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Informative testing method of beer sewage samples for mini-breweries

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ABSTRACT

Purpose: of the article is to investigate the theoretical rules of thermal transformer eddy current converter (TTC) during the preparation of ecological monitoring of brewery sewage samples based on the implementation of contactless two-parameter eddy current method of testing of the specific electrical conductivity λ_t and the temperature t of the beer sewage sample. It should be noted that this makes it possible to simultaneously prevent the causes of beer sewage samples deviation from the specified environmental safety indicators and to take adjustments.

Design/methodology/approach: The theory of TTC operation concerning the electrical and temperature characteristics testing of beer sewage samples has been further developed by implement new universal transformation functions $\Delta\varphi_t = f(G_t)$ and $\Delta\varphi = f(x_t)$, which relate the normalized difference components of the converter signals to physical and chemical characteristics of the sample. Due to this, it is possible to simultaneously prevent the causes of beer sewage samples deviation from the specified ecological safety indicators and to take appropriate adjustments.

Findings: The method of two-parameter measuring test of the specific electrical conductivity λ_t and the temperature t of the beer sewage sample was developed on the basis of new universal transformation functions. Analysing the numerical data of electrical conductivity λ, TDS and pH at the initial temperature t_1 = 15°C, the alkaline nature of beer sewage was determined.

Research limitations/implications: The frequency range of the magnetic field f = 80-100 MHz, it is difficult to maintain in laboratory conditions, so the proposed method requires the use of modern high-frequency equipment, the radius of the probe depends on the radius of the primary converter frame. And therefore is quite a complicate to find appropriate tank.

Practical implications: is to determine the nature of beer sewage based on the results of electrical and temperature parameters measurements during implementing a two-parameter eddy current method, which allows to prevent the reasons for beer sewage samples deviations from the specified environmental safety measures and to take appropriate

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adjustments. An important practical result is also the determination of the signal components and the normalized characteristics of the primary eddy current converter with a sample of beer sewage. They allow to calculate, design and create multi-parameter automated devices for measuring test of the physicochemical parameters of beer sewage samples. In turn, as a result of the physicochemical composition analysis of the sample, improving the accuracy of measurements of physicochemical parameters - there is an opportunity to improve and create advanced methods of wastewater purification on a weak electrolytic basis.

Originality/value: The article originality is the investigation of the theoretical rules of thermal TTC by implementing a new multi-parameter eddy current method of measuring the specific electrical conductivity λ_t and the temperature *t* of the beer sewage sample based on the implementation of universal transformation functions $\Delta\varphi_t = f(G_t)$ and $\Delta\varphi = f(x_t)$ that relate the converter signals to the physicochemical characteristics of the beer sewage sample, which helps to prevent the causes of the beer sewage samples deviation from the specified environmental safety indicators and take appropriate adjustments.

Keywords: Brewing technological process, Sewage, Informative methods, Control, Eddy current devices

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Today, there is a need to provide measures to modernize production facilities on a modern technological basis by defining requirements for environmental standards and product quality [1-5]. All these tasks are the most relevant for the modern industry. The high level of water usage during beer production causes a large volume of sewages. These sewages are highly polluted and pose a risk to the environment. Part of the sewage pollution from brewing production is of an organic nature and has a form of solutions, suspensions, and colloids. Beer sewages also contain dilute sugar solutions, gum, and proteins. At the same time, due to decay and fermentation of carbohydrates and proteins of plant origin, organic pollution of beer flows decomposes into acetic, lactic, and other acids. These processes occurring in beer flows lead to acidification of wastewater and a decrease in the pH of the medium. Pollutants contained in beer flows, that fall into open water bodies, cause a change in the physical properties of the environment: violation of transparency, offensive odours, a change in the chemical composition. Pollutants lead to a reduction in the amount of dissolved oxygen in open water bodies due to its consumption for the organic substances oxidation entering the reservoir (for example, phenols, oleic, benzoic, and other organic acids). It should be noted that the discharge of large masses of waste yeast into water bodies also causes fermentation and decay processes. Thus, organic substances contained in beer flows, getting into water bodies in significant quantities or accumulating in the soil, can quickly decay and worsen the sanitary condition of water bodies and the atmosphere. This pollution strongly affects fish, birds, and other flora and fauna forms, which become sick and die. Sewages are discharged into an urban sewage system for joint treatment with other wastewater if breweries are located within a city. Chlorination of sewages from breweries is mainly used to combat offensive odours already directly in the urban sewage systems (levels of such treatment are approximately 10-15 mg/l), disinfection of beer flows is not used. Secondary raw materials and wastes that must be disposed of include: contaminated flows containing detergents and disinfectants, brewer and hop grain, protein sludge. The enterprise sewage regularly falls into the general sewage system, the pH of the polluted sewage fluctuates in the range of pH = 6-11. At the same time, the temperature t determination has great independent importance, before the sewage falls both the city sewerage system and open water bodies. So, for example, for open reservoirs, the deterioration of water quality with an increase in temperature leads to a decrease in the solubility of oxygen, which decreases by one third at a temperature close to t = 28°C, i.e. eutrophication of water bodies occurs. The process of eutrophication destroys most of the flora and fauna species, greatly transforming the ecosystems of water bodies. Thus, as a result of anthropogenic pollution of natural and artificial reservoirs, important characteristics of the environment deviate from the requirements of regulatory documents [6-9].

The production of non-alcoholic and low-alcoholic beverages should be classified as the most advanced branches of the food industry, especially brewing production. Almost every city and town have mini-breweries and beer sewage characteristics virtually uncontrolled by appropriate informative methods for acidity and alkalinity, and in most cases failing to meet environmental pollution prevention requirements in international practice. The selection of purification method should depend on the physicochemical properties of the beer samples, as well as the purification degree and sewage usage required. The greatest danger to the environment is the sewage appeared from the washing of sedimentary brewer's liquid yeast, the discharge into the sewers of the sediment and the washing of technological containers used for fermentation and final beer fermentation stages. In particular, the beer production process is characterized by explosive releases with fluctuations in concentration and quantity of sewage, i.e., there is a significant unevenness of the alkaline nature, which requires the obligatory use of a pH regulator. During explosive releases, sewage is enriched with used cleaning and disinfecting agents, so the pH can significantly exceed the numerical values of the regulatory indicators [1-5].

There is a need to create new informative methods for the sewage samples parameters testing. Today, relatively simple conductometry and potentiometry methods are used to measure the electrical conductivity of λ weak electrolytes, including foodstuffs: juices, wines, beer, milk, beverages and in particular aqueous solutions of salts and acids, emulsions, alkaline solutions, samples sewage of industrial production including food industry [10,11].

The simplicity of implementation and the low cost of conductometry and potentiometry methods for determining the electrical conductivity λ enables the use of these methods as controls in the analysis of λ samples of semi-finished products, finished products and samples of beer sewages. However, conductometric and potentiometric methods have disadvantages. They are sensitive to the presence of impurities, especially those of an acid-alkaline nature, due to the sharp difference and mobility of the acid-base ions, that is, the difference in the mobility of H^+ and OH ions compared to the mobility of other ions. Since the conductivity λ is additive, it is only possible to obtain information on the total ion concentration in solution due to the use of conductometry and potentiometry methods. That is, the measurement testing of the electrical conductivity λ and its associated TDS mineralization (Total Dissolved Solids), C concentration, and pH levels is much more complicated. Thus, it is possible to argue for the low selectivity of the conductometric and potentiometric methods, which leads to significant errors in the measurements of λ and other physicochemical parameters of multicomponent solutions. That is why, during selection a primary converter for informative testing of the physic-chemical characteristics of beer sewage samples, it is necessary to take into account the joint determination of several connected electrical values that have an equivalent effect on the sensitive element of the converter. All these conditions are met by electromagnetic (eddy current) methods of measurement testing, the implementation of which is carried out on the eddy current converters basis of the transformer type, which at the output allow to obtain measurement information, which includes information about the EMF and phase shift angle of the eddy current converter with tested solution sample. The measurement information obtained can be processed with high accuracy, converted to other physical values, transmitted over a distance, and automated the process of measuring the combined values in accordance with the commands of the computer system to test the basic characteristics of sewage treatment processes.

2. Literature analysis and problem statement

Mini-breweries, as a rule, are located in close proximity to consumption points, many of them are installed in restaurants, cafes, bars and hotels, which makes it possible to expand the range of products and reduce prices during implementing appropriate quality management methods. Mini-breweries are classified according to their capacity indicators, based on their daily output for the finished product, into the following groups:

1st group – mini-breweries with a daily output of 50 to 200 litres of beer per day;

2nd group – mini-breweries with a daily output of 200 to 2000 litres of beer per day. This category includes bar, restaurant and hotel beer production lines that are installed directly at public catering establishments;

3rd group – breweries, allowing to receive from 2,000 to 30,000 litres per day. These microbreweries can provide finished products to catering establishments and small specialty stores.

The advantage of mini-breweries is that mini-breweries can quickly increase or decrease beer production, change the assortment and thus adapt to changing market conditions with significant competition. The prime cost of beer made in mini-breweries is lower than at large factories; their payback period is on average up to one year, which is ensured by minimal production, transportation and other costs. At the same time, the amount of sewage, the concentration of their pollution depends on the beer production technology adopted at the enterprise, water consumption and production capabilities of the enterprise.

In general, breweries use the following purification technologies:

1. Preliminary mechanical cleaning, during which stops the waste on the grid and primary is settling. The cleaning grid is: a strainer, rotary filter or auger built directly into the channel or installed in the tank. Through the open-end side, the sewage enters the mesh drum and then flows through the surface of the grid. At the same time, depending on the grating opening, floating, settling and suspended substances in the drains are retained [12].
2. Chemical-physical treatment, including effluent neutralization and reagents dosing.

   To remove dissolved acidic (CO_2, H_2S, SO_2, SO_3, NO_2) and alkaline (NH_3, CH_3, NH_2) gases from sewage, degassing (air-, inert gases-, or steam stripping) is used with reagents (chemical method) or with heating and by evacuation (physicochemical method) [13,14].

   It should be noted that the pH of industrial wastewater could differ significantly from the standard value for discharge into the sewer (the rate for discharge in the range of pH changes [13-16]). The acidic sewage medium (increased concentration of H^+ ions) is due to the presence in them of free mineral (sulphuric H_2SO_4, hydrochloric HCl, nitric HNO_3, orthophosphoric H_3PO_4, hydrofluoric HF, etc.) and, organic acids to a lesser extent. With an alkaline nature of sewage, neutralization is also necessary to prevent corrosion of pipelines and sewer systems. Depending on local conditions enterprises use the following methods for neutralizing acidic sewages: mutual acidic neutralization and alkaline sewage when they are mixed; neutralization with alkaline reagents: caustic soda NaOH, soda ash Na_2CO_3, calcium hydroxide $Ca(OH)_2$. Neutralization with mineral acids (sulphuric H_2SO_4, hydrochloric HCl, nitric HNO_3) is used for alkaline sewage.
3. The methods of biological treatment include aerobic and anaerobic. Sewage is transferred for biochemical treatment is characterized by the value of BOD and COD. BOD is the biochemical oxygen demand or the amount of oxygen used in the biochemical oxidation of organic matter over a specific period of time. COD - the amount of oxygen equivalent to the amount of consumed oxidant required for the oxidation of all reducing agents contained in water. For inorganic substances that are practically not oxidizable, maximum concentrations are also set. If such concentrations are exceeded, the water cannot be subjected to biochemical treatment [17-20].

Special attention should be paid to modern methods of microbial and electrochemical processing. In article [18], a bioelectrochemical system was improved for removing organic substances from sewage and recovering bio-electricity based on a microbial fuel cell (MFC). It is shown that MFC power generation can be improved by using a cathode catalyst to overcome the sluggish oxygen reduction reaction (RER) on bare carbon electrodes. The results showed that the use of Pd (Palladium) as a cathode catalyst gives a higher power in MFC. In article [19], the synthesis of materials for polymer membranes that are stable in bio-electrochemical sewage treatment systems was investigated. In article [20], to improve the bioelectrochemical system of sewage 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.

In the article [21], the scenario of wastewater treatment of a field hospital is considered. Compared to domestic wastewater, hospital wastewater is much more dangerous, due to containing a wide range of toxic substances (antibiotics, radionuclides, falsified water, waste analyses, drug dyes, etc.). The ways wastewater entering the environment (into the ground and open water bodies) are analysed. The legal framework of the European Union countries and countries with economies in transition is considered. It is noted that the lack of clear legislative norms leads to the unauthorized discharge of hospital wastewater into the sewage system and open water bodies. A review of wastewater treatment methods is performed. Based on the analysis of existing cleaning methods, a combined cleaning method is recommended, including a combination of microbiological reactor technologies and the Fenton process. This reduces cost, reactor size, and the number of reagents required for processing. However, this article does not consider the testing methods and parameters monitoring of hospital wastewater. The authors use the data of chemical analysis, primarily in terms of concentration and "predicted concentration", given in other articles and international standards.

In the beer production from concentrate and natural raw materials in mini-breweries, biological treatment of sewage is quite expensive, since the oxidation of organic substances is accompanied by the release of large amounts of energy, the operating temperature inside the bioreactors can rise significantly. In addition, a sophisticated electronics system is required for the normal operation of biological treatment systems. All this makes it difficult to use biochemical sewage treatment methods for mini-breweries.

This article presents an innovative method for testing sewage, on the basis of which a promising treatment method can be selected.

As a rule, sewage that is discharged from the city's mini-breweries into the general urban sewage system is alkaline-acid. Emulsions resulting from the falling of beer flows into urban sewers, as well as artificial and open reservoirs, may negatively affect the microorganisms of open reservoirs or directly within the enterprise. This may result in the failure of machines, apparatus and sewage treatment devices. However, for open water reservoirs it is also very important to take into account the so-called thermal pollution, which is accompanied by a decrease in the oxygen content in the water, a change in its chemical and gas composition, the flowering of water and an increase in the water content of microorganisms, as a result of thermal pollution can lead to the death of the entire ecosystem. These issues are considered in articles [7-9].

It should be noted that as a result of anthropogenic intervention deviations from the norm of important characteristics of the environment, which meet the norms of reaction of microorganisms to these characteristics, occur [7-9].

That is why in order to perform the modelling of the ecological situation and selection the methods of purification, it is necessary to jointly determine the specific electrical conductivity λ, temperature t and other correlating with electrical and temperature parameters physicochemical values, new informative methods. The results will differ in numerical data for different sewage samples (alkaline and acidic). This paper proposes to determine the electrical and temperature parameters of sewage samples with a two-parameter eddy current method. It should also be determined that measuring temperature testing is important on its own, since the increase in temperature on the signals of the primary converter is reflected by the increase in the number of acidic or alkaline impurities, or the quantitative increase in the liquid pollution due to the increase in electrical conductivity λ. Contact electromagnetic (eddy current) methods of the measuring testing of electrical and weak electrolytes temperature parameters are considered in articles [22-25]. So, in the article [22], the results of measuring testing of specific electrical conductivity λ of concentrated aqueous solutions of oxalic acid in the temperature range 15-90°C were obtained. To generalize the obtained results of measurement testing, the reduced value of the specific electrical conductivity λ_n is used, i.e. the ratio of the specific conductivity λ_I at a certain concentration (initial temperature) to the maximum value of the electrical conductivity λ_m (and the temperature value selected at the end of the range). It is shown that for all investigated solutions the values of the reduced λ_n are placed on one calibration dependence $k = f(t)$.

The disadvantages of this method are associated with the influence on the measurement results of external influencing factors, such as the signal frequency stability, ambient temperature, external magnetic fields, etc., affecting the accuracy of measuring the specific conductivity λ. In addition, the obtained λ values are practically reduced to the initial temperature t_1, while to select a method for purifying sewage from brewing industries, it is necessary to know the value of λ at various temperatures t (from the investigated range, which corresponds to the stages of the production process). It should be noted that such characteristics as the *pH*, the characteristics of the *TDS* mineralization, and the total hardness *dGH* of the samples of beer flows of acidic and alkaline nature, correlate with temperature. Therefore, to improve the accuracy of measurements of these parameters, it is necessary to implement a contactless eddy current method, which makes it possible to determine the electrical conductivity value (from the investigated temperature range) at specific temperature values with a certain step.

In [23], a method is proposed for determining the specific conductivity λ of aqueous solutions of electrolytes KCl and NaCl in the temperature range of 20-70°C using a contact-type capillary cell with three platinum electrodes and an AC bridge.

The technique disadvantage proposed in [23] is that phase-frequency characteristics are used to determine the specific electrical conductivity λ: that is, the dependence of the phase angle shift Δ_φ on the frequency F, $\Delta_\varphi = f(F)$. In this case, due to the nonlinearity of the calibration curve, higher harmonics must appear, and higher harmonics can distort the phase measurement results of specific electrical conductivity λ. Also, the disadvantages include the fact that a significant component of the measurement error is not taken into account, which is introduced at the converting passive parameters stage into active quantities, which makes it relevant to analyse the γ functions errors of many variables. Measuring the physicochemical characteristics of samples of electrolytic liquids, the authors of [23] used converters of various types to obtain information. In this work, the electromagnetic type transducer is used and with the help of this transducer, which operates on the eddy current principle, signal components (signal amplitude E, phase φ and frequency f are obtained, which contain information about the specific conductivity λ and temperature t of the sewage sample.

In [24,25], contact electromagnetic methods for joint measurement control of the electrical and temperature parameters of carboxylic acid samples have been proposed. It is shown that an increase in the accuracy of the measurements of the samples occurs due to the developed algorithms of measurement and calculation procedures, which include operations with the components of the signals of thermal contact electromagnetic converters. However, it should be noted that in [24,25] there are no ways of establishing optimal modes of converter operation with tested samples. Non-contact methods of sample solutions testing and weak electrolytes are not considered, based on simple algorithms of measuring and calculation procedures, no features of physical testing, chemical characteristics of emulsions and suspensions resulting from the waste emissions from the production of acids and alkalis was considered. Presented works also do not outline the basic principles of the theory of multi-parameter eddy current measurements errors of signals components of convertors and physicochemical characteristics of investigated objects. Obviously, this is due to the fact that there is no general approach to the error's estimation of joint measurements of electrical, temperature and other correlating physico-chemical parameters of samples of non-magnetic electrolytic liquid environments in the implementation of informative measurement testing methods. A common disadvantage of these articles is that contactless eddy-current transducers provide a number of advantages over contact ones. They make it possible to measure the specific electrical conductivity λ in a wide temperature range not only of electrolytes but also in the long term of heated aggressive toxic liquid media using a polynomial dependence of the specific electrical conductivity on the temperature of the sixth degree.

It is necessary to take into account factors affecting the measurement error of the specific electrical conductivity λ during developing measuring chart of conductometers [26]. These factors include the temperature dependence of the specific electrical conductivity λ, the intrinsic capacitance of the connecting wires C_0 cell, polarization phenomena at the electrode-solution interface, etc. In this case, the approximate range of changes in the specific electrical conductivity λ of food production wastewater [$7 \cdot 10^{-8}$ – 80 Cm/m], leads either to the need to use several measuring devices or to a significant complication of the entire automated installation. The disadvantages also include a long process of preparation of liquid samples, the need for standard samples, standard solutions and passport calibration dependencies, the absence of theoretical and experimental methods, the implementation of which leads to the acquisition of absolute values of the electrode potential.

In the article [27], the solutions of dimethyl sulfoxide electrical conductivity (DMSO) + KI was determined based on the implementation of the method of impedance spectroscopy. The method is very complicated, and the value of the specific electrical conductivity λ of the solutions has to be recalculated taking into account the limiting λ_0 and the equivalent values of the electrical conductivity λ_g. In addition, for multiparameter methods for determining electrical conductivity, temperature, and concentration during assessing the errors of the measurement result in [26,27], it would be better to investigate the systematic errors of indirect measurements of a function of many variables.

That is, known methods for determining systematic errors in the function measurement of many variables, which represent the dependence of the normalized characteristics of the transducers on the important informative parameters of the samples testing of weak electrolytes (that is, in this case, samples of beer effluents), need further development.

However, the normalized characteristics of primary thermal eddy current converters include EMF, phase shift angle φ, magnetic field frequency f, inductance L, electrical resistance R, magnetic flux linkage ψ and other components of eddy current converters signals, metrological characteristics of which control the metrological characteristics of the system management in general [28]. Therefore, there are reasons to believe that issues related to the selection of purification method require the creation of new wide-ranging informative methods, in turn, the lack of certainty of the theoretical rules of the eddy current device and the limitation of the methods of electrical and temperature sample parameters testing of weak electrolytes, necessitate conducting appropriate investigations to achieve a high degree of purification of beer sewage samples in the above areas.

3. Purpose and objectives of research

The purpose of the article is to investigate the theoretical rules of thermal transformer eddy current converter (TTC) during the preparation of ecological monitoring of brewery sewage samples based on the implementation of contactless two-parameter eddy current method of testing of the specific electrical conductivity λ_t and the temperature t of the beer sewage sample. It should be noted that this makes it possible to simultaneously prevent the causes of beer sewage samples deviation from the specified environmental safety indicators and to take adjustments.

To achieve this purpose, the following tasks were set:

- investigate the possibility of applying the theory of transformer thermal eddy current converter (TTC) operation, with regard to the implementation of informative (for further environmental monitoring), two-parameter method of the electrical conductivity λ_t and temperature t testing of the beer sewage sample of mini-brewery;
- to present an algorithm for modelling the process of measuring testing of the electrical conductivity λ_t and temperature t of the sample using TTC;

- investigate theoretical rules for the errors estimating of joint (multi-parameter) measurements of beer sewage sample parameters in the implementation of the thermal multi-parameter eddy current method for the functions of many variables that relate the components of the eddy current converter signals to the electrical and temperature characteristics of the sample.

4. The method of electrical and temperature parameters testing of the beer sewage sample from mini-brewery sewage

The investigations were performed using transformer thermal eddy current converter (TTC) with a sewage sample from a mini-brewery. Experimental characteristics of the glass tube or probe: radius $a = 10 \cdot 10^{-3}$m, length $l = 0.40$ m. The parameters of the TTC were: $f_1 = 80$ MHz, EMF of thermal TTC in the absence of sample $E_0 = 85$mV, the length of the magnetic winding $l_n = 0.40$ m, the radius of the magnetic winding $a_n = 12 \cdot 10^{-3}$m.

The mini-brewery includes a mash vat, a brew kettle, a mixer located in the mash vat; hot water pump; a valve that opens cold water for churning boiling wort steam from the mash vat into condensate, a coarse water filter also for sealing the process. In addition, there are inlet and outlet valves for the corresponding apparatus. Sewage is discharged from barrels into the sewerage system. The main technical parameters of the mini-brewery: the output of wort per one brewing – 230 litres, the volume of the wort vat – 350 litters, the volume of the filter tank – 350 litres, the heating power – 10 kW, the speed of the stirrer knives – 50 rpm.

The method and thermal eddy current device for the joint informative testing of the electrical conductivity λ_t and the temperature t of the beer sewage sample resulting from the brewing production are investigated below.

The formula for determining the true value of the EMF E_0, i.e. the EMF TTC in the absence of a liquid sample, has the following form:

$$E_0 = 13.9 \cdot W_{wt} \cdot a_c^2 \cdot \mu_0 \cdot \frac{f \cdot I_{mw} \cdot W_{mw}}{l} \tag{1}$$

where W_{wt} – winding turns; a_c – eddy current converter radius; μ_0 – magnetically constant, $\mu_0 = 4\pi \cdot 10^{-7}$H/m; f – frequency of the magnetic field; I_{mw} – magnetizing current; W_{mw} – the number of turns of the magnetic winding; l – the length of the converter, which is equal to the length of the glass probe with the liquid sample.

Further, to extend the limits of measurement of electrical and temperature characteristics of the fluid sample, it is necessary to enter the specific normalized parameter G_t (the specific normalized flow G_t in the sample), the transmission of which causes the emergence of a differential EMF of TTC ΔE_t, with the EMF ΔE_t taking into account [19], find by the formula:

$$\Delta E_t = E_{\Sigma t} - (13.9 \cdot W_{wt} \cdot a_c{}^2 \cdot \mu_0 \cdot \frac{f \cdot I_{mw} \cdot W_{mw}}{l}), \tag{2}$$

where ΔE_t is the total EMF of TTC (index t indicates that the investigated value depends on temperature).

The parameter G_t and the phase shift angle $\Delta\varphi_t$ of the EMF of TTC (phase shift angle between the EMF E_0 and the EMF ΔE_t) are generally determined by the relations:

$$G_t = \frac{\Delta E_t}{13.9 \cdot W_{wt} \cdot a_c{}^2 \cdot \mu_0 \cdot \frac{f \cdot I_{mw} \cdot W_{mw}}{l}}, \tag{3}$$

$$|\mathrm{tg}\phi| = \frac{a_c{}^2 \cdot \Delta E_t \cdot \sin\phi_t}{a^2 \cdot E_0 - \Delta E_t \cdot \cos\phi_t} \tag{4}$$

where a – is the radius of the probe with the tested sample.

It should be determined that for $a \approx a_c$, the formula for determining the complex parameter G_t has the following form:

$$G_t = \frac{\Delta E_t}{E_0} = \frac{2}{x_t\sqrt{j}} \frac{I_1(x_t\sqrt{j})}{I_0(x_t\sqrt{j})} \tag{5}$$

where x_t is a thermally dependent generalized parameter; I_1 and I_0 are modified Bessel function of order one, j – is a complex number.

Next, it is necessary to specify the relations that relate the temperature t to the characteristics G_t and φ_t at a fixed frequency of the magnetic field f.

In the case of maintaining a constant frequency of the magnetic field, the radius of the sample (i.e. the radius of the probe) to be heated during the testing process is determined by the function $\Delta\varphi_t = f(G_t)$:

$$a = a_c\sqrt{\frac{\Delta E_t}{E_0 \cdot G_t}} \tag{6}$$

It should be noted that formula (6) enables the selection of probe with the required geometric dimensions to determine the electrical and temperature characteristics of the sample. Then we find the generalized parameter x_t, depending on $\Delta\varphi = f(x_t)$, and determine the specific electrical conductivity λ_t, by the formula:

$$\lambda_t = \frac{x_t^2 \cdot E_0 \cdot G_t}{\mu_0 \cdot a_C^2 \cdot \Delta E_t \cdot \pi \cdot f}. \tag{7}$$

Given the dependence of λ_t on the temperature t, in the range from 15 to 45°C [22], we have a formula for determining the temperature of the liquid sample to be tested:

$$t = \frac{1}{\alpha} \cdot \left(\frac{x_t^2 \cdot E_0 \cdot G_t}{\mu_0 \cdot a_C^2 \cdot \Delta E_t \cdot \pi \cdot f \cdot \lambda_1} - 1\right) + t_1, \tag{8}$$

where α – the temperature coefficient of fluid sample resistance.

Errors determination of joint measurements of physicochemical parameters of beer sewage samples, allows establishing rational operating modes of thermal multi-parameter eddy current converters, to increase the test probability of physicochemical characteristics of liquid samples and significantly improve the test process quality of technological processes in the future.

On the basis of the universal transformation function $\Delta\varphi_t = f(G_t)$, find the formula for calculating the relative precision of measurements $\frac{\delta a}{a} = \gamma_a$ of the radius of the sample, which is equal to the probe radius at a confidence probability of $P = 0.95$, in the form:

$$\gamma_a = 1.1\sqrt{\left(C_a\gamma_{\Delta\varphi}\right)^2 + \left(\frac{1}{2}\gamma_{\Delta E}\right)^2 + (\gamma_a)^2 + \left(\frac{1}{2}\gamma_{E_0}\right)^2} \qquad (9)$$

where $\gamma_{\Delta_\varphi}, \gamma_{\Delta E}, \gamma_a, \gamma_{E_0}$ – the relative precision of the values indicated by the indexes, C_a – is the influence coefficient.

The effect of C_a is determined by the formula:

$$C_a = \frac{1}{2}\frac{(\partial G/\partial\Delta\varphi)\Delta\varphi}{G} \qquad (10)$$

where $\partial G/\partial\Delta\varphi$ – the G – derivative to φ.

To determine the relative precision of the electrical conductivity measurements, neglecting the magnetic constant measurements error, we have:

$$\frac{\delta\lambda}{\lambda} = \frac{\delta G_t}{G_t} + \frac{\delta E_0}{E_0} + \frac{\delta x}{x} - \frac{\delta\Delta E_t}{\Delta E_t} - 2\frac{\delta a}{a} - \frac{\delta f}{f} \qquad (11)$$

where $\frac{\delta G_t}{G_t}$ is the relative precision in determining the parameter G_t, which is found in the following form

$$\frac{\delta G_t}{G_t} = \frac{\partial G_t \Delta\varphi}{\partial\Delta\varphi G_t}\cdot\frac{\delta\Delta\varphi}{\Delta\varphi} \qquad (12)$$

$$C_{\lambda_1} = \frac{\partial G_x}{\partial\Delta\varphi}\cdot\frac{\Delta\varphi}{G_x} \qquad (13)$$

where C_{λ_1} is the influence coefficient, with a fractional accuracy $\frac{\delta\Delta\varphi}{\Delta\varphi} = \gamma_{\Delta\varphi}$.

Applying the notation for the fractional accuracies of the a radius measurements and the components of the TTC signals ΔE, E_0, $\Delta\varphi$ as well as the specific electrical conductivity λ_1 (at the initial temperature) and the frequency of the magnetic field f in the form γ_a, γ_λ, γ_f, γ_{Δ_φ} and γ_{E_0}, it is possible to represent the expression (11), with confidence $P = 0.95$, in the form:

$$\gamma_\lambda = 1.1\sqrt{\left(C_{\lambda_1}\gamma_{\Delta_\varphi}\right)^2 + \left(\gamma_{\Delta_E}\right)^2 + (2\gamma_a)^2 + \left(\gamma_{E_0}\right)^2 + \left(\gamma_f\right)^2} \qquad (14)$$

$$\gamma_t = 1.1\sqrt{C_{\Delta E}^2\gamma_{\Delta E}^2 + \gamma_{E_0}^2 + \gamma_f^2} \qquad (15)$$

where $C_{\Delta E}$ – the corresponding influence coefficient, γ_f is the fractional accuracy of the measurements of the frequency of the magnetic field f, at the initial temperature $t_1 = 15°C$.

Taking into account the circuit implementations of eddy-current non-destructive testing methods [28], Figure 1 shows a scheme of thermal TTC for joint determination of the electrical conductivity λ and temperature t of the fluid sample, which provides a heating controller TRM10 for testing operation the heating device, which allows controlling the temperature with the given accuracy. HP heating device allows to simulate conditions of sample temperature changing during brewing production process and during method implementation of sewage purification. The scheme contains a TTC with a tested liquid sample, power supply – P on AC, frequency meter – FM, oscilloscope – OS, EMF meter TTP – M2, bareter (current stabilizer) – B, sample resistance – R3, voltage drop meter – M1, recorder – R, phase shift angle meter – Ph, compensating eddy current converter – CC. The scheme also contains a reference eddy current converter RC, herewith TTC, CC and RC having the same number of turns, the radii of the measuring windings and the length (they are identical converters). The primary windings of TTC, CC and RC are series-connected, with the secondary coils of TTC and CC series-opposite connected. The CC is intended for full compensation of the EMF E_0 of TTC in the absence of the sample (before starting the scheme). The test sample is placed in the HD, which, in turn, is located in the TTC. As the control method for measuring the temperature of the liquid sample used thermocouple Chromel Copel TCC, the testing method for measuring the electrical conductivity λ at the initial temperature t_1 is a high-frequency measuring bridge, to determine the total salt content of TDS used laboratory TDS-meter to determine the pH level.

The operation of the TRM10 thermocouple is based on proportional integral differential testing (PID) approach. At the same time, the type of thermocouple is introduced from the beginning by a special program and due to the provided automatic calibration the range of measurements of the liquid sample is set, after which constants (i.e. coefficients of PID) are entered. The thermocouple has two outputs: the regulating unit – the ER connected directly to the heater and the measuring unit connected to the thermocouple. The signal from the thermocouple is inject directly to the TRM, which provides a comparison device, using a comparison device to compare the output signal of the thermocouple with the temperature set on the thermocouple device. Thus, knowing the diameter of the glass probe, first find the values of E_{20}, by the formula:

$$E_{20} = 1.11 f W_2 \pi \frac{d^2}{4}\mu_0 H_0 \qquad (16)$$

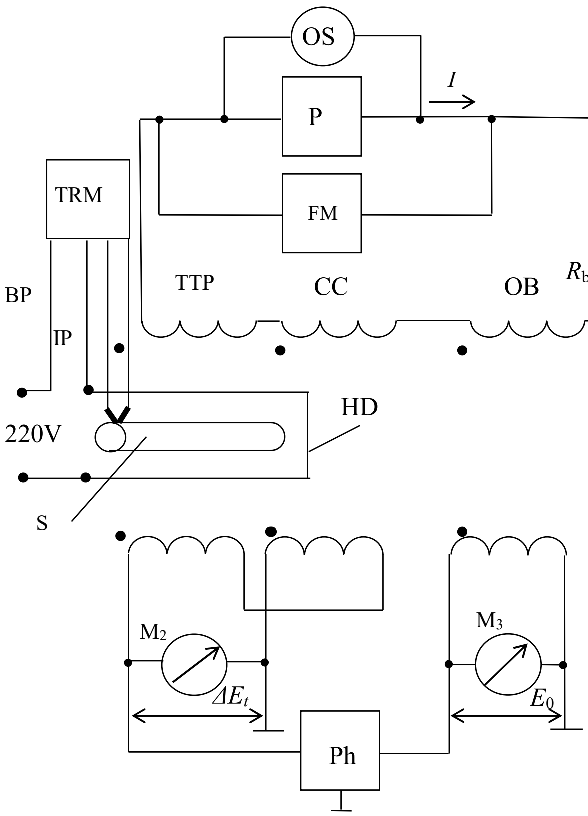

Fig. 1. Scheme of TTC connection with a sample of the tested liquid

After that, in the absence of a sample in the RP and knowing the value of the magnetic current in the primary winding (I = 130 mA, which provides the value of the magnetic field strength H_0 = 230 A/m), the CC changes the EMF of the two opposite-connected winding CC and RC - Ee, until the EMF $E_e = E_{20}$ (where E_{20} EMF, which is caused by the transmission of a magnetic flux in an air circular cross section equal to the radius of the sample a). The following algorithm determines the electrical conductivity λ, the initial temperature t_1, the total salt content of TDS and the pH level and then compares the values of these parameters with the values specified in the regulatory documents. At the initial temperature $t_1 = 15°C$, the values of these parameters were respectively: $\lambda =$ 15.28cm/m, $TDS =$ 8.82 g/l and $pH =$ 12.7. Thus, by analysing the numerical data obtained through experimental investigations, it is possible to note that beer sewages are alkaline in this case.

After that, to determine the electrical conductivity of the sample λ at temperatures in the range from 15 to 45°C, a glass probe with a liquid sample is placed in the RP and the sample temperature is changed with the HD. Next, they change the frequency of the TTP magnetic current by the power source – Ch, until the value of the phase shift angle is equal to the value of the phase angle $\Delta\varphi$ TTC. Then the generalized magnetic parameter x_t and the electrical conductivity λ_t at different temperatures according to the above algorithm should be found. The results of determining the electrical and temperature parameters of the sample based on the implementation of a two-parameter eddy current method of joint test of electrical and temperature parameters of the liquid sample (Tab. 1). In Table 1 also shows the values of the electrical conductivity λ' and the temperature t' of the sample of the liquid, which were determined by control methods (high-frequency bridge, THC thermocouple) and the calculated values of the measurements errors of the electrical and temperature parameters γ_{λ_t} and γ_t.

In Figures 2, 3 show the dependences of the specific normalized parameters of the TTC with a liquid sample, which is heated during the implementation of multi-parameter testing.

Table 1.
The results of measuring tests of the beer sewage sample (alkaline), during implementing a two-parameter eddy current method based on thermal TTC

t', °C	x_t	G_t	$\Delta\varphi_t$, grad	$\lambda_t \cdot 10^{-1}$, Cm/m	t, °C	$\lambda_t' \cdot 10^{-1}$, Cm/m	γ_{λ_t}, %	γ_t, %
15	0.922662	0.105358	-81.925271	14.99	15.53	15.28	-1.89	3.53
17	0.938131	0.111348	-81.658561	15.78	17.45	15.47	2.00	2.58
19	0.953336	0.112263	-81.449979	16.32	18.78	16.00	2.00	-1.17
21	0.968307	0.115770	-81.121387	16.51	20.80	16.80	-1.73	-0.96
22	0.983062	0.119227	-80.854115	17.02	21.87	17.33	-1.79	-0.59
24	0.997562	0.122623	-80.591589	17.52	24.18	17.82	-1.68	0.74
26	1.011904	0.1349410.1	-80.321981	18.33	26.10	18.03	1.66	0.38
28	1.026013	0.1295453	-80.055172	18.82	28.05	18.54	1.51	0.17
30	1.039902	0.132939	-79.792073	19.04	30.03	19.31	-1.39	0.13
32	1.053700	0.136345	-79.527958	19.55	31.95	19.81	-1.33	-0.156
34	1.067321	0.139793	-79.259848	20.06	33.98	20.33	-1.32	-0.03
36	1.081486	0.1432682	-78.989766	20.56	35.98	20.83	-1.29	-0.06
38	1.093916	0.1465391	-78.735455	21.33	38.03	21.07	1.23	0.08
40	1.106951	0.149897	-78.473957	21.84	40.02	21.58	1.20	0.05
42	1.119923	0.153308	-78.207847	22.34	41.98	22.08	1.18	-0.05
44	1.132651	0.1566669	-77.945831	22.85	43.99	22.59	1.15	-0.02

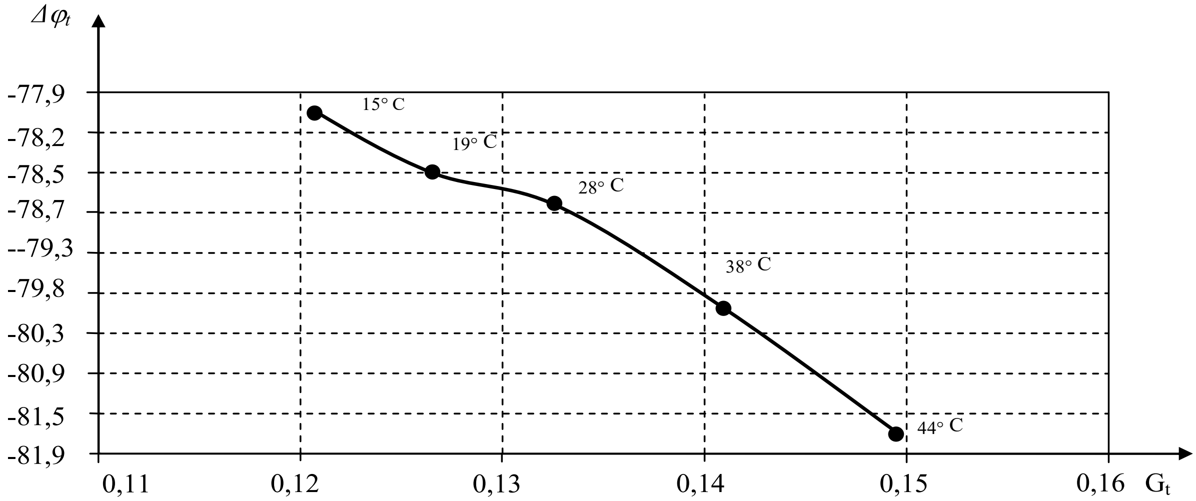

Fig. 2. Dependence of the phase shift angle $\Delta\varphi_t$on the specific normalized parameter G_t

The formation of an acidic flow at the mash vat outlet and wort vat was revealed, an alkaline runoff is observed after receiving the finished product after conductometric method testing. The application limitation of the method for breweries is related with a rather complex automation of the measurement process; at present, the authors of the article are developing a submersible eddy current transducer, the operation of which is based on a parametric effect.

The transducer has only one winding and can be immersed in sufficiently large containers, for example, 200-500 litres, which makes it possible to read information if the liquid is not homogeneous.

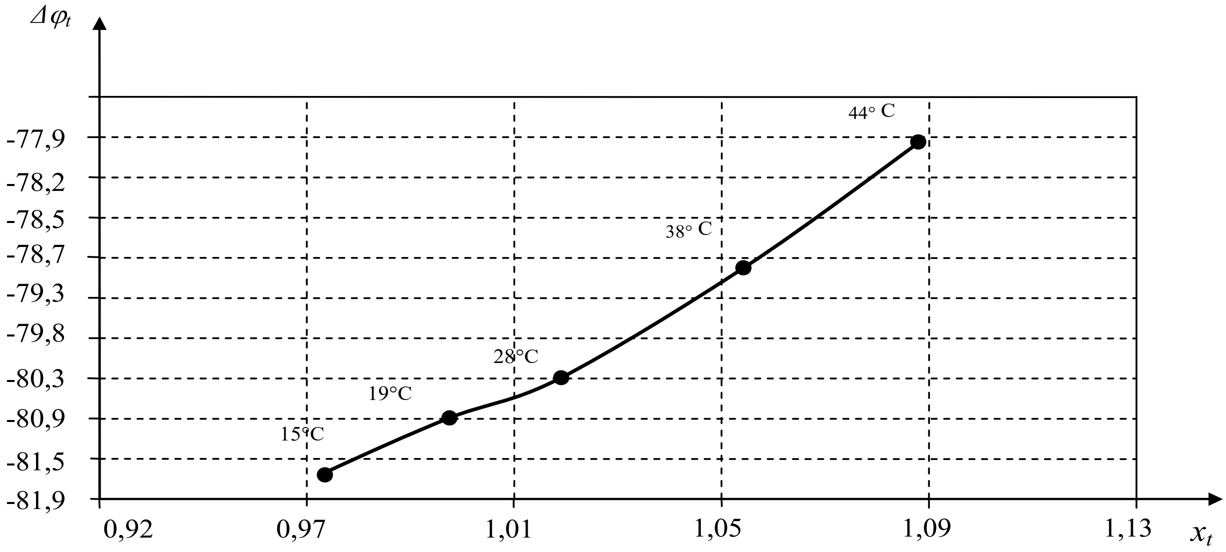

Fig. 3. Dependence of the phase shift angle $\Delta\varphi_t$ on the generalized parameter x_t

5. Results and discussion

A new informative two-parameter method of testing the electrical and temperature parameters of beer sewage samples of brewing products is proposed. Modern conductometric methods [26] determine many physico-chemical parameters of solutions. In article [26], the electrical conductivity λ of potassium salt ions in an aqueous solution of dimethyl sulfoxide (DMSO) was investigated in the temperature range 25-450°C.

The limiting values of electrical conductivity were obtained on the basis of the dependence of λ on the concentration C. The electrical conductivity λ of the solution increased to a certain critical point on the dependence $\lambda = f(C)$, and then fell sharply as the temperature t increased. The electrical conductivity λ of the DMSO - H_2O system is explained by the prototropic mechanism, which is much weaker than the ionic conductivity. Therefore, the conductivity of the solvent is not taken into account. The use of a wide temperature range by the author is explained by the limiting value λ_0 study, since with increasing temperature the mobility of ions increases, which leads to an increase in the limiting λ_0. It should be noted that the experimental dependence $\lambda = f(C)$ obtained in [26] is a working conversion function only for the DMSO-H_2O system; it cannot be considered universal for many types of weak electrolytes (which include wastewater). It should also be noted that it is rather difficult to accurately measure and maintain the temperature in the specified range. This is due to the fact that thermistors and thermocouples have disadvantages associated with the fact that such thermocouples usually measure the temperature of the sensing element, and not the object of study, since there is always a gap filled with air or dielectric between the sensing element and the controlled sample. In the case of using thermocouples and thermistors, errors also appear, the source of which is due to the interaction of the object and the thermal converter, since the temperature field of the medium can be violated. The disadvantages of non-contact optical temperature measuring devices (full and partial radiation pyrometers, colour pyrometers, etc.) are the complexity of the design, the dependence of the measuring instruments indicators on the distance to the controlled object.

In article [27], the electrical conductivity of solutions of dimethyl sulfoxide (DMSO) + hydroiodic acid (KI) was investigated. In this case, the value of the conductivity g (this value is related to the equivalent electrical conductivity λ_g) was determined using direct current by the method of impedance spectroscopy, which is based on the interaction of an external field with the electric dipole moment of the sample. The measurements were carried out in the entire range of KI solubility and in the temperature range from 20-50°C. The limiting molar conductivities g_0 were determined at various temperatures using the Fuss-Onsager method. The constant KA of the ionic association K + + I was determined at various temperatures from the range under investigation. In article [27], the results are presented in the form of graphs of the dependence of the equivalent electrical conductivity λ_g on the concentration of C and tables containing the numerical parameters of the Fuss-Onsager equation. However, for the practical use of methods and devices for measuring the physical and chemical parameters of weak electrolyte samples in automated control systems, values of specific electrical conductivity λ of electrolytic liquids at various concentrations are required.

At this time, eddy current methods and transducers are widely used in many fields of science and industry. In particular, for detecting surface and depth defects in metal products and structures, for controlling the thickness of coatings (metal and dielectric), for the contactless determination of magnetic, electrical and geometric parameters of parts, as well as strength, hardness, the presence of dominant impurities in materials, structure distortion products due to the impact on it of various types of treatments (mechanical, thermal and chemical) [28]. At the same time, eddy current methods and devices were practically not used to determine the informative parameters of electrolytic liquids. This was due to the complex nature of the dependences of the signals of the primary eddy-current transducers on the electrical and temperature parameters of the samples of electrolytic liquids. This article explores the application of the eddy-current transducer theory to measuring control of electrical and temperature parameters of sewage samples from brewing production.

The proposed two-parameter eddy-current method is based on the analysis of the interaction of an external uniform magnetic field with the magnetic field of eddy currents induced by a driving coil in a glass tube with a sewage sample under in investigation. At the same time, in order to connect 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 TTC ΔE_t. Then, based on the experimental data for determining the components of the converter signals and the calculated data associated with the determination of the normalized parameters of the TTC, universal conversion functions were determined and algorithms for measuring and calculation procedures were established. So it is possible obtain information about the specific electrical conductivity λ and the temperature t of the liquid medium by measuring the magnetic fluxes $\Delta\Phi_t$ and Φ_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 $\Delta\Phi_t$ in the liquid sample with respect to the external magnetic flux Φ_0). Then it is possible to judge the physicochemical parameters of the sewage sample characterizing the quantitative composition of the tested object: concentration C, pH, TDS mineralization index and total hardness dGH. In this case, any change in the specific electrical conductivity λ leads to a change in the generalized parameter x and, consequently, to a change in the amplitude and phase components of the signals of the thermal TTC with a sewage sample, i.e. to a change in characteristics: G_t, $\Delta\varphi$, E_0, ΔE_t. The dependences $G_t = f(\Delta\varphi_t)$ and $\Delta\varphi = f(x_t)$ are universal and basic for the implementation in practice of any non-contact eddy current methods of measuring control of specific electrical conductivity λ, temperature t and other (correlated with λ and t) physicochemical characteristics samples of weak electrolytic liquids (in this case, wastewater from breweries). The advantages of the proposed method are contactlessness, simplicity of conversion functions and circuit implementations, high reliability and sensitivity. The analysis of errors in measuring the specific electrical conductivity λ and temperature t by the developed two-parameter method is carried out.

The ranges of measurement errors for specific electrical conductivity λ and temperature t were respectively: $\gamma\lambda_t = 1.15 - 2\%$ and $\gamma_t = 0.02 - 3.53$. The obtained universal transformation functions $G_t = f(\Delta\varphi_t)$ and $\Delta\varphi = f(x_t)$, on the basis of which the proposed two-parameter method for monitoring the electrical and temperature parameters of tested sewage samples is implemented, makes it possible to testing the electrical conductivity λ of weak electrolytic liquids in the temperature range. This temperature range corresponds to the ranges of food production processes. The accuracy and sensitivity of a two-parameter eddy-current transducer have rather high values, so the sensitivity of the TTC is $S = 40$ mv/°C. This is due to the fact that information about the specific electrical conductivity λ and the temperature t is provided by a probing magnetic field, which causes the flow of eddy currents, the eddy currents, in turn, feel the change in the specific electrical conductivity λ, including that caused by a change in the temperature t of the product.

At the same time, the found changes ranges in the transducer signals, as well as the given methods for calculating the measurements errors of the specific electrical conductivity and temperature of a sewage sample t, make it possible to assess the dynamic and static characteristics of thermal eddy-current transducers with different orientations of the magnetic field and, in the future, to establish the optimal operating modes for various types of thermal eddy current transducers with investigated liquid media.

However, the alkaline or acidic nature of the beer sewage sample, it is possible to determine the numerical value of the electrical conductivity λ_t, the total salt content of TDS and the pH level. At the initial temperature $t_1 = 15$°C, the values of these parameters were respectively: $\lambda = 15.28$ Cm/m, TDS=8.82 g/l, $pH = 12.7$, so the sample is alkaline.

The proposed two-parameter eddy current method limitations include the range of glass tube samples diameters from 10 mm to 40 mm. In this case, the lower limit is due to the lower limit of the frequency of the magnetic field $f = 20$ Hz, and the upper limit is due to the diameter of the transducer frame $d = 40$ mm, this range was limited by the diameter of the heater, which is placed directly in the TTC. If it is necessary to increase the upper limit of the diameters of the liquid sample, then it is necessary to increase the diameters of the frame of the windings of the converter and heater. Radial displacement of the sample does not affect the measurement results, since the magnetic field of the transducer is uniform. A heater inside the converter limits sample skews. It has been established that the sample skew within ±5° practically does not affect the measurement results. There are limitations with respect to the temperature error, since a change in the temperature of the medium or sample leads to a change in the resistance R of the magnetizing winding. Moreover, if the magnetizing current is kept constant, the flux in the sample will also be constant, therefore, the EMF of the measuring winding, which is a function of the temperature t, will also be constant. A change in temperature, and hence the resistance of the measuring winding, does not cause a noticeable temperature error, since the resistance of this winding is 5 Ohms. The experiment was carried out in the temperature range from 15 to 45°C. In such ranges, both the windings of the converter and the frames of the heater and converter normally withstand temperature changes. During TTC operation, its windings must be thermally insulated from the environment and from the heated sample.

An insulating layer is placed between the heater and the porcelain frame of the converter; the heat-resistant frame of the converter was made of porcelain.

It should be noted that the obtained relations describing the universal conversion functions, algorithms for measuring and calculating the electrical and temperature characteristics of the sample. As well as the components of the primary heat converter signals, the expressions obtained for determining the of joint multi-parameter measurements errors, allow modelling eco-specific steps which are connected with the processes of urbanization and the destruction of the natural environment of the districts of large cities in which production is located and the brewing industry. As well as providing an opportunity to determine the sewage origin of the respective enterprises by the tested physic-chemical characteristics, allow making decisions on the application of regulation of the waste origin through the technologies of water preparation, facilitate the implementation of technological operations related to methods and means purification of beer sewages, allow to provide recommendations on the consumption of water and raw materials intended for the manufacture of the finished product.

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