Dielectric Characterization of Ethanol and Sugar Aqueous Solutions for Potential Halal Authentication

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Abstract - A potential method for detection and discrimination of alcoholic containing drinks for halal authentication using dielectric properties has been investigated. Behaviors of several concentrations of ethanol solutions in water were studied for verification purpose. The addition of three types of sugar namely sucrose, glucose and fructose show the effect and changes to dielectric properties of solutions. Dielectric constant and dielectric loss factor for each samples were measured over the microwave frequency from 0.5 to 50 GHz. The results showed that dielectric properties manage to discriminate alcohol content until the lowest concentration studied of 0.5% in water mixture. Beyond this limit, solution is considered as alcoholic drinks.

Index Terms - alcohol, dielectric, halal authentication, sugar effect

I. INTRODUCTION

Identification and discrimination of halal and non-halal products has become increasingly important especially to the Muslim communities and has become very challenging nowadays due to the unavailability of robust and rapid methods to detect halal products. Non-halal foods and drinks refer to illicit goods including pork and all its products, improperly slaughtered animals, alcoholic drinks (including all forms of intoxicants), blood and any food or drink contaminated with any of these products. To some extent, the integrity of the halal status of a product depends very much on the technology that supported the halal authentication.

One of the potential methods to facilitate this ongoing research is the use of electromagnetic radiation in the microwave range on food. Dielectric measurement and technique provides a simple, rapid, reliable and also non-laborious alternative compared to current lab-based existing methods such as Fourier transform infrared (FTIR) spectroscopy [1] and species-specific polymerase chain reaction (PCR) detection [2]. Microwave spectroscopy is a very attractive and powerful method for characterising food and some of its components in a non-invasive way. The use of this dielectric measurement could significantly reduce the analysis time required for the determination of a material’s halal status and also assist to more efficient and reliable decision making processes for halal detection.

Sugar is the one of the key components in the manufacture of alcoholic beverage. Glucose, fructose and sucrose which are known as sugar alcohols, are important in fermentation process in tandem with the ability to alter the physical and chemical properties of the system of host food. These sugars also are common sweetener in alcoholic beverages and honey in order to increase the total sugar content [13]. Dielectric properties have been utilised to characterize food quality such as sugar content in yoghurt [4], sugar and ethanol solution [5], sugar and water
content in honey [6] and thermal properties of sugar solution [7].

The aim of this work was to establish the suitability of using dielectric properties for the potentially rapid in situ determination of halal and non-halal products for frequency range 0.5-50 GHz. The objectives of this study were mainly to characterize the dielectric properties of sugar effect in ethanol solutions.

II. MATERIALS AND METHODS

A. Instrument and Dielectric Properties Measurement

Agilent PNA-X Microwave Network Analyzer N5245A which offers range of frequency 10 MHz to 50 GHz were used to perform the dielectric permittivity measurement. The technique used was open-ended probe technique with a coaxial probe and software. Both of them are included in the Agilent 85070E dielectric probe kit. The slim form probe is best used for liquids and there is no need for an external computer as software can be installed directly in the analyzer. All measurements were carried out in the 500 MHz to 50 GHz frequency range at room temperature (20 - 22 °C). Calibration at the tip of the probe must be performed well prior the measurement in order to remove the systematic (repeatable) errors from the measurement. The three well-known standards air, a short circuit and distilled water were measured with the automated Electronic Calibration Module (Agilent N4693A). It calibrates the system automatically, in seconds, just before each measurement was made.

The solutions samples were placed in small beaker (50ml) and the surface of the samples was attached to the slim probe to measure the dielectric permittivity. The air bubbles on the tip of the slim probe should be eliminated before any measurement to avoid inaccuracy of the results. The microwave signal launched by PNA-X was reflected by the sample. The receiver detects the reflected and transmitted signals from the material by tuning to that frequency. The measurement was repeated as the source stepped to another frequency and the measured response produces phase and magnitude data for range of frequency tested.

B. Preparation of samples

Among the primary alcohols, ethanol was selected in this study due to its commonness usage in alcoholic beverages. Ethanol with purity of > 99 % was diluted by deionised water to concentrations ranging from 40 % to 0.5 %. 25 ml of each solutions was added with 1 g of sugar (sucrose, glucose or fructose). The dielectric measurements were first done on solutions of different concentrations of ethanol with similar amount of sugar. Next, 10 % ethanol was selected for studying the effect of different amount of sugar (1 g, 5 g, 10 g and 15 g). Pure ethanol (R & M Chemicals) and three type of sugar (Sigma-Aldrich (M) Sdn. Bhd.) were purchased from a local supplier.

C. Basic principles of dielectric permittivity

The interaction between the materials with electromagnetic energy in the microwave range provides information known as dielectric properties of the material which consists of the dielectric constant, $\varepsilon'$ and dielectric loss, $\varepsilon''$ [8]. Both $\varepsilon'$ and $\varepsilon''$ determine the ability of material to store or dissipate energy in response to an applied electric field [9]. Alcohol, a polar molecule which subjected to dipole moments is resulted to have relaxation phenomena and polarization effects. This interaction is measured by paramenter of relaxation time, $\tau$ that describes the time necessary for approximately $1/e$ ($e=2.718$) of the dipoles to relax under the solution environment [10].

III. RESULTS AND DISCUSSIONS

The analysis pertains to sugar added in alcohol was investigated to observe its effects in the solution. The influence of sugar on the dielectric properties of 40%, 10% and 0.5% ethanol
solution is presented in Fig. 1 and 2. Addition of sucrose has changed to some extent the dielectric constant signal of ethanol solution (without sugar). We can see at both figures that the values becomes lower when there was an addition of sucrose especially at low frequency position starting at 0.5 GHz until 10 GHz ($\varepsilon'$) and 5 GHz to 30 GHz ($\varepsilon''$).

Fig. 1. The changes in the dielectric constant for 40%, 10% and 0.5% ethanol solution in the presence of added sucrose.

In addition, both dielectric constant and loss factor are higher for lower concentrations. This is due to the availability of more water in the solutions, the higher amount of water resulted to more ionic polarization effect. Dipolar and ionic loss are the two primary mechanisms that contribute for microwave absorption in materials. At lower frequency, ionic polarization exerts greater effects on the water molecule more compared to alcohol molecule [11]. At higher frequency, the dielectric signal is more effective since electromagnetic energy penetrate deeper. However, the ionic polarization does not affect the material composition in this range.

The presence of sucrose molecule in ethanol solutions gives the changes of dielectric waves. The fluctuations of wave can be observed especially at higher frequency as reflection that hydroxyl group of sucrose react slowly with water and alcohol molecule which explains the weaker interaction with the microwave field.

The results in Fig. 1 and 2 also highly reflected the ability of dielectric equipment to give a reliable signal for detecting ethanol concentration as below than 1 % particularly within in the range of frequency 10 GHz – 25 GHz. This frequency range shows good separation foe different concentration of ethanol. In some countries especially Islamic countries, the production of intoxicating drink are considered as non-halal for consumption according to alcohol content limits or standards specified. For instance in Malaysia, the Department of Islamic Development or otherwise known as JAKIM sets a limit of 0.5 % of alcohol content in a drink or food (the production is not for the purpose of intoxicating) for which if it exceeds this limit, a drink/food is considered to be non-halal. Normally, in halal aspect it is quite difficult to detect low concentration especially below than 1 %. Thus, it is good to see the dielectric signal in the results able to detect the dielectric properties of ethanol solution as low as 0.5 %.

Next, Fig. 3 illustrated the dielectric constant values for four samples with spectra of 10 % ethanol as a guideline. It is clear that as the amount of sucrose increases, the dielectric constant values decreases and diverge from the 10 % ethanol spectrum. The fluctuations occur around frequency of 30 GHz to 50 GHz, which correspond to common beverages behaviors [12] particularly at higher frequency range. The trend in dielectric constant also found in dielectric loss factor spectrums. The presence of more sucrose molecule in alcohol solution not only gives the
sweetness flavor but shows the less ability in storing and losing energy within the materials.

The effects of another sugar like glucose and fructose were observed and the dielectric results were plotted in Fig. 4. Roebuck and Goldblith (1972) reported that there are differences of microwave interaction between disaccharide (sucrose) and monosaccharide (glucose and fructose) [13]. The hydroxyl groups of monosaccharide are more accessible for hydrogen bonding while in sucrose, fewer hydroxyl groups are exposed to water and fewer stable hydrogen bonds are formed. Therefore, the microwave interaction of sucrose in solution forms some fluctuations as a sign of that instability.

**Fig. 3. The changes in dielectric constant for 10% ethanol solutions in the presence of various amount of sucrose.**

**Fig. 4. The changes in dielectric constant for 10% ethanol solutions in the presence of different type of sugar.**

The graph presented the addition of glucose has lowest values of dielectric than sucrose and fructose. In the previous experimental work, when dissolving each sugar in ethanol solution, fructose was found to have highest level of solubility than others. Theoretically, solubility factor is inversely to the ease of crystallization in sugar. Sugar crystallizes fastest when the solution is concentrated. Glucose was the slowest to fully dissolve in the solution; however, it went through the crystallization process easier than others did.

Overall, according to all results in this work, a good separation of graph in each ethanol concentrations was found in frequency range of 10 – 25 GHz and the presence foreign substance like sugar in solutions will alter the dielectric values. Thus, it is strongly suggest the suitability of using dielectric measurement to discriminate alcoholic and non-alcoholic drinks especially in higher frequency than 10 GHz.

**IV. CONCLUSION**

The experimental data have been found to fit well with the proposed technique for halal authentication. Dielectric method ables to characterize alcohol solutions which has addition of any substances such as sugar. Sugar plays an important role to alter dielectric spectrum due to polarization effects and molecular interaction. Even though many works on the dielectric properties of alcohol have been done before, none of them have linked this technique for verification purpose of halal status at low concentration of alcohol content. The present study and discussion in this paper work is important as the starting point of such an attempt in the field of halal food.

This method thus, has the potential to be tapped as a reliable tool to establish halal status of a product as it is very simple, fast and gives real-time signal, which can be obtained in-situ. This method can be utilized as a support and initial screening of a sample especially for deciding status of doubtful (syubhat) material before proceeding to details analysis using other time-consuming. Faster decision-making can be done to avoid further complication. Henceforth, more research must be done to consolidate of other molecules (additives), temperature, sugar...
contents, viscosity, moisture content and other interfering substance.

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