RADIOMETRIC METHOD OF RESEARCHING THE EMISSION PROPERTIES OF BIO-OBJECTS

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Abstract

A radiometric method is proposed for studying the emission (radiative) properties of microbiological objects (microorganisms, colonies of yeast bacteria, fungi, mold, biological tissue samples) in the microwave range. A block diagram of the implementation of the method using the modulation transformation of information signals is proposed. An algorithm and technology for measuring weak emission signals of the objects under study has been developed. The results of experimental studies of the technological process of maturation of hard cheese, accompanied by an increase in emission radiation, are presented. At the same time, the emission coefficient of radiation during 20-80 days of ripening increases by 5-10%, and then decreases almost to zero.

Keywords: *biological object, emission properties, radiometric system, emission coefficient.*

INTRODUCTION

The surrounding space (air, water, earth) is filled with various types of microorganisms (bacteria, archaea, fungi, eukaryotes, etc.) [1,2]. Some of these micro-objects are useful and are used in technologies for the production of food products (fermented milk and cheese products, wine, beer to create conditions for fermentation and maturation), medical drugs - for the production of antibiotics and other drugs by bioengineering methods [1,3,4].

At the same time, biologically active substances are used that isolate these micro-objects and accelerate the processes of product formation, improving their quality, color, and appearance. All of the listed processes have their own methods and devices for assessing the degree of technological processes of manufacturing products. They can be classified as classic methods, and the application, in the time interval, can be calculated for tens or more years.

At the same time, the development of radio-electronic technology, the emergence of a new element base contributes to the emergence of new, more modern and accurate methods of controlling technological processes, material properties, the state of biological objects, etc.

The use of such equipment and control methods open up additional opportunities for increasing the sensitivity and accuracy of evaluating the parameters of technological processes.

Such innovations include the creation of highly sensitive microwave radiometers. The integral sensitivity of such equipment reaches $10^{-13}…10^{-15}$W, which contributes to its use for the study of "subtle" processes in materials science, biology, medicine, light and even food industry [5].

RADIOMETRIC SYSTEMS FOR EVALUATING THE RADIATION CAPACITY OF BIOLOGICAL OBJECTS

The authors of [6] developed a highly sensitive radiometric system for evaluating the emission properties of biological objects.

In fig. 1 shows the structural implementation of the developed radiometric system for measuring weak emission signals of samples of biological objects.

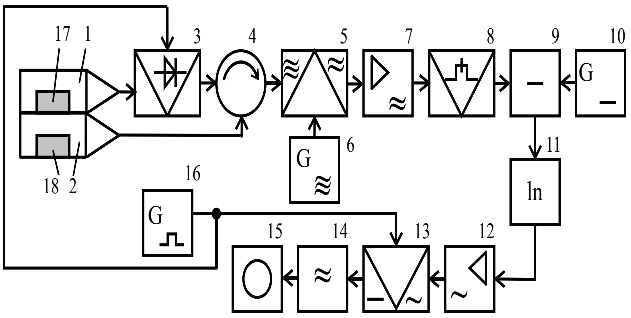

Fig. 1*. Radiometric system for evaluating emission properties of samples of biological objects*

The radiometric system contains the following functional modules: working 1 and reference 2 waveguide sensors, controllable modulator-splitter 3, circulator 4, mixer 5, microwave local oscillator 6, intermediate frequency amplifier 7, amplitude detector 8, difference signal selection module 9, reference constant voltage source 10, logarithm 11, low-frequency amplifier 12, synchronous detector 13, low-pass filter 14, voltmeter 15, low-frequency multivibrator 16, sample under study 17 and sample-simulator 18.

The working and reference sensors are made in the form of waveguide segments mechanically connected to each other.

ALGORITHM AND MEASUREMENT TECHNOLOGY

Emissions from the working 1 and reference 2 sensors enter the inputs of the circulator 4. The working sensor is connected to the circulator through a controlled modulator-branch 3, which is controlled by a low-frequency multivibrator 16. Noise signals from the working 1 and reference 2 sensors when the modulator-branch 3 is open and closed are received at the input of the mixer 5 in different half-periods of the control voltage. Their dispersions have the form:

$$\overline{U}_{11}^2 = K_1\left(\overline{U}_{21}^2 + \overline{U}_3^2 + \overline{U}_4^2\right), \qquad (1)$$

$$\overline{U}_{12}^2 = K_1\left(\overline{U}_{22}^2 + \overline{U}_4^2\right), \qquad (2)$$

where $\overline{U}_{21}^2$, $\overline{U}_3^2$, $\overline{U}_4^2$ – dispersion, respectively, radio-thermal, bio-informational radiation of the studied sample and the inherent noise of the mixer; K_1 – transmission coefficient of the waveguide; $\overline{U}_{22}^2$ is the dispersion of thermal radiation of a simulated sample, which is an object with "inanimate" bacteria.

The amplitude-modulated signal is formed during the periodic operation of the modulator-branch 3 with the frequency of the multivibrator Ω at the out of the mixer 5:

$$M_1 = \frac{\overline{U}_{11}^2 - \overline{U}_{12}^2}{\overline{U}_{11}^2 + \overline{U}_{12}^2} = \frac{\overline{U}_3^2}{2\left(\overline{U}_4^2 + \overline{U}_{21}^2\right)}. \qquad (3)$$

With the help of a microwave signal of the local oscillator 6, the emission radiation spectrum is transferred to the intermediate resonant frequency ω_0, to which the intermediate frequency amplifier 7 is tuned. After heterodyne conversion and detection by the amplitude detector 8 in different half-cycles of the control voltage, video pulses are formed, the amplitudes of which after functional conversion in the subtraction 9 and logarithmization modules in 11 take the form:

$$U_{51} = S_3 \ln\left\{K_1^2 S_1^2 K_2^2 S_2 K_3 \left[\overline{U}_{21}^2(\omega_0) + \overline{U}_3^2(\omega_0)\right]\right\}, \qquad (4)$$

$$U_{52} = S_3 \ln\left[K_1^2 S_1^2 K_2^2 S_2 K_3 \overline{U}_{22}^2(\omega_0)\right], \qquad (5)$$

where S_1, S_2, S_3 – respectively, the steepness of heterodyne, quadratic and logarithmic transformations; K_2 – the gain factor at the intermediate frequency; K_3 – the transfer coefficient of the subtraction module.

Decomposing one by one the component of the sequence of video pulses (4) and (5) into an exponential series, it is easy to see that the reading of the radiometric system indicator (η) are proportional to the ratio of bioinformatic and radiothermal radiation powers:

$$\eta = \frac{K_0 \overline{U}_3^2(\omega_0)}{\overline{U}_{21}^2(\omega_0)}, \qquad (6)$$

where η – emission factor; K_0 - coefficient of proportionality.

The obtained ratio (6) is a desirable measure of emission properties of biological objects and tissues.

At the same time, the power ratio does not depend on the transmission properties of the connecting sensors and waveguides, the instability of the steepness of the heterodyne conversion of the compared signals, the instability of the gain of the selective amplifier, the sensitivity of the amplitude detector and the gain of the subtraction module.

Coefficient of proportionality K_0 depends only on the stability of low-frequency radiometric system modules and is determined in the calibration process by samples of microorganisms, the emissivity of which is estimated based on the results of biochemical studies.

STUDY OF THE TECHNOLOGICAL PROCESS OF MAKING HARD CHEESES

The process of cheese production belongs to dynamic processes with a high level of uncertainty, which combines many physical and chemical processes. During the production of cheeses, phases of heating and mechanical mixing are distinguished, as a result of which a curd (Calie) is formed, which is separated from the liquid part by pressing, and then aged for a certain time, depending on the variety. To ensure guaranteed safe and high-quality cheese products, it is necessary to monitor changes in the main quality indicators, both organoleptic, physicochemical, and microbiological [7]. The duration of maturation of natural rennet cheeses is 20…60 days, and their storage temperature must be maintained with an error of no worse than ±1°C.

The ripening stage of cheeses is determined by the action of milk enzymes, rennet, lactic acid and other microflora. Under their influence, the processes of hydrolysis of proteins, milk fat, lactic acid and propionic acid fermentation take place in the curd mass. The process of product maturation is accompanied by an increase in the number of spoilage agents. At the same time, it is necessary to monitor the condition of the cheese and remove the mold in time. One of the indicators of this process is the emissive (radiothermal) radiation of the cheese mass in the microwave range.

A certified radiometric system with sensitivity was used to study the cheese ripening process $1 \cdot 10^{-14}$ W. A study of 5 cheese samples was conducted over a period of 80 days at a frequency of 50 GHz. In the course of the study, measurements of weak emission radiation were carried out every day.

Experimental radiometric studies of the technological process of hard cheese ripening have shown that this process is accompanied by an increase in emission radiation. Emission factor η at the same time, it increases to 0.05...0.1, which is 5…10% of radio-thermal radiation during 20…80 days of ripening.

Excessive aging of cheeses is accompanied by a decrease in emissive radiation to almost 1%. The consequence of this is a significant deterioration of the taste properties and smell of cheese.

A simulated sample for research was prepared from biological cells of the same mass as the studied sample. Preparation of the protein in the simulated sample was carried out by heating it to a temperature of 80...90°C, at which denaturation of the protein of the living substance occurs.

Additional heat generation associated with biochemical processes in materials and tissues with living protein leads to a slight increase in the temperature of the working sensor. Thanks to the good thermal contact of sensors 1 and 2, the temperatures of the working and reference sensors are equalized. In the same way, the inconstancy of the influence of the external temperature on the level of radiothermal radiation of the tested and simulated samples is compensated.

CONCLUSIONS

1. Conducting experimental radiometric studies of the technological process of ripening hard cheese showed that this process is accompanied by an increase in emission radiation.

2. Emission factor η at the same time, it increases to 0.05...0.1 (5-10% of radio-thermal radiation) during 20-80 days of ripening.

3. Further aging of the cheese leads to a significant deterioration of some of its taste

qualities, which is accompanied by a decrease in the emission coefficient to 0.01 (less than 1% of radiothermal radiation), and further to zero. The latter indicates a decrease in the number of living microorganisms in the product and the end of its ripening stage.

4. The radiometric method of evaluating the emission properties of cheese products can act as a test method when launching new types, as well as a control (verification) method in sustainable technologies.

REFERENCE

[1] Pert S. Dzh. Osnovy kulʹtyvyrovanyya mykroorhanyzmov. Moskva: Myr, 1978- 332 p.

[2] Kondratyuk T.A., Kalinichenko A.V. Mikroskopichni hryby v prymishchennyakh bahatopoverkhovoho budynku v Kyyevi// Visnyk Lʹvivsʹkoho universytetu – Seriya biolohichna, 2013.- 61: 30.

[3] Bylay V.Y. Byolohychesky aktyvnye veshchestva- produtsenty antybyotykov.- Kyev: Naukova dumka, 1965-266 p.

[4] Bylay V.Y, Bylay T.Y., Musych E.H. Transformatsyya tsellyulozy hrybamy.- Kyev: Naukova dumka, 1982.- 296 p.

[5] Kutsenko V. P. Radiometrychnyy NVCH-kontrolʹ vlastyvostey materialiv / V. P. Kutsenko, YU. O. Skrypnyk, M. F. Trehubov, K. L. Shevchenko, O. P. Yanenko — Donetsʹk: IPSHI «Nauka i osvita», 2012. — 348 p.

[6] Patent №33222 A (Ukraine) Mikrokhvylʹovyy prystriy dlya analizu emisiynykh vlastyvostey zhyvoho bilka/ Skrypnyk YU.O., Shevchenko K.L., Tsymbalyuk V.I.- Byul.№1-2001.

[7] I.H. Vlasenko, T.V. Semko, S.V. Hyrych. Innovatsiyi u vyrobnytstvi tverdykh syriv – Vinnytsya, RVV VTEI KNTEU, 2018. – 144 p.