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RESULTS OF STUDIES OF DAIRY PRODUCTS BY THE METHOD OF WEIGHT IMPEDANCE ELECTROMETRY WITH A CAPACITIVE SENSOR

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Milk and products made from it have a number of useful and unique properties. It has the ability to strengthen the immune system, helps in the fight against colds, it contains a large amount of vitamins and minerals. This is due to the fact that milk is produced primarily for feeding young offspring. Milk-based products are essential and indispensable for children of all ages, pregnant and nursing mothers, the sick and the elderly, except for those who suffer from allergies. However, the production of milk and dairy products is associated with high costs, which makes the falsification of these products very tempting. Counterfeit products not only do not carry any benefit, they can also harm the health of the consumer. Therefore, it is necessary to check the products for quality and compliance with all standards. But the examination is a long and complicated process, for which it is necessary to violate the integrity of the package. For these purposes, a method of weight impedance electrometry is being developed, which will allow measurements to be carried out quickly and does not require opening the container.

Keywords: milk, dairy products, quality control, control methods, express method, temperature, comparative analysis

According to a study conducted by the Research Financial Institute of the Ministry of Finance, every second pack of butter, a fourth bottle of milk and every fifth ice cream are counterfeit. In percentage terms, the share of illegal circulation of drinking milk and cream reaches 24.56%, butter and ghee, as well as spreads – 44.13%, ice cream – 21.51%. Given these statistics, we can safely say that the problem of counterfeit products on store shelves is relevant. Therefore, it is necessary to develop a new method for controlling the quality of dairy products [1].

The purpose of this research is to study dairy products by the method of weight impedance electrometry with a capacitive sensor, as well as to obtain data for their further use.

Materials and methods of research

For this study, cream of 10%, 20% and 33% fat content, a capacitive sensor, scales with an accuracy of one hundredth of a gram, a temperature sensor, and an E7-20 immitance meter were used. All experiments were carried out at an air temperature of 22°C and a temperature product at 21°C. The volume of the test product is 50 ml with an error of no more than 0.4 ml.

The presented E7-20 immitance meter (Fig. 1) is a precision device of accuracy class 0.1 with a wide operating frequency range of 25 Hz – 1 MHz and a high measurement rate of up to 25 per second. Measured parameters E7-20: inductance, capacitance, resistance, conductivity, loss factor, quality factor, complex resistance modulus, reactance, phase shift angle; leakage current. various physical quantities [2].

Fig. 1. E7-20 immittance meter

Measurements using an "inserted" dual coaxial sensor of two capacities (C_{os}, C_{is}) and two loss angle tangents ($tg\delta_{os}$, $tg\delta_{is}$) make it possible to calculate the average value of the relative permittivity (ε) of milk, and in the presence of standard data (τ_e, η_e), – to determine the dynamic viscosity of the sample (η_o), by calculating its microscopic (τ_o) and macroscopic relaxation times (τ) [3-5]:

$$\varepsilon = C_{measured} / C_0 , \quad (1)$$

$$\eta_0 = (\tau_0 \eta_e) / \tau_e , \quad (2)$$

$$\tau_0 = 3\varepsilon\tau_0 / (2\varepsilon + 1), \quad (3)$$

$$tg\delta = (\varepsilon - \varepsilon_\infty)\omega\varphi / (\varepsilon + \omega^2\tau^2), \quad (4)$$

where C_0 is the capacitance of the sensor in air; $C_{measured}$ is the capacitance of the sensor in the medium being measured; η_0 – dynamic viscosity; τ and τ_0 are the macroscopic and microscopic relaxation times; ω is the cyclic frequency; η_e and τ_e are tabular air data loaded into the computer.

A capacitive sensor is a parametric type converter in which a change in the measured value is converted into a change in the capacitance of a capacitor. The main element of capacitive sensors is a capacitor, which can be made in a flat or cylindrical form. When the movable plate of the capacitor begins to move, increasing the distance to the fixed plate, the dielectric is deformed, and its position changes, leading to a change in the permittivity and many other parameters [6], The capacitance for a flat capacitor is calculated using the following formula:

$$C = (\varepsilon \times \varepsilon_0 \times S) / d\,, \quad (5)$$

where ε is a constant value relative to the permittivity of the medium between the plates; S is the plate area; d is the distance between the plates.

The density of cream depends on two factors, these are temperature and percentage of fat content. The higher the temperature, the lower the density. To determine the density, the formula is used:

$$\rho = m / V, \quad (6)$$

where m is the mass of the product, V is the volume.

In terms of density, depending on the mass fraction of fat, cream must meet the requirements set forth in Table 1.

Table 2 below shows average measurements of 10% fat cream on a capacitive sensor for frequencies from 100 to 1,000,000 Hz.

Following the data obtained from the table, graphs of conductivity and complex resistance (Fig. 2) were plotted in the range of measured frequencies.

Table 1

Density depending on the mass fraction of fat

mass fraction of fat, %	density at 20°C, kg/m³
9.0 to 20.0	1020.0 to 1008.0
20.0 to 30.0	1008.0 to 997.0
30.0 to 40.0	997.0 to 987.0
40.0 to 50.0	987.0 to 976.0
50.0 to 58.0	976.0 to 968.0

According to the above formula (1), we calculate the permittivity at the studied frequencies and plot the dielectric permittivity graph (Fig. 3).

Knowing the volume and mass, we find the density using the formula (6):

$$\rho = m / V = 0.05041 / 0.00005 = 1008.2 \text{ kg/m}^3$$

The result obtained corresponds to the value indicated in table 1.

Table 3 shows the results of measurements of 20% fat cream on a capacitive sensor for frequencies from 100 to 1,000,000 Hz.

We will also build graphs of conductivity, permittivity and complex resistance (Fig. 4) in the range of measured frequencies.

Let's calculate the density:

$$\rho = m / V = 0.04993 / 0.00005 = 998.6 \text{ kg/m}^3$$

Table 4 below shows average measurements of 33% fat cream on a capacitive sensor for frequencies from 100 to 1,000,000 Hz.

Table 2

Average value of parameters for cream 10%

Frequency average										
Frequency (Hz)	Cp (pF)	L (H)	Rp (Ω)	1/Rp (nS)	Gp (nS)	Q	j (°)	|Z|	tgδ (D)	I(mA) DC
Instruction manual code	0	1	2	x	3	6	10	12	13	14
100	4E-05	-0,07	44,47	0,0225	0,0225	1,07	-47,1	30,5	0,931	1E-05
200	3E-05	-0,02	32,25	0,031	0,031	1,08	-47,3	22	0,9241	
500	2E-05	-0,01	19,87	0,0503	0,0503	1,04	-46,3	13,8	0,9595	
1000	1E-05	-0	13,1	0,0763	0,0763	0,93	-43	9,63	1,0753	
2000	7E-06	-0	8,69	0,115	0,11506	0,76	-37,2	6,93	1,3229	
5000	3E-06	-0	5,53	0,1808	0,18083	0,51	-27,2	4,92	1,9538	
10000	1E-06	-0	4,37	0,2288	0,22883	0,35	-19,5	4,12	2,8394	
20000	5E-07	-0	3,753	0,2664	0,26643	0,22	-12,6	3,67	4,4957	
50000	9E-08	-0	3,43	0,2915	0,29154	0,1	-5,56	3,41	10,35	
100000	7E-09	-0	3,29	0,3039	0,30395	0,01	-0,88	3,29	68,388	
200000	-2E-08	3E-05	3,235	0,3091	0,30912	0,09	5,43	3,22	10,426	
500000	-3E-08	3E-06	3,6283	0,2756	0,2756	0,35	19,51	3,42	2,8169	
1000000	-3E-08	1E-06	4,035	0,2478	0,24783	0,64	32,72	3,39	0,7406	

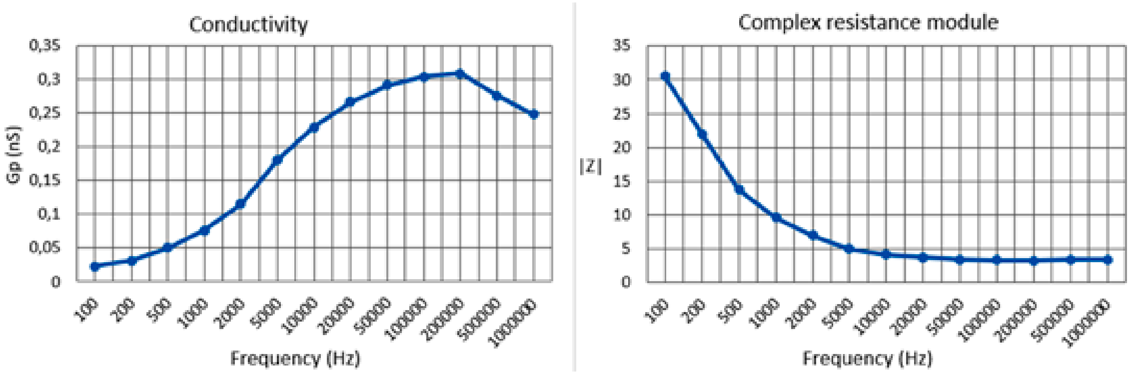

Fig. 2. Graphs of conductivity and the modulus of complex resistance

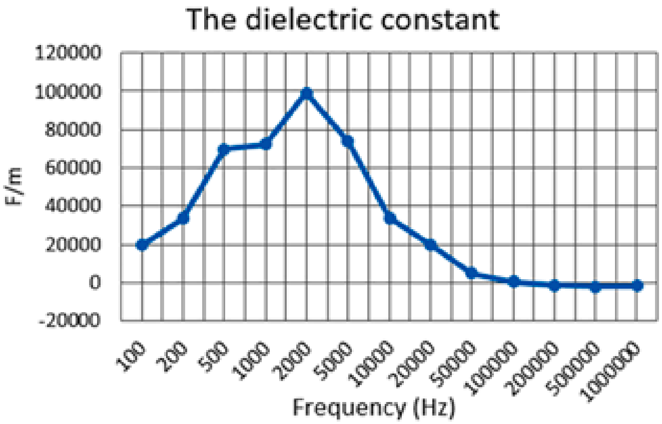

Fig. 3. Graph of dielectric constant

Table 3

Average value of parameters for cream 20%

Frequency average										
Frequency (Hz)	Cp (pF)	L (H)	Rp (Ω)	1/Rp (nS)	Gp (nS)	Q	j (°)	|Z|	tgδ (D)	I (mA) DC
Instruction manual code	0	1	2	x	3	6	10	12	13	14
100	4E-05	-0,06	42,51	0,02352	0,02352	1,121	-48,2	28,438	0,89045	7E-06
200	3E-05	-0,02	29,722	0,03365	0,03365	1,083	-47,3	20,22	0,92576	
500	2E-05	-0,006	17,56	0,05695	0,05695	0,951	-43,6	12,73	1,05226	
1000	1E-05	-0,002	11,6	0,0862	0,0862	0,783	-38,1	9,171	1,27775	
2000	6E-06	-0,001	8,092	0,12358	0,12358	0,594	-30,8	6,96	1,68225	
5000	2E-06	-5E-04	5,74	0,17422	0,17422	0,377	-20,7	5,37	2,65485	
10000	8E-07	-3E-04	4,9	0,20408	0,20408	0,25	-14,1	4,76	4,0081	
20000	3E-07	-2E-04	4,46	0,22422	0,22422	0,153	-8,71	4,41	6,55855	
50000	5E-08	-2E-04	4,22	0,23697	0,23697	0,062	-3,54	4,22	16,27167	
100000	-6E-10	0,004	4,12	0,242719	0,242718	0,0014	0,08	4,12	435,422	
200000	-1E-08	4E-05	4,09	0,244499	0,244499	0,0875	4,99	4,07	6,22375	
500000	-2E-08	5E-06	4,41	0,22676	0,22676	0,287	15,99	4,24	1,47812	
1000000	-2E-08	1E-06	4,62	0,21645	0,21645	0,519	27,4	4,1	1,92847	

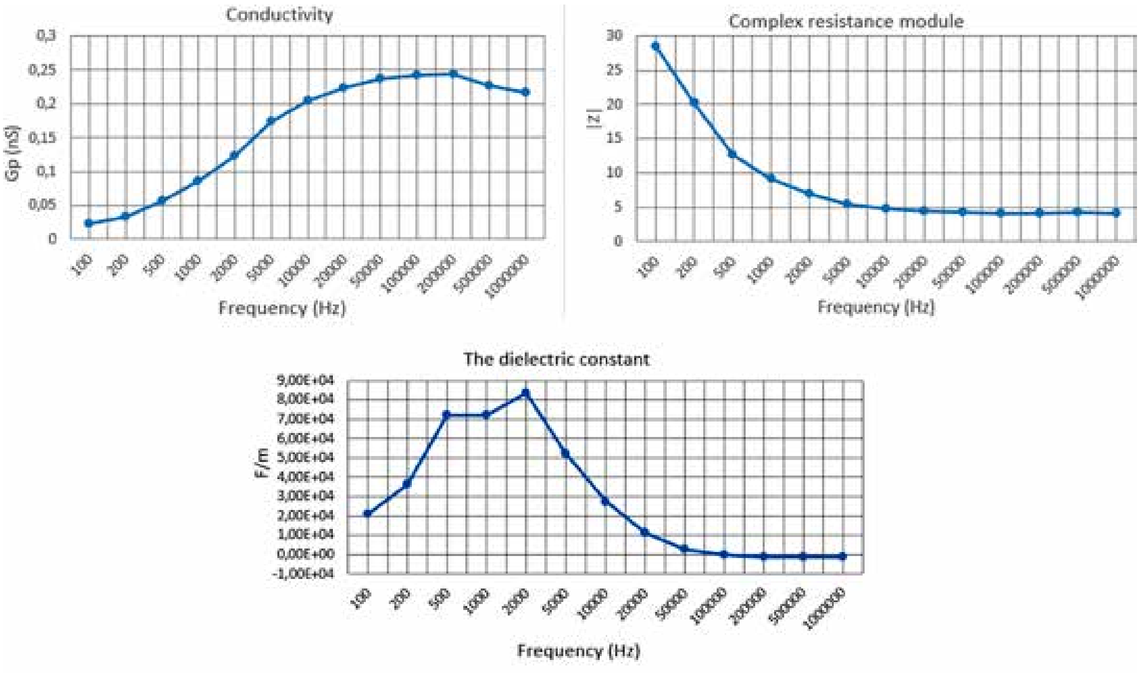

Fig. 4. Graphs of conductivity, modulus of complex resistance and permittivity

Table 4

Average value of parameters for cream 33%

Frequency average										
Frequency (Hz)	Cp (pF)	L (H)	Rp (Ω)	1/Rp (nS)	Gp (nS)	Q	j (°)	|Z|	tgδ (D)	I (mA) DC
Instruction manual code	0	1	2	x	3	6	10	12	13	14
100	4E-05	-0,058	39,178	0,026	0,0255	1,07	-46,88	27	0,9	1,2E-05
200	3E-05	-0,022	26,625	0,038	0,0376	0,97	-44,11	19	1	
500	2E-05	-0,007	15,9	0,063	0,0629	0,77	-37,77	13	1,3	
1000	9E-06	-0,003	11,1	0,09	0,0901	0,6	-30,97	9,6	1,7	
2000	4E-06	-0,002	8,51	0,118	0,1175	0,43	-23,52	7,8	2,3	
5000	1E-06	-8E-04	6,76	0,148	0,1479	0,26	-14,86	6,5	3,8	
10000	4E-07	-6E-04	6,13	0,163	0,1631	0,17	-9,812	6	5,8	
20000	1E-07	-4E-04	5,77	0,173	0,1733	0,11	-6,038	5,7	9,5	
50000	2E-08	-4E-04	5,58	0,179	0,1792	0,04	-2,443	5,6	24	
100000	-5E-10	0,004	5,485	0,182	0,1823	0	0,093	5,5	485	
200000	-9E-09	7E-05	5,447	0,184	0,1836	0,06	3,59	5,4	16	
500000	-1E-08	9E-06	5,66	0,177	0,1767	0,2	11,467	5,5	3,6	
1000000	-1E-08	2E-06	5,57	0,18	0,1795	0,36	19,7	5,2	1,7	

Based on the data from Table 4, we plot conductivity, permittivity and complex resistance (Fig. 5) in the range of measured frequencies.

Let’s calculate the density:

$$\rho = m / V = 0.04952 / 0.00005 = 900.4\ kg/m^3$$

Results of the research and discussions

As can be seen from the above graphs, the impedance modulus with increasing fat content has a lower coefficient at low frequencies.

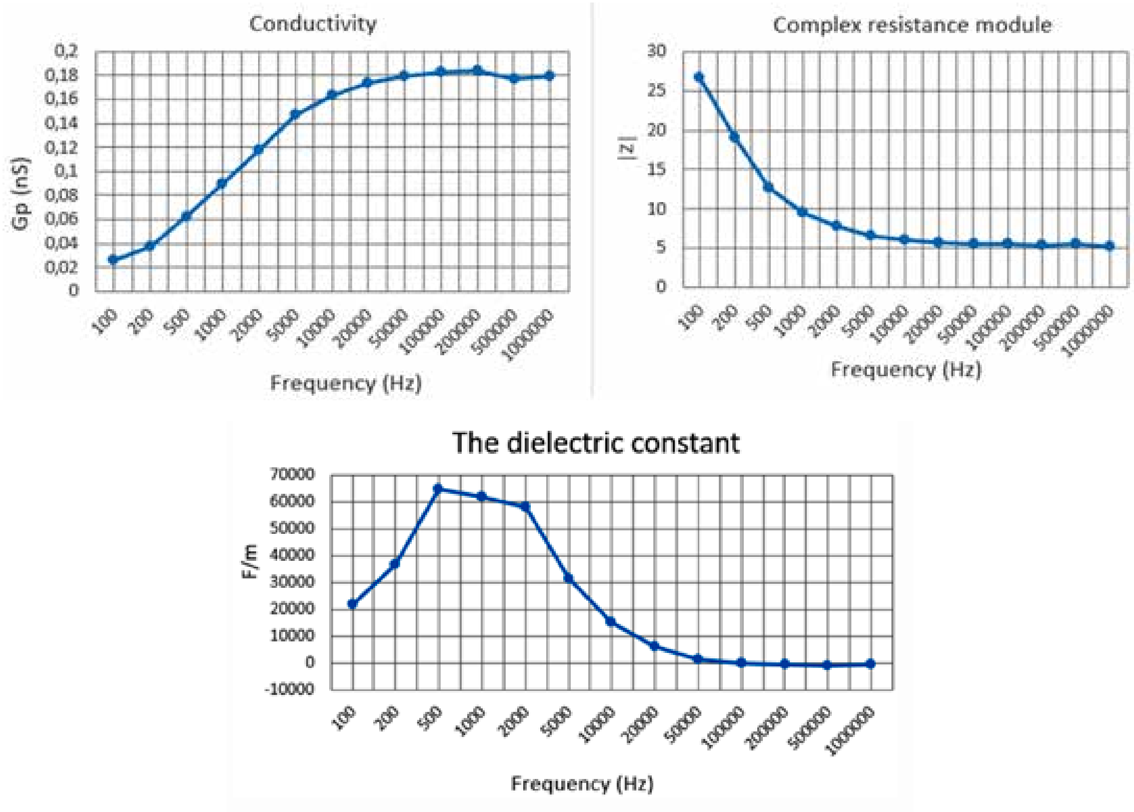

Fig. 5. Graphs of conductivity, modulus of complex resistance and permittivity

But at high frequencies, the coefficient increases with increasing fat content of the product. Regardless of the content of milk fat in the product, the graph does not have bursts and decays exponentially.

The conductivity for 10% and 20% cream increases steadily with increasing frequency and reaches its maximum at about 200,000 Hz, but after that there is a sharp decrease in this characteristic. Cream with 33% fat also reaches a maximum at 200,000 Hz, but this is followed by a slight decrease and increase in characteristic. It can also be seen that with an increase in the fat content of the product, its conductivity decreases.

The dielectric constant for 10% and 20% cream slows down at frequencies from 500 Hz to 1000 Hz, but then there is a sharp increase to a maximum value at 2000 Hz. After this frequency, an exponential decay is observed. For cream with a fat content of 33%, the extremum value is observed at 500 Hz, then a linear decrease in the dielectric constant follows, and after 2000 Hz an exponential decay is observed. There is also a decrease in the maximum dielectric constant with an increase in the fat content of the product.

Density indicators correspond to tabular values, which gives the right to consider this product to be of high quality.

Conclusion

In the course of a series of experiments, the dependences of the conductivity, dielectric constant and complex resistance were established for various indicators of the fat content of the dairy product. The dependence of the density of the product on the content of milk fat in it was also established and a comparison was made with reference values.

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