and 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-matter 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 measure 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 Heston and Smythe Method for low loss liquids[1]. 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, aniline, ethyl alcohol and bromobenzene at X-band frequency of 9.8 GHz have been studied at room temperature (27°C) and results and findings are presented.

II. RELATED WORK

The present work relates to the permittivity of standard non-polar liquid, benzene and carbon tetrachloride and aniline and ethyl alcohol have been measured at 9.8 GHz for mode TE₁₀ and temperature of 27°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 block diagram of the experimental setup is shown in Fig. 1 and photograph of the experimental set up is shown in Fig. 2. In the present work we used two directional couplers with isolator for the measurement of the incident and reflected microwave in terms of current from the detector. This incident and reflected intensity of microwave was used for calculation of VSWR using the relation:

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Vol. 6, Issue 8, August 2017

$$VSWR = S = \frac{I_f + I_r + 2\sqrt{I_f I_r}}{I_f - I_r}$$

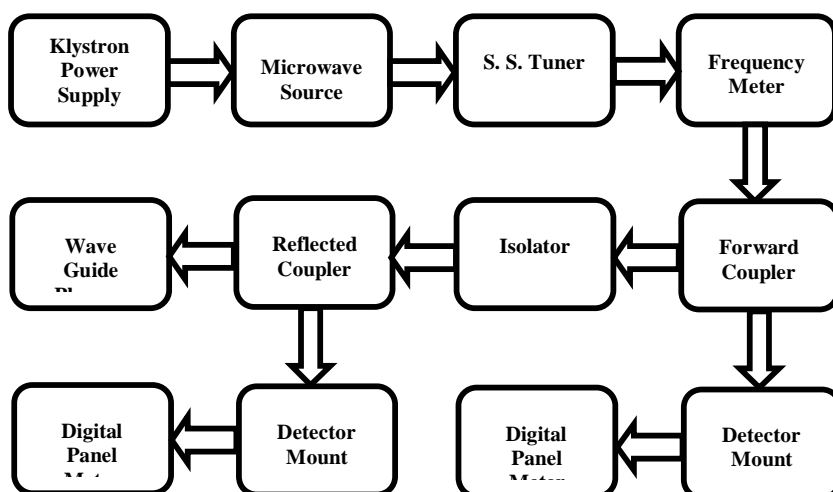


Fig.1 Block diagram of the experimental setup

When microwave is travelling 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 ϵ of the material is expressed as

$$\epsilon = \epsilon' - j \epsilon'' \tag{1}$$

Where,

ϵ' is the dielectric constant

ϵ'' is the dielectric loss

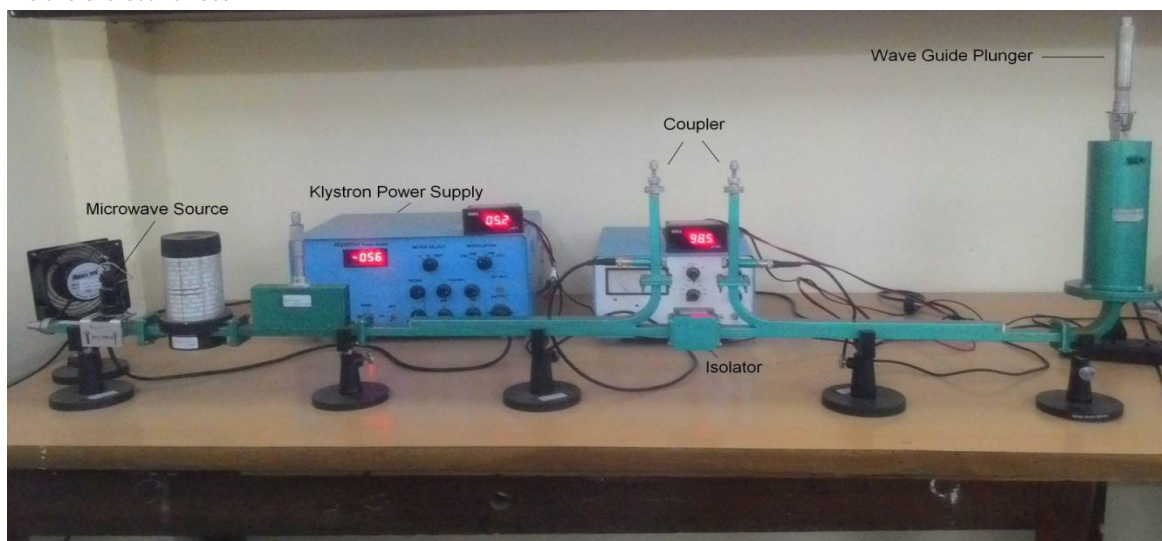


Fig 2 Photograph of experimental setup showing details of various components used like waveguide plunger and the two couplers along with the rest of the system.

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Vol. 6, Issue 8, August 2017

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

$$Z(0) = Z_1 \left[\frac{\rho - j \tan \frac{2\pi x_0}{\lambda_g}}{1 - j\rho \tan \frac{2\pi x_0}{\lambda_g}} \right] \quad (2)$$

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.

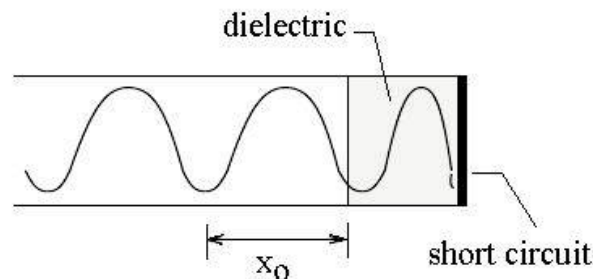


Fig.3 The distance of the first minimum for the interface (x_0)

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

$$Z_{(0)} = Z_2 \tanh \gamma_d d \quad (3)$$

Where Z_2 , γ_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 multiple of $\lambda_d/2$ 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 the equation (2) become

$$Z_{(0)sc} = \rho_n \quad (4)$$

ρ_n denotes inverse of VSWR when liquid length is $n \frac{\lambda_d}{2}$,

If medium 2 is terminated in a short circuit the input impedance at the interface

$$Z_{(0)sc} = \rho_n = Z_2 \tanh \gamma_2 d \quad (5)$$

Since $\gamma_2 = \alpha_d + j\beta_d$ and $d = n \frac{\lambda_d}{2}$, n being an integer, we have

$$\rho_n = Z_2 \tanh \left[\frac{n\alpha_d \lambda_d}{2} \right] \quad (6)$$

For low loss substances, $\tanh x \approx \tan x \approx x$,

$$\rho_n = Z_2 \frac{n\alpha_d \lambda_d}{2} \quad (7)$$

We know that $Z_2 = \lambda_d / \lambda_d$, then equation (7) becomes

$$\rho_n = \frac{n\alpha_d \lambda_d^2}{2\lambda_g} \quad (8)$$

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Vol. 6, Issue 8, August 2017

However, α_d used in equation (8) is the sum of two parts: one due to dielectric attenuation and the other due to plunger resistance and other losses. To eliminate later losses, a graph is plotted between several mean values of ρ_n versus n . The slope of this graph gives the value of $\frac{d\rho_{mean}}{dn}$. The dielectric constant ϵ' and dielectric loss ϵ'' are given by equation (1).

$$\epsilon' = \left(\frac{\lambda_0}{\lambda_c}\right)^2 + \left(\frac{\lambda_0}{\lambda_d}\right)^2 \tag{9}$$

$$\epsilon'' = \frac{2}{\pi} \left(\frac{\lambda_0}{\lambda_d}\right)^2 \left(\frac{\lambda_g}{\lambda_d}\right) \left(\frac{d\rho_{mean}}{dn}\right) \tag{10}$$

Where λ_0 is free space wavelength, λ_d is wavelength in dielectric, λ_c is cut off wavelength = $2a$. Here a is the width of the cell and λ_g is guide wavelength.

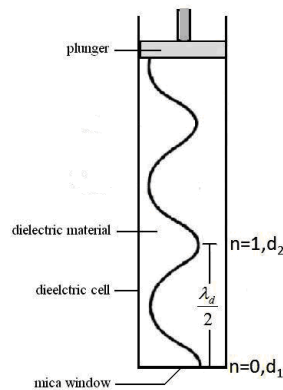


Fig.4 wavelength in dielectric

The relaxation time, τ can be measured by

$$\tau = \frac{\epsilon''}{\omega(\epsilon' - n_D^2)} \tag{11}$$

Where n_D is the refractive index of the sample of dielectric and $\omega = 2\pi f$.

II. EXPERIMENTAL RESULTS

Table- 1 The determined and literature values of dielectric constant, Dielectric loss and Relaxation time of solvents

Liquid	Experimental Value			Literature values		
	ϵ'	ϵ''	τ	ϵ'	ϵ''	τ
Benzene	2.56916	0.207706	4.3	2.26-2.28	-	4.12
Carbontetrachloride	2.522	0.200751	0.84	2.217	-	-
Acetone	20.661	6.635097	5.7	21.3		3.34
Aniline	5.809044	1.59745	3.7	5.597	1.448	-
Ethyl Alcohol	5.781161	0.840873	3.8	2.46	0.020	2.27
Acetonitrile	36.30878	4.161981	0.2	29.93533	4.595124	0.15350
Methanol	11.01672	9.8295	0.17	7.705522	4.335968	0.56271

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Three important dielectric properties i.e. Tangent loss ($\tan \delta$), penetration depth P_d and microwave conductivity σ are calculated using

$$\text{Loss tangent} = \tan \delta = \frac{\epsilon''}{\epsilon'} \quad (12)$$

$$\text{Penetration Depth} = P_d = \frac{\lambda \sqrt{\epsilon_r'}}{2\pi \epsilon_r'} \quad (13)$$

$$\text{Microwave Conductivity} = \sigma = \frac{f \epsilon''}{1.8 \times 10^{11}} \quad (14)$$

for different liquids studied and are tabulated in Table - 2.

Table-2 Experimentally determined values of solvents.

Parameter	Benzene	Carbon tetra chloride	Acetone	Aniline	Ethyl alcohol	Acetonitrile	Methanol
Tan δ	0.080846	0.079589	0.321141	0.15583	0.145451	0.114627	0.892239
P_d	0.32469	0.32769	0.10746	0.20217	0.29465	0.08106	0.14716
σ	0.02491	0.10974	1.12947	0.04954	0.01614	0.22752	0.53735

III. CONCLUSION

The results of measurement of dielectric properties shown above are in good agreement with the corresponding values given in literature. A slight deviation in few cases is attributed to the fact that the literature values shown correspond to different working conditions like temperature and particularly the microwave frequency[6,7] our working temperature was 27°C and microwave frequency was 9.8 GHz.

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