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Electrical Method for the Cyberphysical Control System of Non-Electrical Objects

***Abstract**. The article shows the problem of automating the control of the composition of technical liquids during their work. The authors present the results of tests on the electrical properties of multicomponent fluids in the electromagnetic field of different frequency. The obtained results indicate the existence of a simple, quick assessment of the liquid composition without the need for chemical laboratory analysis, carried out using cheap and simple measuring transducers.*

Streszczenie. *Artykuł pokazuje problem automatyzacji kontroli składu płynów technicznych podczas ich pracy. Autorzy przedstawiają wyniki badań właściwości elektrycznych płynów wieloskładnikowych w polu elektromagnetycznym o różnej częstotliwości. Uzyskane wyniki wskazują na istnienie prostej, szybkiej oceny składu cieczy bez potrzeby wykonywania chemicznej analizy laboratoryjnej, realizowanej z wykorzystaniem tanich i prostych przetworników pomiarowych.(**Metoda elektryczna dla cyberfizycznego układu sterowania obiektami nieelektrycznymi**)*

Keywords: electrophysical characteristics of liquids, conductivity sensor, operational control
Słowa kluczowe: właściwości elektrofizyczne cieczy, przetworniki przewodności, sterowanie operacyjne

Introduction

Fluids are the most common objects for measurement and control in industry, medicine, agriculture, and environmental monitoring. The standard characteristics of control in these areas are concentration. It is important to provide fast and objective control of the composition of technical fluids during the production or operation of equipment. It is advisable to consider the problems of such controls or measurements that are constantly being studied by scientists[1-10].

In order to objectively determine the concentration of the solute, the object must be homogeneous in volume. Therefore, predominantly all analytical control techniques are based on studies of homogeneous liquids. If the object of the study is in solid or free-flowing state, its composition is extracted in the liquid for further laboratory long-term analytical manipulations, leading to large methodological errors of research (60% -100%).

Another important requirement for the test fluid under standard controls is the two-component content of the control substance and the unchanged solvent composition. That is, multicomponent mixtures to investigate are quite problematic.

Therefore, standard laboratory (or portable in the case of chromatography) measurements, these are so-called indirect measurements, which have a number of significant drawbacks that make it impossible to use them during the operation of the equipment.

Only the electrical method of controlling the composition of liquids, where the informative parameter is complex electrical quantities (resistance and conductivity), allows to automate this process.

It should be noted that all real technical fluids are multicomponent fluids, so the object of our study is the processes of electrical testing of multicomponent fluids.

The subject of our research is model multicomponent liquids containing dissolved substances of different chemical and electrical nature. Model fluids were created in a chemical laboratory with a known composition.

Let us analyze the known electrical methods for the study of liquids (Table 1).

All these methods are used as generalized, insensitive to non-electrolytes (some substances of inorganic composition and mainly all organic composition). Only the immitance method, which actually contains methods of conductometric and dielectric methods, is theoretically capable of studying liquids of different chemical nature.

Table 1. Electrical Methods for Fluid Research

Electrical methods	Informative parameter	Peculiarities and possibilities of use for the investigation of the composition of substances (electrolytes, non-electrolytes) in multicomponent liquids		
		Measurement properties of the liquid	Definition composition and concentrations	
			Electrolytes	Non-Electrolytes
Conductometric	Electrical conductivity	+	+	-
Dielectric	Electrical permeability	+	-	-
Immitance	Complex electrical: resistance, conductivity	+	+	+
Potentiometric	Electromotive force of the potentiometric cell	+	+	-
Voltammetric, polarographic	Voltammetric characteristic	+	+	-
Coulomb method	Amount of electricity during the electrolysis process	+	+	-

The conductometric method is based on the measurement of the electrical conductivity of the entire measuring system, which depends on the concentration of only those substances that influence the electric current (electrolytes). The liquid should be only two-component.

The dielectric method, where the informative parameter is electrical permeability, complicates the control of the composition of multicomponent fluids due to the generalization of this indicator.

The complex electrical parameters of the immitance method would give more information about the composition of such liquids.

Research conditions

The authors, after theoretical analysis, have proposed a study of the composition of objects of a non-electric nature (liquid) as a result of the analysis based on simulation spectroscopy. That is, for the experimental studies used a physico-chemical study with elements of conductometry, dielcommetry and imitation spectroscopy, which was carried out using a capacitive primary transducer.

The use of new techniques (RLC meter and information and measurement technologies), which allow to study the electrical properties of liquids over large frequencies of the electromagnetic field, extends the capabilities of the electrical method to quickly control the composition of multicomponent fluids.

The novelty of research conditions is the use of a new approach of dielectric studies of objects of a non-electric nature.

Conductometric cells (of two electrodes) of different designs (wire, plate) and materials (stainless steel, carbon) were constructed.

Model fluids with different concentrations of electrolytes were studied in an electromagnetic field of different frequencies; non-electrolytes and mixtures thereof. The temperature was stabilized and the volume of fluid filled into the cell (for the same working area of the electrode) was taken into account. The immitance spectra for each type of model fluids (electrolytes and non-electrolytes) had the same original forms, but the values of the conductance and susceptance changed as concentrations changed. This confirmed the theoretical expectations about the sensitivity of the chosen method for controlling the composition of multicomponent liquids.

The next series of studies were carried out using a primary converter consisting of a vessel built into a volume in which two carbon electrodes were immersed in a stationary manner. Carbon is a chemically inactive, cheap and durable, coarse-grained material.

The experimental measuring system consisted of a standard RLC meter, a primary transducer with a capacity for the liquids to be tested, and a computer with measurement software.

Let us dwell on the results of studies of model fluids containing non-electrolytes.

It is known that aqueous solutions of organic substances homologous to a number of alcohols with increasing concentrations reduce their specific conductivity. In these studies, the active component of conductivity also decreased. The reactive component did not decrease significantly.

Discussion of research results

Spectra for aqueous mixtures of the same concentrations of methyl, ethyl and butyl alcohols were obtained for the authors' predicted steels. Methyl alcohol had the highest active conductivity component because the molecule is more mobile due to its smaller size. Therefore, if in laboratory tests to set the value for comparing the active and non-reactive component (in the study of model fluids), it is possible to control the composition of both a binary aqueous mixture and a multicomponent mixture with non-electrolytes.

A method of operative control of a substance that reduces the specific electrical conductivity of a fluid (non-electrolyte) is proposed, which allows to detect and determine its concentration in a multicomponent fluid of variable concentrations of components by a measured value of the active and reactive conductivity components at one frequency.

Consider the results of studies of model fluids containing electrolytes. It is known that in aqueous solutions of electrolytes with increasing their concentrations increases the specific conductivity. Experimentally, when the spectra were obtained at certain frequency intervals, the active component increased its value. At a certain frequency (4500Hz) and a certain volume of fluid (V = 500ml), the reactivity of the conductivity became negative, as illustrated in Figure 1.

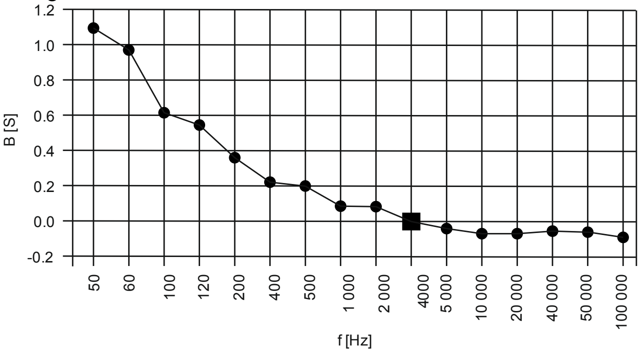

Fig. 1. The dependence of the reactive component of the electrical conductivity of the solution NaCl from frequency V=500 ml concentration C=3,564 kg/m^3

For the first time in the study of liquids with a controlled substance that increases the specific conductivity of the fluid (electrolyte), the existence of a single frequency at which the reactive component of conductivity for the corresponding range of concentrations of the controlled substance in the mixture assumes a certain single value.

This allows the selective detection of such a substance in a multicomponent fluid.

A method is proposed, which allows to control the limiting-permissible component concentrations (Figure 2,3).

Figures 1,2,3 illustrate the study of two-component liquids.

For each controlled substance experimentally (Figure 2), a volume is set at which the reactive component becomes negative in case of exceeding the allowable concentration of the controlled substance.

The results of studies of model fluids with a known concentration of a controlled substance obtained a calibration dependence, which allows to control the maximum permissible concentration by the sign of the reactive conductivity component (zero method).

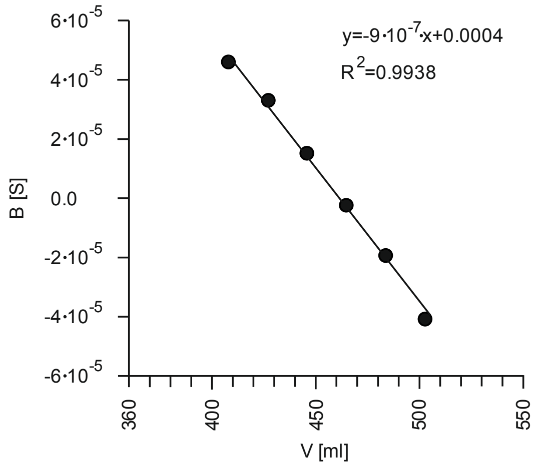

Fig. 2 Approximation of the dependence of the reactive conductivity component of the test KCl solution on the volume of fluid in the converter (B[S] at 100 000 Hz)

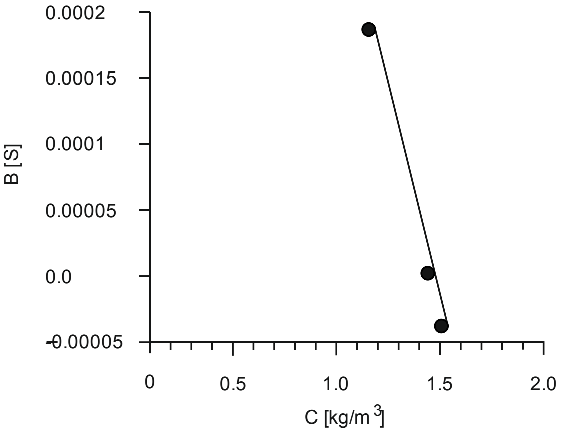

Fig. 3 Dependence of the reactive conductivity component on the concentration of the KCl solution at an electromagnetic field frequency of 100 kHz and for V=0.0004444 m^3, (B[S] at 100 kHz)

The authors do not describe in this work all the scientific facts obtained during the research and used in practice. The purpose of this article is to describe only some of the scientific results that illustrate the possibility of developing a new approach to imitation studies of objects of a non-electric nature - multicomponent liquids. [11-14]

The influence of external factors on the measurement results was investigated. One of the important ones is temperature and ultrasound.

Temperature compensation does not present technical difficulties. It has been experimentally established that ultrasound does not affect the nature of the spectra of both conductance and susceptance, only increases their value. It is suggested to use the amplification of the informative signal when exposed to ultrasound to improve the metrological characteristics of the measuring system.

Immitance studies of real technical fluids with multicomponent composition confirmed the results obtained in experiments with model fluids.

The fluid used to cool the car engine system was studied (Figure 4). On the basis of the industrial brand model liquids with impurities were created, which can be formed or be there.

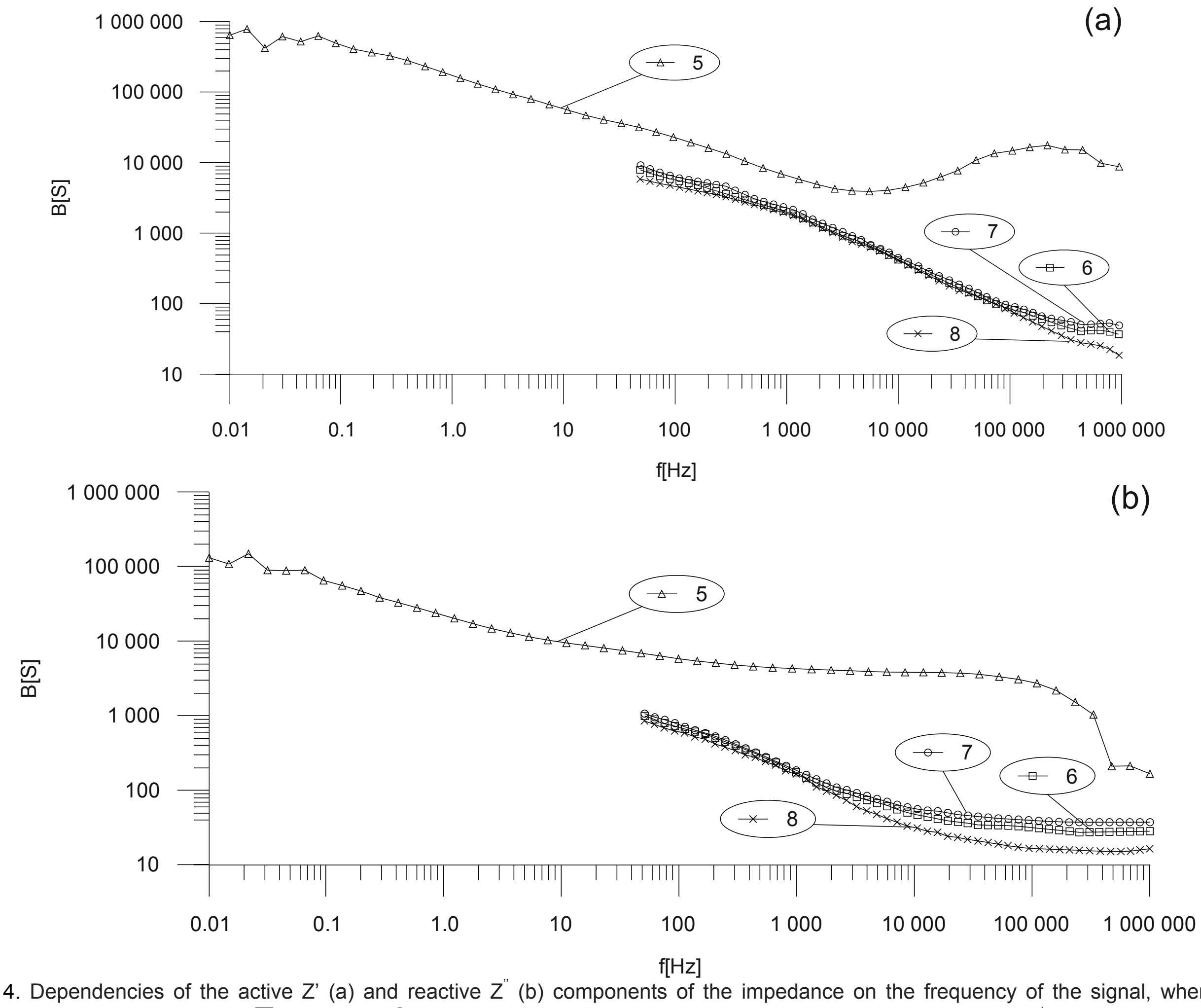

Fig. 4. Dependencies of the active Z' (a) and reactive Z'' (b) components of the impedance on the frequency of the signal, where 8zr (—×—) for the brand, 6zr (—□—), 7zr (—○—) for the model fluid brand with the addition of water and 5zr (—△—) for the brand with the addition of substances that may be undesirable during operation fluid

As can be seen from Figure 4, impurities of different chemical nature affect the shape of the dependence of the immitance and the value of its constituents. At a test signal frequency of 100kHz, the authors suggest controlling the content of unwanted impurities by the values of active and reactive conductivity components. This allows you to automatically control the smooth operation of equipment with the content of technical fluids.

To improve the accuracy of the results of the analysis of the composition of liquids, a method of planning a measurement experiment and estimating the characteristics of errors (uncertainties) of the construction of a linear characteristics caliper is proposed. An electronic measuring unit can be made "intelligent" by incorporating a microprocessor. With the help of appropriate firmware, the functions of the electrochemical sensor can then be greatly expanded.

It performs the following functions: processing of data during calibration (calibration) of ion-selective electrodes; construction of calibration graphs; memorizing the calibration information received; automatic calculation according to the measurement of the potential difference of the concentrations of ions, taking into account the actual temperature of the test solution, taking into account its dilution with the used corrective additives and other side data; fixation of date and time of measurement; the accumulation and formatting of data, issuing them in any units specified by the user not only on their digital display, but also on an external computer or in a communication network.

Conclusions.

The results of studies using RLC-meters allow us to determine the dependence of the electrical parameters of liquids in a wide range of frequencies of the electromagnetic field on the chemical nature and the concentrations of their constituents. The use of set of electrical parameters, which correspond to the normalized component concentrations, improves the informativeness of conductometric studies of multicomponent liquids. This allows to expand the list of controlled substances with different electrical properties, to increase the selectivity, precision and efficiency of the analysis. On the basis of theoretical and practical research, a method of operational control of the composition of coolants is proposed, based on the dependence of the values of active and reactive conductivity components on the signal frequency. This method allows to quantitatively and qualitatively evaluate the liquid composition for the content of controlled constituents in a laboratory and for a short period of time (up to 2 seconds) and to ensure the smooth operation of the equipment.

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