

# Dispersion Properties of Red Wine Based on Cole-Cole Plot

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**Abstract** — To evaluate the quality of wine, we previously measured the complex relative permittivity of red wine in the frequency range from 10 MHz to 6 GHz with a network analyzer, and showed that the maturity and alcohol concentration of red wine can simultaneously be estimated from the dispersion parameters of Cole-Cole plot consisting of a semicircle at frequencies above 1 GHz and straight line at frequencies lower than 1 GHz, respectively, while the evidence was not validated. In this study, to investigate the dispersion properties of red wine based on Cole-Cole plot, we measured the complex relative permittivity from 100 MHz to 40 GHz before/after distillation, and compared their Cole-Cole plots to reveal that the semicircle and straight line come from the dispersion for the water solution of alcohol and residue peculiar to ingredients of red wine, respectively.

**Key words:** Red wine, water solution of alcohol, ingredient, Cole-Cole plot, dispersion properties.

## I. INTRODUCTION

Nowadays, people have much interest in the quantitative evaluation of taste, which is one of five senses in humans, while its evaluation is not so easy because taste is generally caused by a chemical reaction of food materials to nose cells [1]. On the other hand, “quality” guaranteeing the taste of food including drinks is being so far evaluated by chemical analyses of component and expert’s sensuality.

Nishikata and his group showed a possibility from the objective of quality control in Japanese wine or SAKE that the fermentation process can be monitored from the relative complex permittivity in the frequency region of millimeter waves [2]. This method is based on the fact that time dependence of the relative permittivity for SAKE was similar to the concentration change of alcohol and glucose with respect to fermentation days.

In this context, to evaluate the quality of wine, we measured the complex relative permittivity of red wine in the frequency range from 10 MHz to 6 GHz with a network analyzer, and showed a possibility that the ingredient amount and alcohol concentration of red wine can simultaneously be evaluated from the Cole-Cole plot [3]. Furthermore, we estimated the Cole-Cole plot parameters of red wine for quality evaluation, which demonstrated that the alcohol concentration of red wine can be estimated from the parameters for semicircle dispersion, and other ingredient components can be evaluated by the parameters for straight line dispersion. For the estimation accuracy of alcohol

concentration [4], on the other hand, we also measured the complex relative permittivity of pure water and diluted ethanol solution from 100 MHz to 40 GHz, and obtained the dependence of the Cole-Cole plot parameters on alcohol concentration and temperature. By using these results as calibration data, we estimated the alcohol concentration of five kinds of red wine from their Cole-Cole plots, and compared the results with the measured one based on a distillation method, which is being used for alcoholic beverages with alcohol concentration of less than 30 % [5]. As a result, it was shown that the estimated alcohol concentration of red wine agrees with the measured results in error by less than 1 %.

The method we developed is allowed to simply estimate the alcohol concentration of alcoholic beverages without any distillation equipment, while we assumed that the properties of a semicircle and straight line should come from the dispersion of water solution of alcohol and ingredients peculiar to red wine, respectively.

In this study, to investigate the dispersion properties of red wine, we measure the complex relative permittivity from 100 MHz to 40 GHz before/after distillation, and compare their Cole-Cole plots in order to show how the alcohol component and other ingredients should affect the dispersion properties of the Cole-Cole plot.

## II. METHOD

Figure 1 shows a setup for measuring system and dielectric probe. Liquid samples used for estimating alcohol concentration were pure water and dilute ethanol solution, whose complex relative permittivity was measured in the frequency range from 100MHz to 40GHz with a dielectric

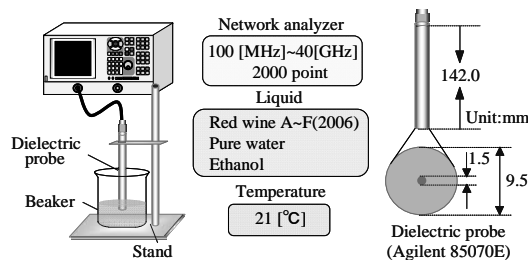


Fig. 1 Measurement setup and configuration of dielectric probe for measurement of permittivity.

probe connected to a network analyzer, as shown in Figure1. The alcohol concentration and temperature were changed from 0% up to 45% by 3% and from 14°C to 21°C by 1°C, respectively. The alcohol concentration of dilute ethanol solution was measured with a retained digital ethyl alcohol concentration meter (accuracy of measurement: 0~30% with an error of ±0.5%, 30~40% for ±0.8% and 40~45% for ±1.2%).

Complex relative permittivity of pure water and dilute ethanol solution can be expressed as Debye dispersion formula of Cole-Cole type [6],[7]:

$$\begin{aligned} \epsilon_r^* = \epsilon_r' - j\epsilon_r'' &= \epsilon_{r\infty} + \frac{\epsilon_{r0} - \epsilon_{r\infty}}{1 + (j\omega\tau_0)^\beta} \\ \epsilon_r' &= \epsilon_{r\infty} + \left( 1 - \frac{\sinh \beta x}{\cosh \beta x + \cos \frac{\beta\pi}{2}} \right) \times \frac{\epsilon_{r0} - \epsilon_{r\infty}}{2} \\ \epsilon_r'' &= \frac{\sin \frac{\beta\pi}{2}}{\cosh \beta x + \cos \frac{\beta\pi}{2}} \times \frac{\epsilon_{r0} - \epsilon_{r\infty}}{2} \end{aligned} \quad (1)$$

$$x = \ln \omega\tau_0$$

where  $\epsilon_{r0}$  is the DC relative permittivity,  $\epsilon_{r\infty}$  is the relative permittivity at infinite frequency,  $\beta$  represents the degree of relaxation distribution, and  $\tau_0$  are the relaxation time constant. Equation (1) shows that alcohol concentration can be evaluated by using the following four kinds of parameters:  $\epsilon_{r0}$ ,  $\epsilon_{r\infty}$ ,  $\tau_0$  and  $\beta$ .

For red wine, which also includes conductive impurities, its complex relative permittivity having DC conductivity [8],[9] can be given by

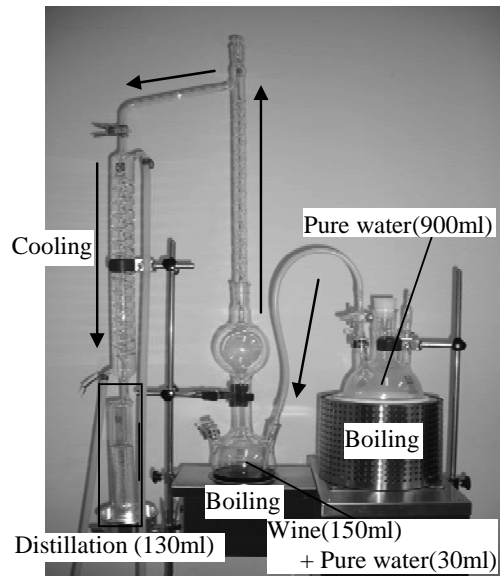


Fig.2. Distilling equipment for alcoholic drinks.

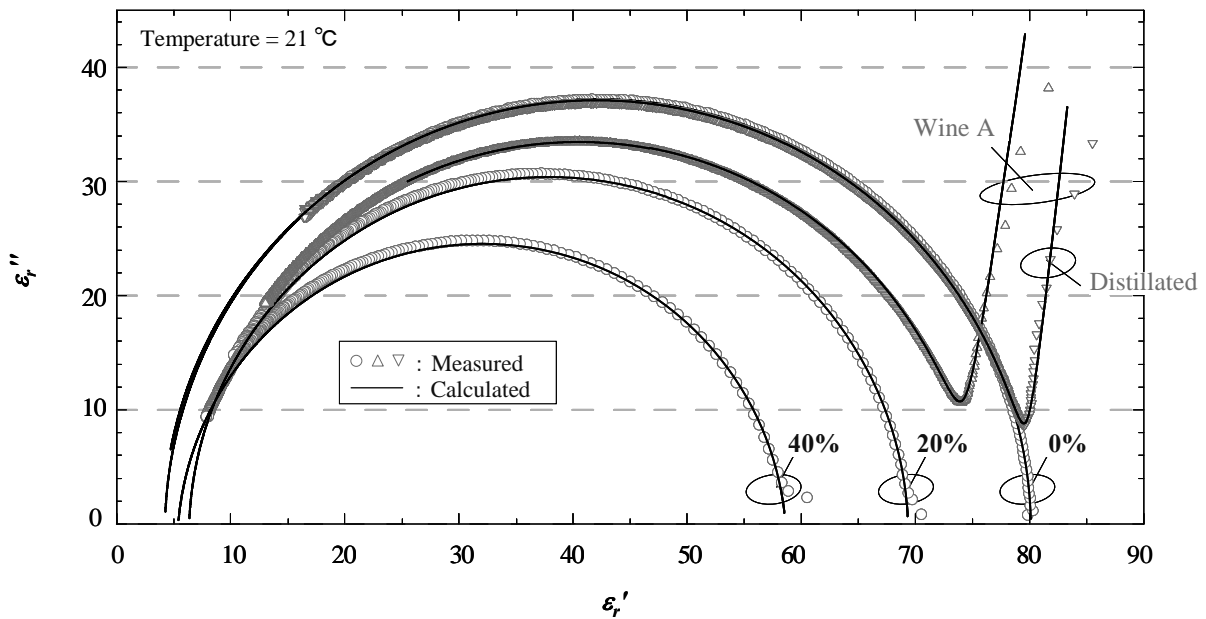


Fig. 3 Measured and estimated Cole-Cole plots.

$$\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r'' = \varepsilon_{r\infty} + \frac{\varepsilon_{r0} - \varepsilon_{r\infty}}{1 + (j\omega\tau_0)^\beta} + \frac{1}{(j\omega\tau)^\alpha}$$

$$\varepsilon_r' = \varepsilon_{r\infty} + \left(1 - \frac{\sinh \beta x}{\cosh \beta x + \cos \frac{\beta\pi}{2}}\right) \times \frac{\varepsilon_{r0} - \varepsilon_{r\infty}}{2} + \cos \frac{\alpha\pi}{2} (\cosh \alpha y - \sinh \alpha y)$$

$$\varepsilon_r'' = \frac{\sin \frac{\beta\pi}{2}}{\cosh \beta x + \cos \frac{\beta\pi}{2}} \times \frac{\varepsilon_{r0} - \varepsilon_{r\infty}}{2} + \sin \frac{\alpha\pi}{2} (\cosh \alpha y - \sinh \alpha y) \quad (2)$$

$$x = \ln \omega\tau_0$$

$$y = \ln \omega\tau$$

where  $\tau$  are the relaxation time constant, and  $\alpha$  represents the degree of relaxation distribution.

The alcohol concentration of red wine can also be evaluated from the parameters of  $\varepsilon_{r0}$ ,  $\varepsilon_{r\infty}$ ,  $\tau_0$  and  $\beta$  in Equation (2), which was estimated in the following way. Measurement of the Cole-Cole plots was made for pure water and dilute ethanol solution, which were fitted to Equation (1) to reveal the dependence on alcohol concentration of the above-mentioned parameters for calibration data. The parameters in Equation (2) were also obtained from the Cole-Cole plot measured for red wine, whose alcohol concentration was estimated from the calibration data for pure water and dilute ethanol solution, and was validated by using a distilling equipment shown in Figure 2.

To examine the dispersion properties of red wine, we used six kinds of 2006 Japanese products made from merlot, which were named A, B, C, D, E and F, and also employed the residue of wine A.

### III. RESULTS AND DISCUSSION

Figure 3 shows the Cole-Cole plots measured and calculated for pure water and dilute ethanol solution together with wine A and its residue, which demonstrates good agreement between measurement and calculation by Equations (1) and (2). The results also shows that the residue of wine A has a semicircle and straight line in the Cole-Cole plot, the former of which almost agrees with the case for pure water. This means that the semicircle and straight line can essentially be governed by the dispersion properties of alcohol component and specific impurities of red wine. It should be noted that there are some discrepancies between the minimum point of the Cole-Cole plot and the gradient of the straight line before/after distillation, which may be due to the chemical changes of the wine ingredients affected by the distillation.

Based on the dependence on alcohol concentration of the parameters in Equation (2), we estimated the alcohol concentration of the wine A and residue from the parameters of the measured Cole-Cole plots, which is summarized in Table 1. The measured alcohol concentration of wine A was

TABLE I

Cole-Cole parameters and their estimated values of red wine before/after distillation.

Merlot wine	$\varepsilon_{r0}$	$\varepsilon_{r\infty}$	$\beta$	$\tau_0$ [ps]	$\tau$ [ps]	$f_m$ [MHz]	$\omega_m\tau_0$	$\omega_m\tau$	$\alpha$
Wine A	73.6(12.2)	6.2	0.986	12.76	25.70	798	0.064	0.129	0.910
Distilled	79.3(2.1)	4.0	0.986	9.43	33.50	898	0.053	0.189	0.913

( ) : Estimated alcohol concentration value [%]

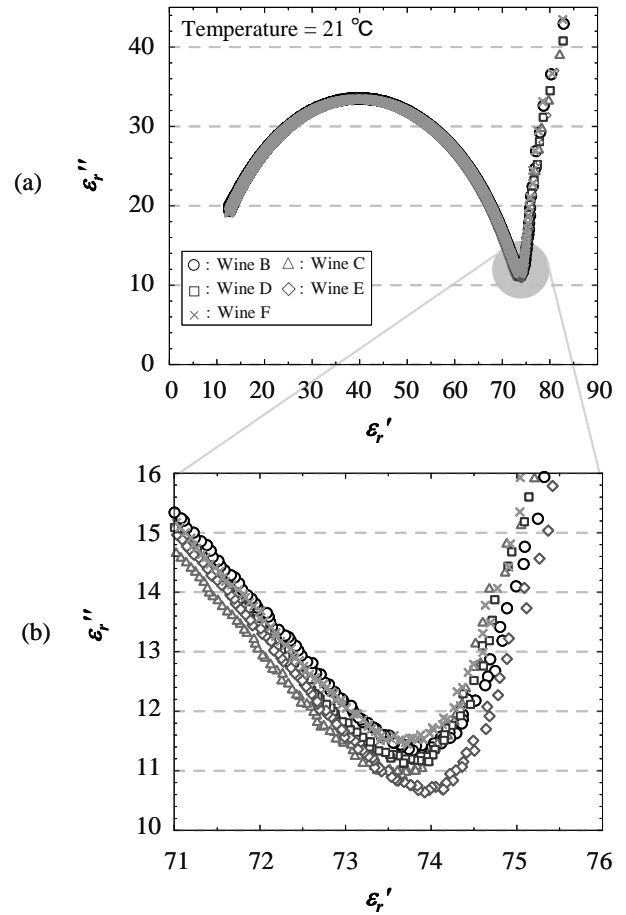


Fig. 4 (a) Measured results of Cole-Cole plots for different kinds of red wine and (b) enlargement of the Cole-Cole plot around the minimum point .

12.3 % from a distillation method. From the table, we confirmed that the estimated alcohol concentration of wine A agrees well with the measured result.

Figure 4(a) shows the Cole-Cole plots measured for five kinds of wine B to F, which come from the same brand of merlot. Also shown in Figure 4(b) is an enlargement of the Cole-Cole plot around the minimum point. These Cole-Cole parameters are summarized in Table 2 together with the estimated values of alcohol concentration. We found that all the semicircle parts almost coincide, which shows the same alcohol concentration for wine B to F, while there are some differences between the minimum points and gradients of straight lines for the same brand of wine, which suggests a

TABLE II

Estimated values of alcohol concentration and parameters for Cole-Cole plot of red wine shown in Fig.4.

Merlot wine	$\epsilon_{r0}$	$\epsilon_{r\infty}$	$\beta$	$\tau_0$ [ps]	$\tau$ [ps]	$f_m$ [MHz]	$\omega_m \tau_0$	$\omega_m \tau$	$\alpha$
Wine B	73.6(12.2)	5.5	0.978	12.88	23.50	938	0.076	0.139	0.912
Wine C	73.4(12.6)	5.5	0.976	13.03	25.20	839	0.069	0.133	0.911
Wine D	73.5(12.4)	5.6	0.978	12.96	24.50	898	0.073	0.138	0.913
Wine E	73.6(12.2)	5.6	0.977	13.13	26.40	839	0.069	0.139	0.905
Wine F	73.5(12.4)	5.6	0.978	12.95	23.00	858	0.070	0.124	0.916

( ) : Estimated alcohol concentration value [%]

possibility that impurities peculiar to red wine could be evaluated from the corresponding Cole-Cole parameters.

#### IV. CONCLUSION

In comparison of the Cole-Cole plots of red wine before/after distillation, we have examined to what extent the alcohol component and specific wine ingredients should affect the dispersion properties. As a result, we have found that the semicircle is strongly reflected by the dispersion of water solution of alcohol, while the straight line is based on the ingredients peculiar to the red wine.

The future subject is to evaluate the quality of red wine from the Cole-Cole plot in the low frequency region based on TDR (Time Domain Reflectmeter) measurement.

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