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Four-parameter electromagnetic method for determining the parameters of brewery effluents

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ABSTRACT

Purpose: of the article is to study a four-parameter electromagnetic method for joint measurements of electrical resistivity k, relative permittivity ε_r, temperature t and density ρ of samples of acidic, alkaline and average effluents from a microbrewery based on a magnetic flux probe (MFP), which considers the influence of informative parameters of beer effluents on the components of the amplitude and phase signals of a multiparameter device.

Design/methodology/approach: The implementation of the four-parameter method is carried out on the basis of the dependences $G_1 = f(A_1)$ and $G_2 = f(A_2)$ at two frequencies of the electromagnetic field f_0 and f_1 for acid, alkaline and average effluent and allows you to jointly determine the four parameters of effluent samples with the same converter in the same control area. The proposed method makes it possible to improve the accuracy of identifying effluent samples since the obtained multiparameter information makes it possible to determine the nature and properties of effluent samples using only one transducer with certain physical characteristics. The research results lead to the expansion of the technical capabilities of electromagnetic measurement methods, as well as to an increase in the metrological characteristics of electromagnetic transducers and an increase in the accuracy of measuring the parameters of effluent samples compared to reference methods and measuring instruments. Thus, the implementation of this approach contributes to the prediction and prevention of the reasons for the deviation of beer effluent samples from the specified indicators of environmental safety.

Findings: The universal conversion functions MFP have been established, connecting the amplitude and phase components of the converter signals with the parameters k, ε_r, t and ρ of acidic, alkaline and average effluents. Based on the universal transformation functions $G_1 = f(A_1)$ and $G_2 = f(A_2)$, a four-parameter electromagnetic method for joint measurements of electrical resistivity k, relative permittivity ε_r, temperature t and density ρ of acidic, alkaline, and average effluents from breweries has been developed. When conducting research at two close frequencies of the electromagnetic field f_0 = 20.3 MHz and f_1 = 22 MHz, algorithms were obtained for measuring and calculating procedures for determining k, ε_r, t and ρ for samples of acidic, alkaline and average effluents from the brewing industry.

Research limitations/implications: Research perspectives consist in the creation of automated systems for multiparameter measuring control of the physicochemical characteristics of acidic and alkaline effluent from food and processing industries based on the immersed electromagnetic transducer. Based on the data obtained using informative methods to measure the parameters of effluent samples, an integrated method for treating beer effluents of various compositions will be proposed. At the same time, the scheme of the integrated treatment method should include a filter that provides the introduction of a magnetic fluid and a separation device that allows us to remove a fraction, including pollution in itself.

Practical implications: Is that the proposed four-parameter electromagnetic method makes it possible to determine to what composition the controlled samples of wastewater should be attributed (acidic or alkaline). It, in turn, makes it possible to choose a rational method for treating beer effluents and to prevent the reasons for the deviation of effluent samples from the environmental safety indicators set by the standards.

Originality/value: of the article is the research related to the expansion of the functional and technical capabilities of the electromagnetic two-frequency transducer MFP through the implementation of a four-parameter electromagnetic method of joint measurements of electrical resistivity k, relative permittivity ε_r, temperature t and density ρ of acidic, alkaline and average effluents from breweries. The universal transformation functions $G_1 = f(A_1)$ and $G_2 = f(A_2)$ found in the work at two close magnetic field frequencies, $f_0 = 20.3$ MHz and $f_1 = 22$ MHz, make it possible to control four physicochemical parameters of acidic, alkaline and average wastewater at the same time by the same MFP. An algorithm has been developed for determining the signal components of a two-frequency thermal MFP, the ranges of which correspond to the ranges of changes in electrical resistivity k, relative permittivity ε_r, temperature t and density ρ of acidic, alkaline, and average brewery effluents. The basic relations that describe the two-frequency four-parameter electromagnetic method of joint measurements of the physicochemical parameters of acidic, alkaline and averaged beer effluents have been obtained.

Keywords: Four-parameter electromagnetic method, Brewery effluents, Magnetic flux probe (MFP), Conversion functions, Joint measurements, Electrical conductivity, Relative permittivity, Density, Temperature

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METHODOLOGY OF RESEARCH

1. Introduction

Today, the most important tasks of environmental protection are water disposal and wastewater treatment of food and processing industries. Today, the most important tasks of environmental protection are water discharge and wastewater treatment in the food and processing industries.

The high level of consumption of water resources in the production of brewing products causes a large number of effluents, which are highly concentrated and pose a danger to the environment. When creating treatment facilities at brewing enterprises, it is necessary to consider the specific features of beer effluents, which are due to production technologies, water consumption, effluent treatment methods, as well as the technical capabilities of informative methods for monitoring the physicochemical characteristics of effluent samples. The development of the food and processing industries is related to the need to consume clean water and the subsequent discharge of wastewater. The most developed branches of the food industry include the brewing industry, the development of which reaches significant rates, including in the EU countries.

In the EU countries, the successful development of the brewing industry is traditionally associated with the directions of the integrated use of raw materials, as well as the use of new technological processes that ensure the reduction of waste in the production of the finished product [1-3]. Despite the tightening of quality requirements for the purified brewing waters that are discharged into watercourses, the state of water bodies is unsatisfactory [4-6].

Wastewater from breweries contains a wide range of contaminants suspended particles of spent grain, hop particles, dilute sugar solutions, solutions of phosphate salts, a mixture of separated barley residues, malt and yeast (protein sludge), finished product residues (beer enters effluents as a result of burst emissions), solutions of sanitary wastewater.

It requires modern treatment methods. For small brewing enterprises, wastewater treatment issues are important and relevant because most of the breweries are located in largely populated places, and their wastewater goes directly to the sewer. As a rule, the following cleaning technologies are used at specialized brewing enterprises:

1. Preliminary mechanical filtration. The purpose of mechanical filtration is to prepare industrial wastewater, if necessary, for physicochemical, biological, or other methods of deeper treatment. Mechanical filtration ensures the release of up to 90-95% of suspended solids from wastewater and a decrease in organic pollution [7].
2. Physicochemical treatment ensures the removal of both solid suspended particles and dissolved impurities. One of the most cost-effective treatment methods for acidic and alkaline effluents is wastewater neutralization. Mutual neutralization of acidic and alkaline wastewater during mixing; – neutralization with alkaline reagents: caustic soda NaOH, caustic soda ash Na_2CO_3, calcium hydroxide $Ca(OH)_2$. For alkaline wastewater, neutralization with mineral acids (sulfuric H_2SO_4, hydrochloric HCl, nitric HNO_3) is used [8].
3. The main purpose of biological treatment of wastewater from food production is the decomposition and mineralization of organic substances in a colloidal and dissolved state. These substances cannot be removed by mechanical and physicochemical treatment methods [9]. Biological treatment methods include aerobic and anaerobic.

   Special attention should be paid to modern methods of microbial and electrochemical processing [10-12]. In [10], a bioelectrochemical system was improved for removing organic substances from wastewater and recovering bioelectricity based on a microbial fuel cell (MFC). In doing so, it is shown that the power generation of MFC can be improved by using a cathode catalyst to overcome the slow oxygen reduction reaction (ORR) on bare carbon electrodes. The results showed that the use of Pd (Palladium) as a cathode catalyst gives a higher capacity in MFC. In work [11], the synthesis of materials for polymer membranes that are stable in bioelectrochemical wastewater treatment systems was investigated. In [12], in order to improve the bioelectrochemical system of wastewater treatment based on MFC, an inexpensive cathode catalyst CuZn made of brass (a double alloy based on copper in which the main alloying component is zinc) was investigated in laboratory and real operating conditions.

   Biological wastewater treatment is quite expensive in the beer production from concentrate and natural raw materials in mini-breweries because the oxidation of organic substances is accompanied by the release of large amounts of energy, the operating temperature inside the bioreactors can increase significantly. In addition, a sophisticated electronic system is required for the normal operation of biological treatment systems. All this makes it inexpedient to use biological methods of wastewater treatment for mini-breweries [13].
4. To date, the most promising among the low-cost purification methods of wastewater from mini-breweries are the magnetic treatment methods [13]. The key point of the magnetic treatment method is that a finely dispersed sediment is formed not on the heating surface during crossing water the magnetic lines of force but in the mass of water, from where it can be removed using a mechanical post-treatment filter. Coagulated to a size of 0.02-0.04 microns due to physical processes of orientation, ferromagnetic particles are magnetized and grow to sizes that allow them to be crystallization centres. Crystallization of ions from supersaturated unstable solutions occurs in these centres.

In magnetic processing, the nature of the impurities is important. In addition, an optimal flow rate is required for the effect to be fully manifested. It also takes a certain time (from three to five minutes) while the water passes through the post-treatment filter.

Accordingly, it is necessary to collect information on the requirements for wastewater compliance with regulatory documents before determining which wastewater treatment methods are appropriate for a particular mini-brewery based on the results of measurements of physicochemical parameters. The main informative parameters that are contained in regulatory documents and sanitary instructions for wastewater are electrical conductivity κ, relative dielectric constant ε_r, density ρ, temperature t, and related characteristics of TDS mineralization, total hardness dGH and pH [4-6].

Typically, wastewater discharged from city breweries into sewers can be alkaline or acidic alternately. The acidic composition of mini-brewery wastewater is due to the fact that yeast, proteins, and carbohydrates, as a result of decay, form mainly monobasic weak carboxylic acids in this case $pH < 3.5$. The alkaline composition is contingent on wastewater enriched with used detergent and disinfectant solutions during burst emissions; therefore, the pH value is ≥ 9. Wastewater that goes to the water treating system and has an alternating acid and alkaline composition is also formed at various stages of the production process (malt mashing, fermentation, storage, filtration, etc.). Pollution of sewage and, as a consequence, frequent pollution of natural and artificial reservoirs leads to deviations from the normative documents of important characteristics of the environment, which meet the norms of the reaction of microorganisms to certain characteristics of ecosystems [4-6].

Further research is required to improve the accuracy of measurements and manage the environmental safety of artificial and natural water bodies by creating new wide-range multiparameter informative methods for measuring the parameters of effluent samples.

It should be noted that several measuring devices (densitometers, capacitive transducers, conductometers, AC bridges, pH meters, TDS meters, and thermometers) are used to measure various characteristics of weak electrolytes samples (which include wastewater from breweries). In this case, it is appropriate to use only one primary device – an electromagnetic transducer. With its help, information redundancy is created, and then, based on the theory of indirect and aggregate measurements, three or four parameters of effluent samples can be determined simultaneously. The main advantages of electromagnetic methods are contactlessness, conversion functions simplicity and circuit implementations, high reliability and sensitivity, the ability to measurement process automation, and low cost. All this makes it possible to further develop these methods and devices in the direction of joint multiparameter measurements of physicochemical parameters that characterize the composition of wastewater from brewing industries.

As a rule, the information signal of an electromagnetic transducer is an AC signal. Its components include the magnetic flux F amplitude, the phase angle φ of the shift between the normalized (reference) magnetic flux and the informative one, as well as the frequency of the magnetic field f, which probes the object [14]. At the same time, the metrological characteristics of the primary electromagnetic transducer determine the metrological characteristics of the entire automated system for monitoring the physical and chemical parameters of wastewater. Accordingly, it is possible to increase the accuracy of identification of an effluent sample since the multiparameter nature of the information makes it possible to determine the nature and properties of effluent samples during using one transducer with certain physical characteristics. All this expands the technical capabilities of electromagnetic measurement methods and leads to an increase in the metrological characteristics of electromagnetic converters and the accuracy of measuring the parameters of effluent samples in comparison with reference methods and measuring instruments.

That is why, for modelling the ecological situation and selecting appropriate cleaning methods, it is necessary to jointly measure control of specific electrical resistivity k, relative dielectric constant ε_r, density ρ, and temperature t during implementing new informative multiparameter electromagnetic methods.

2. Analysis of references data and problem statement

Accordingly, the joint measurement of the specific electrical resistivity k, the relative dielectric constant ε_r, the density ρ, and the temperature t of effluent is important for the reason that by analysing the numerical data of effluent samples, one can find out the composition of the wastewater and the presence of various impurities in it. The most important physicochemical parameters that determine the properties and characterize the composition of wastewater are density ρ and relative dielectric constant ε_r. The density of electrolytic liquids is determined by densitometers, while the process of measuring the density is one of the most complicated [15]. There are many types of densitometers: float-weight density meters, piezometers, adsorption densitometers, vibration (frequency densitometers), radio-isotope density meters. Among the huge variety, it is worth highlighting density meters whose output quantities are electrical quantities that can be transmitted over a distance, processed with high accuracy, and converted into other physicochemical quantities. Such devices include, first of all, submersible capacitive densitometers, the operation of which is based on measuring a conventional capacitor formed by the controlled medium and capacity [15]. The capacity of the capacitor does not depend on the size and shape of the capacitor but depends on ε_r and ρ of the controlled liquid medium. For weak liquid electrolytic media, capacitive densitometers with one electrode covered with an insulating layer are used, and the second electrode is a conducting liquid (in this case, an effluent sample) [15]. The advantages of the capacitive control methods ρ and ε_r are simplicity, ease of installation and maintenance, speed, versatility, and durability. The disadvantages include a significant methodological error that arises due to the effect of the values of electrical resistivity and temperature on the results of measurements of ρ and ε_r of effluent samples. The adhesion of the liquid itself also introduces the measurement error to the contact elements – all these limits the use of capacitive methods for measuring the density ρ and the relative permittivity ε_r.

Many physicochemical parameters of solutions are determined by modern conductometric and so-called combined methods [16]. It should be noted that all conductometric methods are united by the implementation of the basic operations for determining κ in a conductometric cell. When measuring the specific electrical conductivity κ of purified water, conductometric methods are often used as reference methods for selective measurements of one parameter. The disadvantages of conductometric methods are that in the development of measuring circuits of conductometers [16], it is necessary to take into account several factors affecting the measurement error of the specific conductivity κ: the temperature dependence of the specific electrical conductivity [16], the intrinsic capacity of the cell of the connecting wires C_0, polarization phenomena at the electrode interface -solution, etc. In this case, the approximate range of changes in the specific electrical conductivity κ of wastewater from food production $[7 \cdot 10^{-8} - 80$ Sm/m$]$ leads either to the need to use several measuring devices or to a significant complication of the entire automated installation.

In [17], a method for measuring the specific conductivity κ and the relative dielectric constant ε_r was investigated based on the analysis of the electrical equivalent circuit of contact and contactless capacitive measuring cells with a solution of electrolytic liquids. The authors of the work consider the contribution of specific conductivity κ when measuring the relative dielectric constant ε_r. The processes occurring under conditions of superposition of an alternating electric field are described. The initial values of the capacity of electrolyte solutions at low and high frequencies f of the electric field are found. The disadvantage of this method is that with a significant decrease in κ of solutions of weak electrolytes, as well as a decrease in the κ parameter of emulsions arising in wastewater, rather stringent requirements begin to be imposed on the designs of the electrodes of the corresponding devices and on the conductometric cell itself. The approximations adopted in [17] lead to significant methodological errors in the measured values. At the same time, the implementation of thermal electromagnetic multiparameter methods will improve the accuracy of measurements of the informative parameter κ of aqueous solutions of weak electrolytes and emulsion liquids, as well as consider the dependence of electrical parameters on temperature t. In [18], the frequency spectra of the dielectric constant $\varepsilon_1(\nu)$ and dielectric losses $\varepsilon_2(\nu)$ of an aqueous solution of NaCl were investigated depending on the values of the concentration C (the range of concentration variation $0.35 \leq C \leq 4.64$ mol/l) and density ρ at a fixed temperature $T = 298$ K. The disadvantages of [18] are that when determining the parameters $\varepsilon_1(\nu)$ and $\varepsilon_2(\nu)$ of NaCl solutions, the measurement results are reduced to a fixed temperature value $T = 298$ K and fixed values of the density ρ solutions (at certain concentrations from the range $0.35 \leq C \leq 4.64$). Also, the questions of the influence of temperature T on the measurement results have not been investigated; correlations between the relative dielectric constant ε_r and the density ρ of the controlled samples of solutions have not been shown.

In [19], investigations were carried out related to the use of an oscillatory circuit as a controlled measure (comparison standard). During implementing the method for measuring the electrical characteristics of electrolyte solutions, the implementation of which is carried out using contactless measuring cells and consists in separating the impedance components of the measuring cell with the investigated aqueous solutions of KCl, the studies are carried out in the temperature range [18-29°C]. The disadvantage of the method described in [19] is the description uncertainty of the transformation functions $C = f(\varepsilon)$, as well as complex instrumental techniques associated with the cell calibration.

In [20], an optimal model was proposed for determining the conductivity κ, temperature t, and concentration C, which is described polynomially. The model validity is confirmed by experimental data, as well as data on conductivity κ, concentration C, and samples temperature t of twenty-eight electrolyte solutions. The results showed that the proposed model is in good agreement with the experimental data for both pure and mixed solvent systems. The disadvantage of [18] is that the effect of such an important parameter as density ρ on the physicochemical properties of electrolyte solutions has not been investigated; that is, the relationship between density ρ and relative dielectric constant ε_r, electrical conductivity κ and temperature t of the corresponding samples of electrolytes solutions has not been investigated.

Today, electromagnetic transducers and methods are widely used in metallurgy industries, mechanical engineering, instrument making, etc. For example, to detect cracks, cavities, discontinuities, surface, and deep defects, in products and structures of machines and apparatus of the food and chemical industries, to control the thickness of coatings of parts and structures, for the non-contact determination of magnetic, electrical, and geometric parameters of parts. They are also used to determine the ultimate stress, yield stress, the presence of dominant impurities in materials, distortion of the product structures due to the impact of various types of metal processing [21-23].

That is why, until now, the theory of electromagnetic transducers operation has been insufficiently developed concerning the measurement of many parameters of liquid electrolytic media. Although some of the electromagnetic methods were described in scientific articles [24,25], this was explained, first of all, by the complexity of electromagnetic processes occurring in conducting liquid media associated with the diffusion of an alternating magnetic field in them. Therefore, calculations of through-flow eddy-current transducers with controlled liquid samples were difficult. It should be noted that taking into account the effect of eddy currents leads to the possibility of simultaneous measurements of the specific electrical resistivity k, relative dielectric constant ε_r, density ρ, and temperature t of the controlled liquid medium using the same electromagnetic transducer. In this case, electromagnetic parameters can make an equivalent contribution to the transducer signals components, and an increase in the temperature of the controlled liquid according to the electromagnetic transducers' signals can be identified with an increase in the number of particles inside the liquid (temperature makes an additional contribution to the signals of electromagnetic transducers). It should be noted that the joint measurement control of four parameters of effluent samples k, ε_r, t and ρ makes it possible to select a wastewater treatment method following the experimental data analysis, as well as to find out the reasons for the deviation of effluent samples from the environmental safety indicators specified in the standards. At the same time, for measuring the testing of liquid electrolytic media, it is advisable to use electromagnetic transducers with two windings. The coils in such transducers cover the controlled object – a liquid sample (located in a glass tube). Also, immersed electromagnetic transducers are used, the coils of which are immersed in a liquid conductive medium, since both the first and second devices have two windings: measuring and magnetizing; according to the common classification, they belong to electromagnetic transformer electrothermal transducers [14].

In [24], a miniature immersed electromagnetic transducer (EMAT) is considered, on the basis of which a two-parameter electromagnetic method for monitoring the electrical resistivity k and the temperature t of engine oil is realized (the electromagnetic transducer is immersed in a container with oil). The purpose of work [24] is to study the possibility of further use of machine oil for cooling bearings or its rejection based on the results of measurements of electrical resistivity k and temperature t. The disadvantages of [24] include the fact that by measuring only two parameters of machine oil, it is difficult to establish rational criteria for selecting machine oil samples in production conditions. It should be noted that a common disadvantage of the implementation of electromagnetic methods based on immersed electromagnetic transducers, which are used to determine the specific electrical conductivity κ of a controlled liquid medium, is also the need to compensate for the external magnetic flux that passes over the surface of the liquid. Therefore, for such compensation, a combined converter with two windings is used (one winding is located above the surface of the monitored liquid, and the other winding is immersed in the liquid), which significantly complicates the design of the converter and leads to errors associated with under-compensation and over-compensation. That is why, for further research, it is reasonable to use a transformer-type pass-through electromagnetic transformer with two windings, which can be used to control samples that have free access to their ends (a sample of the controlled liquid is placed in a glass tube).

In the article [25], a two-parameter electromagnetic method of joint measurements of electrical conductivity κ and temperature t of effluent samples was investigated. Based on the experimental data for determining the components of the converter signals and the obtained calculated data associated with the determination of the normalized parameters of the thermal transformer transducer, universal conversion functions were determined, and algorithms for measuring and calculation procedures for determining k and t were established. The disadvantages of [25] include the fact that by two informative parameters, it is impossible to determine what composition a particular effluent sample has (acidic or alkaline) since, all the same, knowing κ and temperature t, several methods of chemical analysis must be used, and also analytical instruments for determining the qualitative and quantitative composition of effluent samples.

So for the most complete identification of controlled effluent samples and the rational treatment method selection, it is necessary to jointly measure testing of the electrical resistivity k, relative dielectric constant ε_r, temperature t, and density ρ of beer effluent samples based on new wide-range multiparameter measurement methods.

In this regard, there is a need to improve the known and create new wide-range electromagnetic methods for joint measurements of electrical conductivity κ (electrical resistivity k), the relative dielectric constant ε_r, temperature t and density ρ of wastewater by the same converter in the same control zone of samples of effluents from food production (including brewing), which belong to weak electrolytic liquids.

3. Purpose and objectives of the research

The purpose of the work is to develop the scientific foundations of electromagnetic methods and corresponding instruments for measuring the parameters of wastewater from brewing industries, which consider the effect of informative parameters of controlled samples of beer effluents on the signal components of primary transducers.

To accomplish these purposes, it is necessary to solve the following tasks:

- to investigate the theoretical foundations of the operation of a thermal transformer electromagnetic transducer concerning the implementation of the electromagnetic four-parameter method for measuring the specific electrical resistance k, the relative dielectric constant ε_r, density ρ and temperature t t of acidic, silk and average effluents from brewing production;
- provide algorithms for modelling the process of joint measurements of electrical resistivity k, relative dielectric constant ε_r, density ρ and temperature t of effluent samples;
- to obtain the basic relations describing the implementation of the four-parameter electromagnetic method of joint measurements of the parameters k, ε_r, ρ, and t of effluent samples.

4. Investigated materials and equipment used in the experiment

The research of acidic, silk and average effluent samples was carried out based on a thermal transformer electromagnetic transducer (MFP). Geometrical parameters of an effluent sample: radius $a = 60 \cdot 10^{-3}$ m, length of a glass tube with effluent samples $l_c = 0.50$ m, relative magnetic permeability $\mu_r = 1$, constant magnetic $\mu_0 = 4\pi \cdot 10^{-7}$ H/m; the previously measured temperature coefficients of resistance for the samples of acidic, alkaline and averaged effluents were respectively $\alpha_1 = 1.99 \cdot 10^{-2} \cdot 1/°C$; $\alpha_2 = 1.69 \cdot 10^{-2} \cdot 1/°C$; $\alpha_3 = 2.55 \cdot 10^{-2} \cdot 1/°C$; temperature measurement range of effluent samples $t = [15 - 35°C]$. MFP parameters: number of turns measuring and magnetizing windings $W_1 = 800$; $W_2 = 1400$; value of magnetizing current $I_н = 49.85$ mA; frequency of the electromagnetic field $f = 20$ MHz; EMF MFP without sample $E_0 = 306.16$ mV; the value of the EMF, which is due to the passage of the magnetic flux F_1 in the air gap between the sample and the measuring winding $E_1 = 12.32$ mV.

<u>Four-parameter electromagnetic method for measuring physicochemical parameters of samples of beer effluents</u>

The physical essence of the implementation of multiparameter electromagnetic methods is based on the interaction of the electromagnetic field MFP penetrating the controlled sample of wastewater with the subsequent registration of the components of the multiparameter signal and analysis of their changes. For this purpose, special normalized parameters are introduced, and universal transformation functions are established that link the physicochemical parameters of liquid media with the signal components of the primary electromagnetic transducers (amplitude and phase components of the multi-component signal of the transducer and the frequency of the magnetic field).

As such parameters for the MFP, taking into account the results of [21-26], it is necessary to use expressions for the normalized dimensionless amplitude G and phase $tg\varphi$ components of the MFP signal and the expression for determining the parameter A – a generalized parameter with a magnetic component [21-25].

$$G = \frac{F_{2t}}{F_0 \cdot \theta} = \frac{2}{A_t} \sqrt{\frac{ber_1^2 x + bei_1^2 x}{ber_0^2 x + bei_0^2 x}} \tag{1}$$

$$tg\phi_t = \frac{bei_1 x(ber_0 x + bei_0 x) + ber_1 x(ber_0 x - bei_0 x)}{bei_1 x(ber_0 x - bei_0 x) - ber_1 x(ber_0 x + bei_0 x)} \tag{2}$$

$$A_t = a_{\Pi} \sqrt{\mu_0 \cdot \kappa_t \cdot 2 \cdot \pi \cdot f} \tag{3}$$

where G – the amplitude of the magnetic flux penetrating the glass tube with the effluent sample; F_0 – reference magnetic flux; F_2 – magnetic flux in a sample of beer effluents; $tg\varphi$ – the tangent of the phase shift angle between the reference magnetic flux F_0 and the magnetic flux F_2 in a sample of beer effluents; θ – filling factor of the transducer with an effluent sample; $ber_n -, bei_n -, ber_0 -, bei_0 -, ber_1 -$ and $bei_1 -$ Kelvin functions of n -th, zero and first orders, which are tabulated in the reference literature on Bessel functions [24]; a_p – the radius of the glass tube in which the effluent sample is settled $(a = a_p)$; κ_t – electrical conductivity; index t – indicates that the investigated value is temperature-dependent.

At the same time, using the representations of the Kelvin functions in the form of power series, it is possible to calculate the universal transformation functions $G = f(A)$ and $\varphi = f(A)$. At the same time, even insignificant changes in specific electrical conductivity κ, relative dielectric constant ε_r and temperature t, lead to a change in the signal components of thermal multivariable electromagnetic converters: magnetic fluxes F_0 and F_2, phase shift angles φ_0 and φ_2 , as a consequence, the normalized characteristics G and A, which relate the MFP signal components to the physicochemical characteristics of the effluent samples. Tables 1-3 shows the dependences $G = f(A)$ and $\varphi = f(A)$ for acidic, alkaline, and averaged effluents.

In Figure 1, a diagram of the MFP connection is shown for measuring the specific electrical resistance k, relative dielectric constant ε_r, temperature t and density ρ of samples of acidic, alkaline and averaged effluent samples. The circuit includes recorder – R, generator – G, frequency meter – Fm, working transducer – WT, reference transducer – RT, voltmeters – V_1, V_2 and V_3, oscilloscope – OS, phase meter – F.

Table 1.
Dependences of the normalized parameters G_t and φ_{2t} on the generalized parameter A_t of the thermal MFP a sample of acidic effluent

φ_{2t}, grad	G_t	A_t
-6.47	0.9893	0.924000
-6.65	0.9886	0.939913
-6.84	0.9872	0.992944
-6.91	0.9865	1.013400
-7.20	0.9853	1.024145
-7.45	0.9844	1.031100
-7.74	0.9831	1.054202
-8.05	0.9820	1.069998
-8.25	0.9812	1.008622
-8.46	0.9801	1.112100

Table 2.
Dependences of the normalized parameters G_t and φ_{2t} on the generalized parameter A_t of the thermal MFP a sample of alkaline effluent

φ_{2t}, grad	G_t	A_t
-6.07	0.9906	0.938100
-6.28	0.9899	0.940341
-6.48	0.9893	0.961020
-6.68	0.9886	0.977141
-6.78	0.9882	0.986044
-6.98	0.9876	0.992910
-7.18	0.9869	1.099000
-7.38	0.9862	1.023931
-7.58	0.9854	1.042432
-7.78	0.9846	1.058922

Table 3.
Dependences of the normalized parameters G_t and φ_{2t}on the generalized parameter $A_t$of the thermal MFP a sample of averaged effluents

φ_{2t}, grad	G_t	A_t
-7.04	1.0619	0.960000
-7.17	1.0611	0.977141
-7.32	1.0602	0.980002
-7.53	1.0596	0.992910
-7.68	1.0591	1.008403
-7.81	1.0586	1.039102
-7.92	1.0579	1.041100
-8.08	1.0571	1.053934
-8.14	1.0565	1.069314
-8.31	1.0558	1.083111

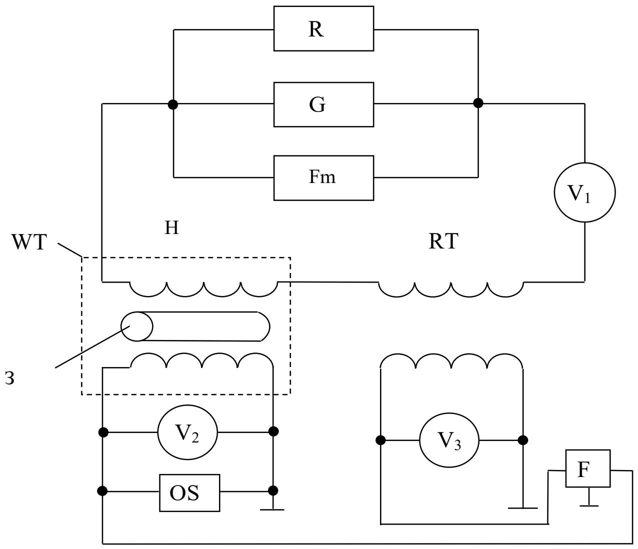

Fig. 1. Scheme of MFP for joint multiparameter electromagnetic measurements of the parameters of beer effluents samples

RT has an identical number of turns with WT, length l and radius a_p. The exciting coil is designed to create an electromagnetic field and, as a result of eddy currents in the liquid sample (which is placed in a glass tube), in turn, the measuring coil is designed to measure the EMF E_{2t}, which is induced by the total magnetic flux passing directly in the sample.

To control the shape of the magnetizing current and voltage of the alternating current source of the generator G, a recorder – R is used, and the frequency of the current change is recorded by the frequency meter – C. With a voltmeter V_2, the EMF E_{2t} (which depends on the temperature of the effluent samples) is determined, while the oscilloscope OS determines the shape of this EMF. Voltmeter V_2, reads its output signal to one input F, the reference EMF E_0 is measured with a voltmeter V_3, the OP input is combined with another input F. Thus, with the help of F, the phase angle φ_{2t} between the EMF E_0 and the EMF E_{2t} TECT is determined. It should be noted that, in this case, the TECT signals (E_{2t} and φ_{2t}) depend on the temperature t of the effluent samples. For heating effluent samples during measurement control, the circuit provides a heater – H .

It should be noted that in this case, for the implementation of the four-parameter method of joint measurements of the physicochemical parameters of effluent samples, two close frequencies of the magnetic field $f_0 = 20.3$ MHz and $f_1 = 22$ MHz are used, which in the MFP scheme are set using the generator G and on these frequencies, corresponding to two values of the generalized parameter A: $A_1 = 0.96$ and $A_2 = 0.99$, measure the EMF E_Σ, E_0 and φ_0 at the frequency f_0 of the magnetic field and the EMF $E_{\Sigma 1}$, E_{01} and φ_{01} at the frequency f_1.

After that, find the EMF E_1 and E_{12} by the formulas:

$$E_1 = E_{01}(1-\eta) \tag{4}$$

$$E_{12} = E_{02}(1-\eta) \tag{5}$$

Next, we find the values of the EMF E_2 and E_{21} at frequencies f_0 and f_1:

$$E_2 = \sqrt{{E_\Sigma}^2 + {E_1}^2 - 2E_1 E_\Sigma \cos\varphi_0} \tag{6}$$

and

$$E_{2_1} = \sqrt{{E_{\Sigma_1}}^2 + {E_{12}}^2 - 2E_{12}E_{\Sigma 1} \cos\varphi_{01}} \tag{7}$$

We determine the parameters G_1 and G_2 (at the first and second frequencies, respectively) according to the formulas

$$G_1 = \frac{G_{2_1}}{G_{0_1} \cdot \theta} \tag{8}$$

and

$$G_2 = \frac{G_{2_2}}{G_{0_2} \cdot \theta} \tag{9}$$

where G_1 and G_2 are normalized magnetic fluxes in the controlled effluent samples.

Further, according to the dependence of G on A (see Tabs 1-3), find the value of A for samples of acidic, alkaline and average effluents.

After that, knowing the generalized parameter A, we obtain an expression for determining the specific electrical resistance k, at temperatures from the investigated range at frequencies f_0 and f_1, in the form:

$$k_{1_t} = \frac{a^2 \mu_0 2\pi f_0}{{A_1}^2} \tag{10}$$

and

$$k_{2t} = \frac{a^2 \mu_0 2\pi f_1}{{A_2}^2} \tag{11}$$

The values of the relative dielectric constant ε_r at the first frequency are determined by the formula

$$\varepsilon_{r1} = \frac{\mu_0 \cdot {f_0}^2 \cdot a^2 \cdot \pi}{{A_1}^2 \cdot \varepsilon_0 \cdot 10^{-8}} \tag{12}$$

at the second frequency f_1 MFP, we get

$$\varepsilon_{r2} = \frac{\mu_0 \cdot {f_1}^2 \cdot a^2 \cdot \pi}{{A_2}^2 \cdot \varepsilon_0 \cdot 10^{-8}} \tag{13}$$

The temperature resistance coefficient α is determined experimentally by measuring two values of electrical conductivity κ_1 and κ_2, which correspond to two values of temperature t_1 and t_2 from the investigated range

$$\alpha = \frac{\kappa_t - \kappa_2}{\kappa_2 \cdot (t_1 - t_2)} \tag{14}$$

Next, the temperature of the effluent sample is determined at two frequencies of the electromagnetic field f_0 and f_1

$$t_1 = \frac{1}{\alpha} \cdot \left(\frac{a^2 \cdot \mu_0 \cdot 2 \cdot \pi \cdot f_0}{{A_1}^2 \cdot \kappa_1} - 1\right) + t_{01} \tag{15}$$

and at the frequency f_1, we find the temperature t_2

$$t_2 = \frac{1}{\alpha} \cdot \left(\frac{a^2 \cdot \mu_0 \cdot 2 \cdot \pi \cdot f_1}{{A_2}^2 \cdot \kappa_2} - 1\right) + t_{02} \tag{16}$$

where t_{01} and t_{02} are the initial temperatures of the samples at two frequencies.

Based on the processed data array obtained as a result of measuring the parameters of effluent samples, the power series reflecting the dependence of the dielectric constant ε_r on the density of effluent samples ρ were calculated. In the general case, this dependence is a simple interpolation polynomial of the third degree, so on the first electromagnetic field MFP, we get

$$\varepsilon_r^1 = K_0 + \frac{\rho \cdot \sum_{n=1}^{4} K_n}{\sum_{m=1}^{4} {t_1}^m} \tag{17}$$

For the frequency f_1, we have

$$\varepsilon_r^2 = K_{01} + \frac{\rho \cdot \sum_{n=1}^{4} K_{1\mathrm{n}}}{\sum_{m=1}^{4} {t_2}^m} \tag{18}$$

where ε_r^1 and ε_r^2 are the values of the relative dielectric constant at frequencies f_0 and f_1 of the MFP electromagnetic field; K_0 and…K_{11} , K_{01} and… K_{1n} are constant coefficients disclosed in Table 4 and Table 5, respectively, for averaged, alkaline and acidic effluents at two frequencies of the MFP electromagnetic field; t_1^m and t_2^m are temperatures at frequencies f_0 and f_1.

As an example, Table 6 shows the results of the parameters measurements k, ε_r, t and ρ of the sample of the averaged effluents, which were performed using the MFP circuit in Figure 1, at MFP frequencies f_0 and f_1.

Tables 7-9 show the dependences of the relative dielectric constant ε_r and density ρ of samples of acidic, alkaline and averaged beer effluents (at the MFP frequency f_0) at different temperatures from the range under investigation, the measurement errors of the parameters γ_k, $\gamma_{\varepsilon r}$, t and γ_ρ of acidic, alkaline and averaged effluents are determined.

Table 4.
Values of constant coefficients of the interpolation polynomial at the first frequency of the magnetic field f_0

Constant coefficients of the interpolation polynomial	Effluents composition averaged	 alkaline	 acidic
K_0, kg/m³·°C	0.8995	0.7019	0.9694
K_1, kg/m³·°C	0.9145	0.7215	0.9811
K_2, kg/m³·°C	0.9331	0.7398	1.0029
K_3, kg/m³·°C	0.9557	0.7624	1.0196
K_4, kg/m³·°C	0.9707	0.7774	1.0346

Table 5.
Values of constant coefficients of the interpolation polynomial at the first frequency of the magnetic field f_1

Constant coefficients of the interpolation polynomial	Effluents composition averaged	 alkaline	 acidic
K_{01}, kg/m³·°C	0.9001	0.7149	0.9835
K_{11}, kg/m³·°C	0.9131	0.7335	0.9952
K_{12}, kg/m³·°C	0.9460	0.7528	1.0159
K_{13}, kg/m³·°C	0.9686	0.7743	1.0316
K_{14}, kg/m³·°C	0.9838	0.7893	1.0466

Table 6.
Results of joint measurements of the parameters k, ε_r, t and ρ of effluent samples of the averaged effluent in the implementation of the four-parameter electromagnetic method ($t_0 = 15°C$; $f = 20.3$ MHz; $\mu_r = 1$; $\alpha = 1.69 \cdot 10^{-2} \cdot 1/°C$; $\mu_0 = 4\pi \cdot 10^{-7}\ H/m$; $t = 15 - 35°C$)

t_1, °C	k_1, Om·m	ε_{r1}	ρ_1, kg/m³	t_2, °C	k_2, Om·m	ε_{r2}	ρ_2, kg/m³	A_{1t}	φ_t, grad	A_{2t}	φ_{2t}, grad
15.72	0.052	73.16	1187.29	15.53	0.055	72.96	1185.21	0.96	-6.47	0.99	-6.08
16.80	0.050	72.89	1181.01	17.45	0.054	72.74	1179.63	0.97	-6.65	1.01	-6.28
18.82	0.048	72.10	1173.56	18.78	0.052	72.23	1174.11	0.99	-6.84	1.02	-6.48
21.11	0.047	70.09	1167.15	20.80	0.049	70.16	1169.21	1.01	-6.91	1.04	-6.68
23.07	0.046	66.27	1160.98	22.85	0.047	66.25	1163.44	1.02	-7.20	1.07	-6.99
24.96	0.045	62.19	1158.20	25.18	0.045	62.22	1160.18	1.03	-7.45	1.09	-7.18
27.04	0.043	57.01	1155.09	27.10	0.040	56.89	1157.50	1.05	-7.74	1.10	-7.38
29.02	0.041	49.74	1153.01	29.05	0.037	49.75	1155.70	1.07	-8.05	1.11	7.58
31.01	0.040	43.51	1149.19	31.06	0.034	43.52	1151.09	1.08	-8.25	1.13	-7.78
33.01	0.039	40.82	1146.03	33.01	0.031	40.61	1148.90	1.09	-8.46	1.15	-7.89

Table 7.
Dependences of ε_r and ρ on temperature t (acidic effluent)

t', °C	t, °C	γ_t, %	ε_r'	ε_r	$\gamma_{\varepsilon r}$, %	ρ' kg/m³	ρ, kg/m³	γ_ρ	$k' \cdot 10^{-1}$, Om·m	$k \cdot 10^{-1}$, Om·m	γ_k, %
15	15.18	1.2	65.57	65.78	0.30	969.81	970.95	0.12	0.1064	0.1076	1.13
17	16.93	-0.4	59.97	60.09	0.21	968.03	969.10	0.11	0.1035	0.1041	0.58
19	19.04	0.19	54.00	53.96	-0.07	967.84	966.81	-0.11	0.1004	0.1008	0.09
21	20.98	-0.09	49.05	48.99	-0.12	967.24	966.25	-0.10	0.0985	0.0977	-0.81
23	23.02	0.09	44.07	44.09	0.05	965.07	965.90	0.09	0.0947	0.0943	-0.42
25	24.98	0.08	40.53	40.54	0.03	965.21	965.37	0.02	0.0920	0.0925	0.54
27	27.03	0.04	37.40	37.41	0.02	965.38	965.43	0.01	0.0891	0.0894	0.34
29	29.02	0.07	34.74	34.72	-0.06	964.98	965.01	0.003	0.0869	0.0872	0.35
31	31.01	0.03	32.49	32.48	-0.03	963.48	963.49	0.001	0.0848	0.0847	-0.12
33	32.99	0.03	30.51	30.52	0.03	962.94	962.93	0.001	0.0825	0.0824	-0.12

Table 8.
Dependences of ε_r and ρ on temperature t (alkaline effluent)

$t^{'}$, °C	t, °C	γ_t, %	$\varepsilon_r^{'}$	ε_r	$\gamma_{\varepsilon r}$, %	$\rho^{'}$, kg/m^3	ρ, kg/m^3	γ_ρ	$k^{'}\cdot10^{-1}$, Om·m	$k\cdot10^{-1}$, Om·m	γ_k, %
15	15.09	0.6	57.80	58.16	0.62	1175.40	1170.28	-0.43	0.0663	0.0687	3.62
17	17.02	0.12	53.17	52.95	0.46	1172.90	1174.98	0.17	0.0641	0.0655	2.18
19	18.95	-0.26	47.58	47.78	0.38	1172.66	1174.74	0.17	0.0623	0.0636	2.09
21	21.06	0.26	42.80	42.96	0.37	1171.31	1169.20	-0.18	0.0617	0.0608	-1.46
23	23.03	0.13	39.00	39.09	0.23	1170.01	1168.80	-0.10	0.0610	0.0602	-1.31
25	24.97	-0.12	35.94	35.89	0.14	1168.20	1169.33	0.09	0.0590	0.0597	1.19
27	27.02	0.07	33.16	33.13	-0.09	1167.92	1168.75	0.07	0.0572	0.0577	0.87
29	29.01	0.05	30.76	30.78	0.07	1167.12	1167.90	0.07	0.0560	0.0564	0.71
31	30.98	-0.06	28.80	28.79	-0.03	1167.01	1167.53	0.04	0.0540	0.0543	0.56
33	33.02	0.06	27.06	27.05	-0.04	1166.89	1167.10	0.02	0.0522	0.0524	0.38

Table 9.
Dependences of ε_r and ρ on temperature t (averaged effluent)

$t^{'}$, °C	t, °C	γ_t, %	$\varepsilon_r^{'}$	ε_r	$\gamma_{\varepsilon r}$, %	$\rho^{'}$, kg/m^3	ρ, kg/m^3	γ_ρ	$k^{'}\cdot10^{-1}$, Om·m	$k\cdot10^{-1}$, Om·m	γ_k, %
15	15.72	3.42	70.61	72.30	2.39	1187.29	1184.16	-0.26	0.0498	0.0523	5.02
17	16.80	-1.19	67.35	66.20	-1.74	1179.23	1181.03	0.15	0.0501	0.0509	1.59
19	18.82	-0.95	59.46	58.53	-1.58	1173.56	1175.10	0.13	0.0480	0.0486	1.25
21	21.11	0.52	49.44	49.87	0.87	1167.15	1168.46	0.11	0.0467	0.0472	1.08
23	23.07	0.30	44.11	44.42	0.70	1160.98	1162.01	0.09	0.0463	0.0468	1.07
25	24.96	-0.16	40.58	40.80	0.54	1158.20	1158.72	0.04	0.0450	0.0454	0.89
27	27.04	0.16	36.62	36.76	0.38	1155.09	1155.34	0.02	0.0435	0.0432	-0.69
29	29.02	0.07	33.11	33.18	0.21	1153.02	1152.95	0.01	0.0415	0.0412	-0.73
31	31.01	0.03	30.46	30.50	0.13	1149.19	1149.16	-0.002	0.0407	0.0409	0.49
33	33.01	0.03	28.29	28.31	0.07	1146.01	1145.98	-0.002	0.0393	0.0394	0.25

In Figures 2-4, graphical dependences of the density ρ of effluent on the relative dielectric constant ε_r are shown, i.e. $\rho = f(\varepsilon_r)$ for acidic, alkaline and averaged samples of beer effluents at different temperatures t from the investigated range. The same figures show the dependences of errors $|\gamma_{\varepsilon r}| = f(|\gamma_\rho|)$ for acidic, alkaline, and averaged effluents, taken in modulus.

Analysing the dependencies in Figures 2-4, we see that with increasing temperature, the measurement errors $|\gamma_{\varepsilon r,}|$ and $|\gamma_\rho|$ are significantly reduced. It should be noted that an increase in the temperature of the wastewater sample according to the MFP signals can be erroneously identified with an increase in the number of particles inside the liquid (in the absence of preliminary mechanical treatment of effluents from the brewery). In addition, with an increase in the field frequency, the power losses due to eddy currents inside the sample increase, which in turn leads to heating the sample by eddy currents and, consequently, to an increase in the values of errors in the measured parameters of effluents. Thus, the factor limiting the frequency of the field is the presence of a measurement error caused by the heating of the sample by eddy currents (to avoid this, it is necessary to provide a special porcelain frame of the transducer and isolate its windings). Random errors were evaluated in this article, from the results of ten measurements of electrical resistivity k, relative permittivity ε_r, temperature t and density ρ of effluents samples (according to the Gaussian distribution law). The confidence interval for errors, for example, for acidic effluent, was $(\bar{\kappa} \pm 0.003 \cdot 10^{-1} \cdot t_\alpha)$ Om·m or $0.094 \pm 0.003 \cdot 10^{-1} \cdot t_\alpha$ Om·m; $(\overline{\varepsilon_r} \pm 3.809 \cdot t_\alpha)$ or $44.86 \pm 3.809 \cdot t_\alpha$; $(\bar{t} \pm 1.907 \cdot t_\alpha)$ or $24.02 \pm 1.907 \cdot t_\alpha$; $(\bar{\rho} \pm 0.761 \cdot 10^{-1} \cdot t_\alpha)$ kg/m^3 or $966.124 \pm 0.761 \cdot 10^{-1} \cdot t_\alpha$ kg/m^3, where $\overline{\square}$ – are the arithmetic mean values of 10 measurements of parameters κ, ε_r, t, ρ; (±0.003 10^{-1};±3.809; ±1.907; ±0.761 – the dispersion or scatter of the measured value with respect to the arithmetic mean values of the parameters κ, ε_r, t, ρ ±); t_α is Student's coefficient, for the results of ten measurements n=10, with a confidence probability P = 0.95, Student's coefficient is $t_\alpha = 2.26$ [27]. In the existing technical literature, dispersion is denoted by the letter G [27]. At the same time, as is known, the larger G is, the more often in a series of multiple measurements, the appearance of both small and large values of random measurement errors is equally probable. In turn, small values of G indicate an increase in the probability of the occurrence of small values of random measurement errors [27].

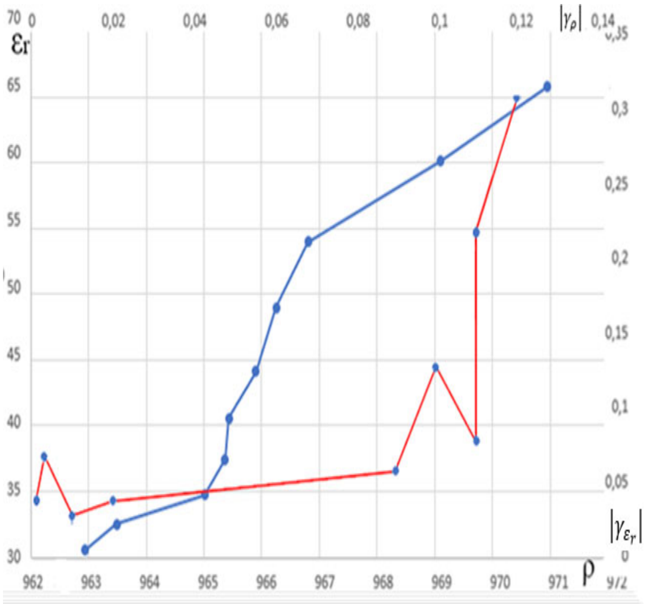

Fig. 2. Dependencies $\varepsilon_r = f(\rho)$and$|\gamma_{\varepsilon r}| = f(|\gamma_\rho|)$ (acidic effluent)

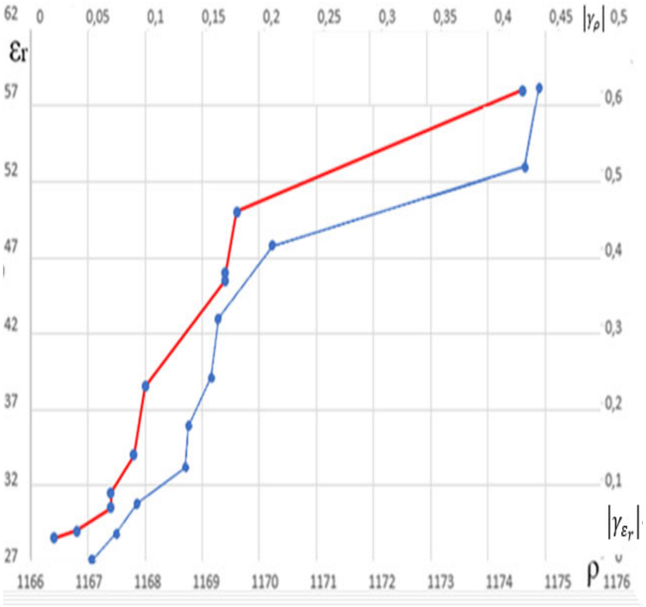

Fig. 3. Dependencies $\varepsilon_r = f(\rho)$and $|\gamma_{\varepsilon r}| = f(|\gamma_\rho|)$ (alkaline effluent)

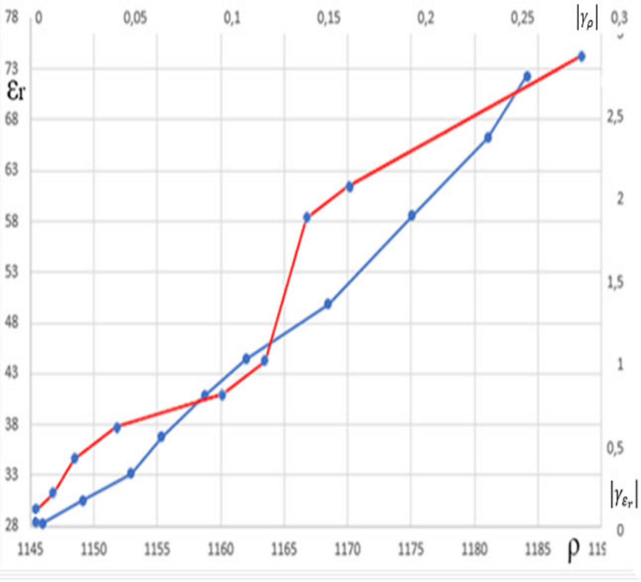

Fig. 4. Dependencies $\varepsilon_r = f(\rho)$ and $|\gamma_{\varepsilon r}| = f(|\gamma_\rho|)$ (averaged effluent)

So, while implementing the four-parameter electromagnetic method using the above MFP scheme, it is necessary to determine two magnetic fluxes: the reference magnetic flux F_0 (in the absence of a glass tube with liquid in the transducer) and the magnetic flux F_2 in the presence of acid, alkaline and averaged effluents samples in the transducer). After that, find the phase angle φ_2 between them, and then highlight the amplitude and phase components of the multiparameter signal MFP and using the transformation function $G_1 = f(A_t)$ and $G_2 = f(A_t)$ at two frequencies of the magnetic field, find the electrical resistivity k, relative dielectric constant ε_r, density ρ and temperature t of effluent samples. The results of joint measurements of the parameters k, ε_r, t, and ρ obtained in this article are in good agreement with the data of testing methods. The control methods for measuring the electrical resistivity k', the relative dielectric constant $\varepsilon_r{}'$, the temperature t' and the density ρ were the potentiometric method, the method for measuring the electrical capacity, the thermoelectric method, the implementation of which was carried out using a chromel-alumel TCA thermocouple, the density of the sample was measured portable density meter.

5. Conclusions

In this article, we propose a new four-parameter method for joint measurements of electrical resistivity k, relative dielectric constant ε_r, density ρ, and temperature t of acidic, silk, and averaged minibrewery effluents.

At the same time, joint multiparameter measurements of physicochemical parameters of electrolyte solutions have advantages over separate (selective measurements). For example:

1. allow to increase the coordination of the primary transducer with the automated system for measuring control of the solutions parameters;
2. usability of several measuring devices (in the case of separate measurements), in order to exclude the influence of external electric and magnetic fields, it is necessary to use one measuring device, and the rest must be turned off;
3. during selective measurements of the physicochemical characteristics of electrolyte solutions, it is difficult to consider the effect of the ambient temperature on the results of measurements of the parameters κ and C.

The complexity of the implementation of electromagnetic multiparameter methods based on immersed transducer for monitoring the electrical resistance ρ and temperature t of engine oil described in [24] include the need to compensate for the external magnetic flux that passes over the surface of the liquid. Therefore, for such compensation, a combined transducer with two windings is used (one winding is located above the surface of the monitored liquid, and the other winding is immersed in the liquid), which significantly complicates the design of the transducer and leads to errors associated with under compensation and overcompensation. It should be noted the limitations on the geometric dimensions since the author uses miniature transducers in which the range of variation of the core diameters is from 0.5 to 2 mm so that the core can quickly warm up and accept the temperature of the environment.

The determination of the electrical and temperature parameters of effluent samples based on the difference amplitude and phase signals is considered in [25]. In order to relate the signals of the transducer with the parameters of the controlled liquid medium, normalized generalized characteristics were introduced: the specific normalized magnetic flux G_t, which passes through the liquid (the liquid, is placed in a glass tube) and the generalized parameter x_t, which expresses the ratio of the radius a of the glass tube to the depth of penetration of the magnetic field δ into the sample. The flux G_t induces the differential EMF of the thermal transducer ΔE_t. Thus, by measuring the magnetic fluxes ΔE_t and F_0 or the corresponding EMF ΔE_t and E_0, as well as the phase shift angle $\Delta\varphi$ (i.e., the phase shift angle of the magnetic flux ΔF_t in the liquid sample with respect to the external magnetic flux F_0), it is possible to obtain information about the specific electrical conductivity κ and temperature t. The method proposed in [25] has a number of disadvantages associated with the fact that it is necessary to consider the electric currents that heat the windings of the converter and introduce a significant temperature error. Also, before samples control of electrolytic liquids, it is necessary each time to clarify the temperature coefficient of TCR resistance α, since in the general case it is unknown. The disadvantage of the electromagnetic two-parameter method, which uses the difference amplitude or phase signal of the transducer, is also the fact that in the two-parameter version there are difficulties in monitoring samples with a pronounced inhomogeneity of the distribution of electrical and temperature parameters along the radius of the liquid. In [23], no correlations were established between such important physicochemical parameters of effluent samples as relative dielectric constant ε_r, density ρ, and temperature t. Thus, in order to determine the qualitative and quantitative composition of effluent samples, joint multiparameter measurements of four parameters of the investigated liquid media are required: electrical resistivity k, relative dielectric constant ε_r, temperature t and density ρ in the same control zone, with the same electromagnetic transducer. The physical essence of the four-parameter electromagnetic method of joint electromagnetic measurements proposed in this work is the interaction of an electromagnetic field penetrating into a controlled effluent sample with subsequent registration and analysis of its change in comparison with a reference liquid sample.

So, during implementing the four-parameter electromagnetic method using the above MFP scheme, it is necessary to determine two magnetic fluxes: the reference magnetic flux F_0 (in the absence of a glass tube with liquid in the transducer) and the magnetic flux F_2 in the presence of acid, alkaline and averaged effluents samples in the transducer). After that, find the phase angle φ_2 between them, and then highlighting the amplitude and phase components of the multiparameter signal MFP after introducing the normalized parameters G and A, which connect the components of the MFP signals with the physicochemical characteristics of the effluent sample, find the electrical resistivity k, relative permittivity ε_r, density ρ and temperature t. In this case, a homogeneous alternating two-frequency magnetic field is used (two close frequencies $f_0 = 20.3$ MHz and $f_1 = 22$ MHz are used), which makes it possible to tune out the influence of the parasitic magnetic flux F_1. Then, at two close frequencies f_0 and f_1, using the dependences $G = f(A)$ at frequencies f_0 and f_1 for acidic, alkaline and averaged effluents, jointly determine the four parameters of effluent samples without using complex instrumental techniques for compensating for the effects of the air gap, which lead to complication and increasing the cost of the measuring unit.

Using the processed data array obtained as a result of measuring the parameters of effluent samples, the power series reflecting the dependence of the dielectric constant ε_r on the density of effluent samples ρ were calculated. In the general case, this dependence is a simple interpolation polynomial of the fourth degree. The coefficients k_0 and k_1 of the interpolation polynomial for acidic, alkaline and averaged effluent samples have been calculated. It should be noted that the results of joint measurements of the parameters k, ε_r, t, and ρ obtained in this article are in good agreement with the data of control methods. The control methods for measuring the electrical resistivity $k^{'}$, the dielectric constant $\varepsilon_r{}^{'}$, the temperature $t^{'}$ and the density ρ were the potentiometric method, the method for measuring the electrical capacity, the thermoelectric method, the implementation of which was carried out using a chromel-alumel TCA thermocouple, the density of the sample was measured portable density meter.

The limitations of the proposed four-parameter eddy current method include the fact that measurements are carried out in uniform magnetic fields (magnetic fluxes F_1 and F_2 are directed along the longitudinal axis of the product). It is necessary that the length of the magnetizing winding of the transducer be 10 times the diameter of the magnetizing winding in order to achieve such field uniformity in the transducer without a product. In turn, in order to detune from the demagnetizing factor, the sample length l_c must be greater than or equal to the length of the magnetizing winding $l_{н}$, i.e. $l_c > l_{н}$. The frequency range is determined by the optimal range of the generalized parameter A (which depends on the geometric parameters of the glass tube and the transducer, the specific electrical resistance of the liquid k and the temperature t) and was selected for reasons of the greatest steepness of the characteristic, and therefore the sensitivity of the transducer to the physicochemical parameters of the effluent samples, i.e. $0.9891 \leq A \leq 1.1493$. The limitations of the method include the fact that in the absence of special hardware and technical means, a significant temperature error may occur. So, the temperature of the medium and the heated product can affect the windings of the transducer, while a change in the temperature of the medium or product leads to a change in the resistance r of the magnetizing winding. However, if the magnetizing current is kept constant, then the flux in the sample will also be constant, and therefore the EMF of the measuring winding, which is a function of temperature, will also be constant. The windings of the converter should be thermally insulated from the environment and from the heated part at the enterprises during the measuring testing use a ready-made monolithic structure (and in laboratory conditions the converter itself is wrapped with keeper tape, which is covered with BF-2; BF-4; BF-6 glue and baked in muffle furnace at temperatures of 350-400°C). The experiment was carried out with a change in the temperature of the samples of acidic, alkaline and averaged effluents in the range from 15 to 35°C (in this range, both the windings of the transducer and the frames of the heater and converter normally withstand this temperature). Eddy currents can also heat the sample by heating, which is described by the Joule-Lenz law. At a frequency of $f = 20$ MHz, calculations show that the relative error caused by heating the sample by eddy currents does not exceed 0.09% (this is less than the resulting instrumental error in measuring the physicochemical parameters of the samples). It should be noted that the proposed theoretical foundations for the operation of a contactless, four-parameter MFP with samples of acidic, alkaline and averaged beer effluents, the obtained algorithms for modelling the process of electrical resistivity k joint measurements, relative dielectric constant ε_r, density ρ and temperature t of samples of wastewater from brewing industries, obtained power series, and the coefficients of the interpolation polynomial of the fourth degree, which reflect the dependence of the relative permittivity ε_r on the density ρ and temperature t – make it possible to model certain stages of environmental safety management of artificial and natural water bodies by creating new wide-range multiparameter informative methods for measuring the parameters of effluent samples , allows you to identify controlled samples of wastewater from brewing industries, as well as to identify the acidic, alkaline or averaged composition of beer effluents in the implementation of the proposed phenomenological model and, as a result, to choose a rational method of wastewater treatment in accordance with the analysis of experimental data.

The purpose of the article is to develop the scientific foundations of electromagnetic methods and corresponding instruments for measuring the parameters of effluents from brewing industries, which consider the effect of informative parameters of controlled samples of beer effluents on the signal components of primary transducers.

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