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MEASUREMENT OF ELECTROPHYSICAL PARAMETERS OF ALCOHOLIC SOLUTIONS

Mathematical models are analyzed which describe active and reactive components multielement two-terminal admittance, which provides system "electrode-alcohol solution."

Key words: admittance, capacity double layer, dielectric conductivity, specific conductance.

Introduction

Today, the need to control the quality of any products is known. The evaluation of quality of liquor (vodka, whiskey, gin, etc.) and ethanol is especially important. This is due to the advent of mass production of such low quality, which is dangerous for society, imitations of the products of large manufacturers, unaccounted products beyond the production control and replacement products on counterfeit analogue during transport from manufacturer to consumer. That is why speed control, eliminating subjective errors of assessment of product quality, comparing the quality control results of production by manufacturer with the results of monitoring by consumer provides its identification.

Control of electrophysical parameters for the components immittance.

One method of such controlling is a method, which is based on measuring electrophysical parameters, namely the dielectric permeability ε_x and conductivity σ_x of control object [1, 2]. Realized measuring of these parameters can be simple technical means of a special purpose or using serial wide-range meters of complex impedance parameters or conductivity (immitance) [3]. You must additionally have a primary converter of dielectric permittivity and conductivity of control object in measurable parameters applied device. Preferably these parameters are resistance *R*, and capacitance *C*, active *G* and reactive *B*, which are components of complex resistance Z (impedance) or active *G* and reactive *B*, which are components of complex conductivity *Y* (admittance). In this case permittivity and conductivity using capacitive primary converter of plane parallel constructures is determined by known formulas:

$$C = \frac{e_0 e_x S}{d}, \tag{1}$$

$$G = s\,\frac{d}{S}, \tag{2}$$

from which get:

$$e_x = C \cdot \frac{d}{S} \cdot \frac{1}{e_0} = \frac{A}{e_0} \cdot C, \tag{3}$$

$$s_x = G\frac{S}{d} = \frac{1}{A}\cdot G, \qquad (4)$$

where $A=d/S$ – was the primary converter (S and d – area of electrodes and the distance between them); ε_0 – permittivity of vacuum.

In the light of the results of measurement parameters C and G by the expressions (3) and (4) define the electrophysical parameters ε and σ.

Since the electrical parameters linearly depend on the capacity (3) and conductivity (4), it is advisable for these kinds of measurements to use the appropriate mode of device measurement, i.e. mode of separate measurement of complex conductivity parameters for parallel circuit admittance parameters with its reactive ωC and active G conductivity. One more fact should be noted that to ensure the adequacy between the measured values of these parameters and the corresponding real parameters of control objects (alcoholic solutions) it is necessary that the replacement scheme of object was the same as at a given frequency test signal device. In case of inadequacy of these mentioned schemes [4], we will have methodological error of measurement informative object parameters.

Experimental investigations

Scheme of control object substitution. To determine the nature of the replacement circuit the authors conducted research of the alcoholic solution of three different concentrations (distilled water and alcohol) in the frequency range from 100Hz to 100 kHz by immittance meter with contact two electrode capacitive primary converter (sensor) in the measurement mode of admittance parameters. The results are presented in graphical interpretation in Figure 1 (active component) and Figure 2 (reactive component). On the figures curves correspond to alcohol concentration B – 40 % curves D – 60 %, and the curves C – 80 %.

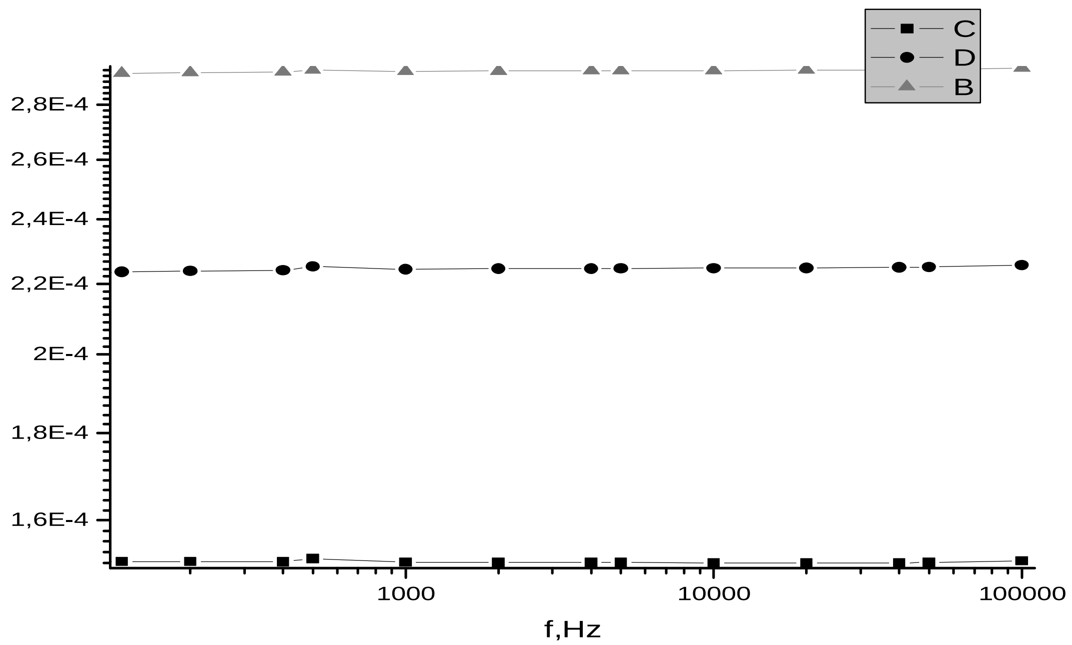

Fig. 1. The dependence of active component of alcohol solution of the frequency

Analysis of the results showed that the active component is virtually independent of frequency in the test range. This lower concentration of alcohol in the solution meets the larger value of active component. However, reactive component has a nonlinear dependence of the frequency range up to 1 kHz, and further almost linear dependence of the selected frequency range is observed. The dependence of reactive component of concentration at a fixed frequency is significantly less of the dependence of active component, but the nature is the same. Based on the experimental results can be considered that the object replacement scheme at frequencies exceeding 1kHz used for primary capacitive transducer is approximate to a scheme under which the device measurements are made, ie parallel circuit with RC-elements. The higher is the rate, the less methodical error of measurement. Nonlinear nature of reactive component dependence of the frequency up to 1 kHz is explained by the presence of double layer capacitance C on the verge of electrode-solution. [5]. So, in this case, the scheme of system replacement "electrode-object" will appear as shown in Figure 3.

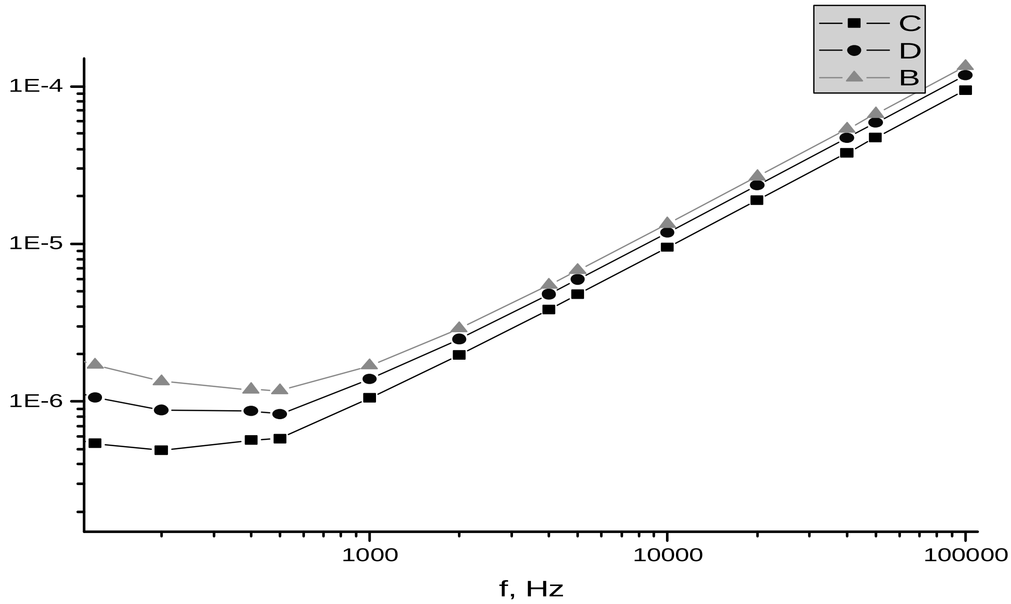

Fig. 2. The dependence of reactive component of alcohol solution of the frequency

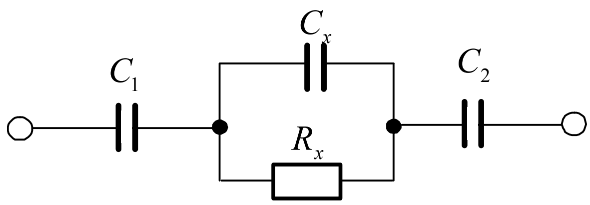

Fig. 3. Scheme of system replacement "electrode-object"

Mathematical models and its analysis. Let's analyze the impact of the double layer capacitance in the case of using admittance components as informative parameters. It is necessary to write the expression admittance two-terminal *Y* shown in Figure 3. Then considering dependence *Y=1/Z* and one electrode get:

$$Y = \frac{jwC - w^2 CC_x R_x}{1 + jwR_x(C_x + C)}, \tag{5}$$

where active Re *(Y)* and reactive Im *(Y)* admittance components are described by formulas that $C >> C_x$ [5] simplified provided:

$$\mathrm{Re}(Y) = G_x \cdot \frac{w^2 C^2 \left(1 - \frac{C_x}{C}\right)}{G_x^2 + w^2 C^2} \approx G_x \frac{1}{1 + \left(\frac{G_x}{wC}\right)^2}, \tag{6}$$

$$\mathrm{Im}(Y) = \frac{wC + w^3 C^2 C_x R_x^2}{1 + w^2 C^2 R_x^2} \approx wC \frac{1}{1 + \left(\frac{wC}{G_x}\right)^2} + wC_x \frac{1}{1 + \left(\frac{G_x}{wC}\right)^2}, \tag{7}$$

where C_x and G_x – object control parameters; $C=C_1=C_2$, and C_1 and C_2 – double layer capacitance of the first and second electrodes primary converter, which is proportional to their areas appropriately.

If the primary converter electrodes have the same active area (area of the electrode in contact with the object of control), the $C_1=C_2$. This is inherent to capacitive primary converter of plane-parallel structures. For coaxial construction transducer this equality is not provided, since the area of the electrodes is different. It depends on the diameter electrodes and their length, and therefore area ratio, and accordingly the double layer capacitance is proportional to the ratio of the diameter of the sensor.

Let's analyze dependences (6) and (7) of admittance components. As seen from the expressions on the dependence character of two expressions affect the ratio between active conductivity G_x of control object and reactive conductivity ωC, formed double layer capacity. Moreover, the impact in expressions of such kind of ratio is reversed and determined by the frequency at which measurements are made. If you provide a condition $\left(\frac{G_x}{wC}\right)^2 << 1$ (expression (6)), and accordingly will be $\left(\frac{wC}{G_x}\right)^2 >> 1$ (expression (7)), the conductivity of these components will be as follows:

$$\mathrm{Re}(Y) = G_x, \tag{8}$$

$$\mathrm{Im}(Y) = \frac{G_x^2}{\omega C} + \omega C_x, \tag{9}$$

Accepted condition is achieved by high frequency of test signal and low active conductivity at constant values of double layer capacitance for the selected type of primary converter. Under this condition there will be independence of solution active conductivity of the double layer capacitance in this frequency range. However, under these same conditions reactive conductivity is defined by the sum of the components (9), which in different ways depend on the frequency, i.e. if the first decreases non-linearly with frequency increasing, the second increases linearly with frequency increasing. This explains the nonlinear dependence of reactive component at frequencies up to 1 kHz. In the future, with increasing frequency the second component of reactive conductivity, i.e. ωC, defines the nature of the admittance component change, that will have:

$$\mathrm{Im}(Y) = \omega C_x \tag{10}$$

Under condition $\left(\frac{G_x}{wC}\right)^2 >> 1$, and appropriately get $\left(\frac{wC}{G_x}\right)^2 << 1$, з (6) and (7) appropriately get the following expressions:

$$\mathrm{Re}(Y) = \frac{w^2 C^2}{G_x}, \tag{11}$$

$$\mathrm{Im}(Y) = wC + wC_x \frac{w^2 C^2}{G_x^2}, \tag{12}$$

Such condition is achieved by low frequency and high conductivity at constant value of double layer capacitance. Under this condition, as seen from the expressions (11) and (12), the active component is proportional to the frequency square and inversely proportional to the active conductivity, and reactive has component, which has a cubic dependence on the frequency and the inverse square dependence of conductivity. As expressions (11) and (12) do not satisfy the dependence (3), (4), there is no need to measure the above electrophysical parameters of the alcohol solutions under these conditions.

Conclusion

Analysis of obtained mathematical models of the system "electrode-solution" in the frequency range showed the following:

1) The electrical equivalent circuit of alcohol solutions (alcoholic beverages and ethyl spirit) can be considered a two-element in the frequency range from 1 kHz to 100 kHz. It contains a parallel connection of resistance and capacitance.

2) The active component of admittance (of) alcohol solution is determined by resistance of replacement circuit and does not depend on the frequency of the test signal provided $\left(\frac{G_x}{wC}\right)^2 << 1$. Conductivity can be determined by measuring results of the admittance active component and is inversely proportional to the alcohol content in the solution.

3) Reactive component of admittance is linearly dependent on frequency provided $\frac{G_x^2}{wC} << wC_x$. In this case, the dielectric permeability is determined by measuring results reactive component at a given frequency of test signal.

4) The lower limit of frequency range measurement of electrical parameters of alcoholic solutions is defined by outside value of methodical error of reactive component measurement. This limit can be reduced for solutions with low conductivity (high concentration of alcohol) or increase the sensor electrodes area.

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