Installations for defrosting and warming colostrum in continuous mode

G Novikova¹, O Mikhailova², M Prosviryakova³, A Tikhonov⁴, D Tarakanov⁵, D Dulepov³ and N Kirillov⁶

¹Laboratory of energy and technological equipment, Nizhny Novgorod State Engineering and Economic University, 22a Oktyabrskaya Street, Knyaginino 606340, Russian Federation
²Chair of Info-communication Technologies and Communication Systems, Nizhny Novgorod State Engineering and Economic University, 22a Oktyabrskaya Street, Knyaginino 606340, Russian Federation
³Chair of Electrification and Automation, 22 Nizhny Novgorod State Engineering and Economic University, 22a Oktyabrskaya Street, Knyaginino 606340, Russian Federation
⁴Chair of Metal technology and car fixing, Nizhny Novgorod State Agricultural Academy, 97 Gagarina Prospect, Nizhny Novgorod 603107, Russian Federation
⁵Chair of Laboratory Protection and Life Safety, Nizhny Novgorod State Engineering and Economic University, 22a Oktyabrskaya Street, Knyaginino 606340, Russian Federation
⁶Chair of Morphology, Obstetrics and Therapy, Chuvash State Agricultural Academy, 29 Karl Marx Street, Cheboksary 428003, Russian Federation

*E-mail: ngic1-126@mail.ru

Abstract. The article is devoted to the development of microwave technology and installations for preparing frozen cow colostrum for calf feeding by exposure to an ultrahigh-frequency electromagnetic field in two volume resonators, which allow defrosting and heating of cow colostrum at different doses in a continuous mode. Two resonator microwave installations designed for farms have been developed and described. Effective modes of defrosting and warming up cow colostrum in an electromagnetic field of ultrahigh frequency: duration of exposure to ultra-high frequency electromagnetic field in a resonator is 12 min; power of microwave generators 3.5–3.65 kW; plant productivity 25–30 kg/h; energy costs for the process 0.12–0.18 kW·kg/h, heating temperature of raw materials to 38–40 °C. For cattle farms up to 600 heads, one microwave installation is enough to defrost and heat cow colostrum. The annual economic effect due to lower operating costs will be 153600 rubles. The profitability of the process will increase by 3.22%.

1. Introduction
Colostrum is known to be a complete calf feed. According to the nutritional value, cow colostrum is 1.5 times better than milk. Compared to cow's milk, colostrum has a higher nutrient content (27.6 %, compared to 12.3 %), a significantly higher protein content (14.9 % versus 2.8 %), and fat (6.7 % versus 4.4 %). Immunoglobulin in the colostrum in the first hours after childbirth is up to 90 % of the total number of proteins [1].
Therefore, it is necessary to keep this biological product frozen. For defrosting cow colostrum for the purpose of drinking calves, Salutem type defrosters are used, including BMA-50 (Belarus, Minsk), Primalact, Iglus-2, Solnyshko (Saint Petersburg). For thawing cow colostrum for the purpose of feeding the calves, thawers of the Primalact, Iglus-2, and Sun types are used. In this case, the heating of colostrum takes place due to heat transfer from hot water washing the containers with colostrum [2]. Tanks are placed on a rotating carriage. Existing thawers do not allow uniformly thawing colostrum over the cross-section of containers, which makes the process lengthy (40–90 min). Over such a period of time, the feed value of cow colostrum decreases by 20–50 %, i.e. it is not possible to maintain the concentration of immunoglobulin at the level of 50 mg/ml; other indicators (proteins, vitamin A) are also significantly reduced. Statistical data show that on the scale of the Russian Federation, 0.2 million t/year of cow colostrum should be thawed, and 150 t/year in the Nizhny Novgorod Region figure 1. Consequently, the number of installations for thawing and heating cow colostrum, with a productivity of 20–40 l/h in the Russian Federation will be 20–25 thousand units, and in the Nizhny Novgorod region – 20–40 units.

![Figure 1. Number of cows and volume of cow colostrum for 2018.](image)

The problem of maintaining the concentration of immunoglobulin, and therefore the nutritional value of thawed cow colostrum, remains unresolved today. Therefore, the development of technology and ultra-high-frequency installations for thawing and heating cow colostrum while maintaining feed value is relevant. To solve this problem, an innovative idea was proposed to reduce the duration of defrosting and warming up of cow colostrum by exposure to an electromagnetic field of ultra-high frequency (EMF, 2450 MHz, 12.24 cm), which allows to maintain the feed value of the product. First, the dielectric characteristics of frozen cow colostrum with a fat content of 4.5 % were analyzed [3]. It was found that the dielectric loss factor of frozen cow colostrum increases from 4 to 27 in the temperature range from −10 to 0 °C, and from 0 to +40 °C it drops from +27 °C to +11.9 °C. Therefore, to accelerate the technological process, thawing and warming of cow colostrum should be carried out in different volume resonators and at different doses of exposure to the electromagnetic field of ultrahigh frequency (EMF). The resonator is a volumetric system with distributed parameters [4-7].

The conditions for the operation of the installation for thawing and heating cow colostrum by the action of UHFEMF were developed. These are ensuring the continuity of the process; the content of several magnetrons with low-power air-cooled magnetrons; uniform defrosting of crushed frozen cow colostrum in one resonator at one dose of exposure, and heating in another resonator at a different dose of exposure; low-temperature disinfection of the product due to the high electric field strength; compliance with electromagnetic safety [8].
The purpose of the study is to develop and justify microwave installations of continuous-flow action for defrosting and heating cow colostrum while preserving the feed value at reduced operating costs in compliance with electromagnetic safety.

2. Materials and methods

In the basic version, colostrum was stored in plastic bottles with a volume of 1.5 l in the freezer at a temperature of \(-18 \pm 23 ^\circ C\) for 5 days. Colostrum was thawed and heated using BMA-50 equipment operating on the principle of a water bath. At the same time, the duration of defrosting and heating of 15 liters of colostrum from \(-6 ^\circ C\) to \(+40 ^\circ C\) was 90 min at a specific energy cost of 0.3 kWh/kg.

In the design version, colostrum with a fat content of 6.5% was stored in special bags in the freezer at a temperature of \(-18 \pm 23 ^\circ C\) for 5 days. They allow you to pour colostrum through a special valve and freeze in the form of briquettes, 3×3 cm in size, no more than two depths of penetration of the EMFV. Thawing of colostrum from \(-6 ^\circ C\) and heating to \(+40 ^\circ C\) was performed using a manufactured laboratory sample of a continuous-flow microwave installation with a biconic resonator that allows loading frozen colostrum briquettes through a truncated vertex, ensuring electromagnetic safety and separating processes. These studies allowed us to obtain regression models describing the relationship between the specific power, duration of exposure to EMF AND generator power with the performance of the microwave installation, energy costs and heating temperature. Effective modes of defrosting and heating cow colostrum: generator power 3.5-3.65 kW; plant capacity 25-30 kg/h; energy costs for the technological process 0.12-0.18 kWh/kg.

3. Results and discussion

We have developed more than 10 microwave installations continuous-flow action with unconventional resonators for defrosting and heating cow colostrum in continuous mode have been developed [9-14]. Below are described and analyzed some of them, designed for work in a farm.

Microwave installation with spherical and cylindrical resonators you can see on figure 2. It contains magnetrons located on the surface with a shift of 120°, and allows you to separate the processes of defrosting and warming up of cow colostrum, due to the location of the cylindrical perforated rotating resonator 4, where the cow colostrum is defrosting, inside the spherical resonator 3, which provides heating of the cow colostrum to 38 °C.

![Figure 2. Microwave installation with coaxially located resonators: a) a schematic representation; b) spatial image; 1 – receiving capacity; 2 – magnetrons; 3 – spherical resonator; 4 – cylindrical perforated rotating resonator; 5 – stationary bases; 6 – additional magnetron; 7 – fluoroplastic sleeve; 8 – transcendental waveguide with ball valve; 9 – fluoroplastic shaft.](image)

In a multi-generator installation, a rotating cylindrical perforated resonator is coaxially mounted along the horizontal axis of the spherical resonator. Such a separation of raw materials with different
patterns of change in dielectric parameters depending on the heating temperature (the factor of dielectric loss of the raw material increases from −10 to 0 °C and drops from 0 to 40 °C) can dramatically reduce the duration of the whole process, at different doses in coaxially located resonators. The advantage of this design is that the spherical resonator has the highest intrinsic Q factor, since it is known that the Q factor of a resonator will be the higher, the smaller its surface for a given volume. The technical characteristics are given in table 1. The carrying value of the designed microwave installation with four magnetrons and two resonators for defrosting and heating cow colostrum is 50,000 rubles.

Table 1. Technical characteristics of a microwave installation with two resonators.

| Parameters                                      | Value     |
|------------------------------------------------|-----------|
| Productivity, kg/h                              | 25–30     |
| Power consumption of microwave generators, kW (4 magnetrons of 0.8 kW each) | 3.2       |
| Fan motor power, kW                             | 0.2       |
| Centrifuge power, kW                            | 0.25      |
| Microwave power consumption, kW                 | 3.65      |
| Productivity, kg/h                              | 25–30     |

A feasibility study was carried out on the effectiveness of the implementation of this installation in farming. For the basic version, the installation was used, which is used on dairy farms to defrost the BMA-50 (a water bath for thawing colostrum) cow colostrum, with a book value of 112 thousand rubles. It is made in the form of a stainless steel tank, equipped with a control panel, a drum rotating from an electric motor, and electric heating elements for heating water up to 42 °C. Its technical characteristics are given in table 2. The results of the assessment of economic indicators of the installation of the basic and design options are shown in the form of a diagram figure 3.

Figure 3. Economic indicators of the use of installations of the design and basic options: 1 — installation cost, rubles; 2 — productivity, kg/h; 3 — power consumption, kW; 4 — specific energy costs, kW·h/kg; 5 — operating costs, rubles; 6 — the cost of defrosting colostrum, rubles/kg; 7 — the volume of output, kg/month; 8 — profitability, %.

When introducing a microwave installation for defrosting and heating cow colostrum, the annual economic effect due to lower operating costs is 153600 rubles. The profitability of the process will increase by 3.22 %, and the payback period will decrease from 9 to 4 months. Below is a description of the developed installations of other structural versions.
Table 2. Technical characteristics of BMA-50 P.

| Parameters                           | Value   |
|--------------------------------------|---------|
| Productivity, kg/h                   | 12      |
| Power, kWt                           | 6       |
| The working volume of the inner flask, l | 50      |
| Defrosting colostrum volume, l       | 12      |
| The duration of the defrosting process, min | 30      |
| Reboot time 30 min.                  | 30      |
| Specific energy costs, kW·h/kg       | 0.25    |
| Overall dimensions, mm               | 550×400×710 |

Microwave installation with a biconical resonator figure 4 can provide electromagnetic safety even without a shielding housing due to the special design of the resonator. From the theory of electromagnetic waves it follows that near the vertices of the biconus surfaces are formed where complete reflection of the waves is observed; therefore there is no radiation from the truncated open ends [15]. In the center of the resonator there is a perforated disk 5 in the ring gear 6. The lower truncated apex of the resonator is coupled to the transcendental waveguide 11. The main advantage of this design is the radio tightness when the critical section at the vertices of the bicone is correctly determined.

Figure 4. Microwave installation with a biconical resonator for thawing cow colostrum: 1 – capacity for frozen raw materials; 2 – ribbed rollers; 3 – biconical resonator; 4 – magnetrons; 5 – perforated disk; 6 – ring gear; 7 – a leading asterisk; 8 – electric drive; 9 – cylindrical container; 10 – tubular electric heater; 11 – transcendental waveguide; 12 – tap for draining the product; 13 – dielectric scraper.

Microwave installation with prismatic resonators you can see on figure 5. It is assembled from three hexagonal prismatic resonators arranged in tiers. The lower faces 5 of the first tier are perforated and are the faces of the corresponding prismatic resonators 7, 10 of the second tier. Dissectors 6 are located near each emitter. At the junctions of the lower faces of the prismatic resonators of the second tier there are slots 8 for draining thawed cow colostrum. Rotating finned rollers 2 are located inside the loading tank. The main advantages of the installation are the uniform distribution of the electromagnetic field in the resonator due to dissectors and the observance of electromagnetic safety.

Microwave installation with a ring resonator figure 6 allows you to separate the processes of thawing and heating of cow colostrum due to the compartments formed using dielectric perforated plates installed in the cross section of the resonator. Magnetrons are installed along the perimeter of the ring resonator with a shift of 120 degrees. The upper compartment is designed to defrost colostrum, and the lower
compartment is for warming up. The ring resonator allows you to separate the processes of thawing and heating of raw materials and performs the function of a shielding enclosure and a traveling wave field is excited in it. The resonator has a large intrinsic Q factor and provides in-phase wave addition.

![Figure 5](image1.png)

**Figure 5.** Microwave installation with prismatic resonators: 1 – capacity for receiving frozen raw materials; 2 – ribbed rollers; 3 – upper prismatic resonator; 4 – magnetrons from microwave generators; 5 – perforated edges of the resonator; 6 – dissectors; 7, 10 – lower prismatic resonators; 8 – slots in prisms for draining the product; 9 – electric drive.

![Figure 6](image2.png)

**Figure 6.** Continuous microwave installation with a ring resonator: 1 – receiving pipe; 2 – ring resonator; 3 – perforated dielectric disk; 4 – magnetrons; 5 – ball valve; 6 – transcendental waveguide.

Microwave installation with unconventional resonators you can see on figure 7. An analogue was the magnetron resonator block, where not individual resonators are used, but a chain of resonators connected to each other, for example [1]. It is a chain of slit-hole resonators rolled into a ring. The connection between the resonators is through open ends and slots. If the first resonator is excited, then the microwave energy will not remain in it, but through the neighboring hole it enters first into the second resonator, then into the third, etc. In this magnetron resonator [2], the capacities play the role of gaps in each cell, and cylindrical volumes are the inductance and the magnetic field is concentrated in them. As a result of such a constructional design of the resonator chamber, it becomes possible to uniformly thaw and heat the raw materials by controlling the power of individual generators that excite the EMF microwave in non-traditional resonators, which are located half-way in a continuous installation. The microwave installation consists of an inner 2 and an outer shielding 14 cylinders arranged coaxially in a vertical plane. In the annular space, a distance multiple of half the wavelength, the non-ferromagnetic half cylinders 1 are vertically evenly distributed along the perimeter with slots in the side surfaces along the entire height, the open part to the shielding outer cylinder, divided in height into the upper and lower tiers 5 using perforated non-ferromagnetic bases 7.

Dielectric plates 3 are inserted along the side surface of the inner non-ferromagnetic cylinder 2 uniformly around the perimeter, closing the slots on the side surfaces of the non-ferromagnetic half
cylinders, ranging in size from a quarter to half a wavelength. A gap on the side surface of each half cylinder is formed in place contact with the surface of the dielectric plates. In the halves of the inner cylinder separated by a non-ferromagnetic perforated disk 6, there are emitters with magnetrons 4 from microwave generators. The volumes enclosed between the lateral surfaces of the half-cylinders, dielectric plates on the inner cylinder, perforated non-ferromagnetic bases, the lateral surface of the shielding outer cylinder and its lower 8 and upper 15 bases form a tiered array of unconventional resonators 5. A storage tank 10 is installed under the lower base 8 of the outer cylinder 14 with a common ball valve 11. The Central part 13 of the lower base of the cylinder is perforated, and on the periphery under each resonator 5 n lower pole disposed tiers ball valves 9. Inside the storage tank situated on the center non-ferromagnetic additional cylinder containing a fan 12 to the motor and the air directed towards the inner cylinder 2.

![Diagram](image)

**Figure 7.** Microwave installation with unconventional resonators: 1 – half-cylinders with slots in the side surfaces; 2 – inner cylinder; 3 – side dielectric plates; 4 – emitters; 5 – upper and lower tiers of the chains of resonators; 6 – non-ferromagnetic perforated disk; 7 – non-ferromagnetic perforated bases of the resonators; 8 – the bottom base of the shielding cylinder; 9 – ball valves; 10 – storage capacity; 11 – a common ball valve; 12 – fan; 13 – perforated part of the cylinder; 14 – shielding outer cylinder; 15 – the upper base of the cylinder; 16 – intermediate capacity; 17 – spherical segment; 18 – a scraper; 19 – receiving capacity.

Above the upper base of the outer cylinder, an intermediate non-ferromagnetic cylindrical tank 16 is installed with scrapers rotating in it from the electric motor 18. The radius of the upper base 15 is a quarter of the wavelength smaller than the radius of the shielding outer cylinder. Above the tank 16, a tank 19 is installed in the form of a truncated cone without bases, where at the level of its small diameter a non-ferromagnetic ball segment 17 with an electric motor inside is located with a gap from the scrapers. The diameter of the base of the spherical segment is larger than the diameter of the inner non-ferromagnetic cylinder 2.

The technological process is as follows. Freeze cow colostrum in molds with lids (for example, in molds for freezing ice). In this case, the size of the cells of the form should not exceed two depths of penetration of the wave of the centimetre range. Turn on the fan to cool the magnetrons. Close all ball valves and turn on the scraper motor and pour the frozen raw material from the molds into the receiving tank 19. Frozen colostrum in cubes enters through the annular gap between the ball segment and the receiving non-ferromagnetic tank into the upper resonators using a rotating scraper. Then turn on the microwave generators. Each magnetron excites EMFs in the resonators of the corresponding tier. This is due to the fact that along each side surface of the half cylinder there is a gap covered by a dielectric plate. In the resonators, pieces of frozen cow colostrum are exposed to EMPS of a certain specific power, thawed, and the liquid flows through the perforated bases of the resonators into the resonators of the second tier. Here colostrum warms up to a temperature of 38 °C, but with a different specific power.
4. Conclusions
In all multi-generator installations for thawing and warming cow colostrum, the scientific component is that they contain two resonators each, which provide the corresponding EMF-U exposure modes to accelerate the entire technological process in a continuous mode, which preserves the feed value of the product at reduced operating costs. Colostrum is thawed in a gentle mode, evenly, while maintaining useful trace elements. The preparation time for colostrum for feeding calves is much reduced. The design of the resonators provides electromagnetic safety without an additional shielding housing.

Effective modes of defrosting and warming up cow colostrum in EMFHF [16]: duration of exposure to EMFHF in the cavity 12 min; power of microwave generators 3.5–3.65 kW; plant productivity 25–30 kg/h; energy costs for the technological process 0.12–0.18 kW∙h/kg, heating temperature of raw materials to 38–40 °C. One microwave installation for defrosting and heating is enough for a cattle farm up to 600 heads, depending on the uniformity of calving.

References
[1] Atuonwu J C and Tassou S A 2018 Quality assurance in microwave food processing and the enabling potentials of solid-state power generators: A review. *Journal of Food Engineering* 234 15 DOI: 10.1016/j.jfoodeng.2018.04.009
[2] Tushar G, Huacheng Z, Ashim K D and Kama H 2015 Microwave drying of spheres: Coupled electromagnetics-multiphase transport modeling with experimentation. Part II: Model validation and simulation results. *Food and Bioproducts Processing* 96 326 DOI: 10.1016/j.fbp.2015.08.001
[3] Donglei L, Juming T, Patrick D P, Frank L and Zhongwei T 2016 Analysis of electric field distribution within a microwave assisted thermal sterilization (MATS) system by computer simulation. *J. of Food Eng.* 188 87 DOI: 10.1016/j.jfoodeng.2016.05.009
[4] Tianyi S, Zhijun Z, Jingxue H, Shiwei Z, Xiaowei W and Wenqing Z 2020 Sensitivity analysis of intermittent microwave convective drying based on multiphase porous media models. *Int. J. of Thermal Sci.* 153 106344 DOI: 10.1016/j.ijthermalsci.2020.106344
[5] Campaño C A and Zaritzky N E 2005 Mathematical analysis of microwave heating process. *J. of Food Eng.* 69(3) 359 DOI: 10.1016/j.jfoodeng.2004.08.027
[6] Guido S J, Martin D V, Andrzej I S and Georgios D S 2012 On the effect of resonant microwave fields on temperature distribution in time and space. *International Journal of Heat and Mass Transfer* 55(13–14) 3800 DOI: 10.1016/j.ijheatmasstransfer.2012.02.065
[7] Mohammad R H, DoY B and Prashanta D 2010 Analysis of microwave heating for cylindrical shaped objects. *International Journal of Heat and Mass Transfer* 53(23–24) 5129 DOI: 10.1016/j.ijheatmasstransfer.2010.07.051
[8] Resurreccion F P Jr, Luan D, Tang J, Liu F, Tang Z, Pedrow P D and Cavaliere R 2015 Effect of changes in microwave frequency on heating patterns of foods in a microwave assisted thermal sterilization system. *J. of Food Eng.* 150 99 DOI: 10.1016/j.jfoodeng.2014.10.002
[9] Budd C J and Hill A D 2011 A comparison of models and methods for simulating the microwave heating of moist foodstuffs. *International Journal of Heat and Mass Transfer* 54(4) 807 DOI: 10.1016/j.ijheatmasstransfer.2010.10.022
[10] Jinghua Y, Junqing L, Yuan X, Yang Y, Huacheng Z and Kama H 2019 An approach for simulating the microwave heating process with a slow-rotating sample and a fast-rotating mode stirrer. *International Journal of Heat and Mass Transfer* 140 440 DOI: 10.1016/j.ijheatmasstransfer.2019.06.017
[11] Ershova I G, Poruchikov D V, Novikova G V, Vasiliev A N and Belova M V RU Patent No. 2694944 (12 Desember 2018)
[12] Kumar C, Joardder M U, Farrell T W, Millar G J and Karim M A 2016 Mathematical model for intermittent microwave convective drying of food ma trials. *Drying Technology* 34(8) 962 DOI: 10.1080/07373937.2015.1087408
[13] Rudobashta S P, Zueva G A and Kartashov E M 2016 Heat and mass transfer when drying a
spherical particle in an oscillating electromagnetic field. *Theor. Found. Chem. Eng.* **50**(5) 718 DOI: 10.1134/S0040579516050365

[14] Spyridon D, Anand N P, Georgios D, Junwang T and Asterios G 2019 Experimental and computational investigation of heat transfer in a microwave-assisted flow system. *Chemical Eng. and Proces.– Process Intensification* **142** 107537 DOI: 10.1016/j.cep.2019.107537

[15] Mirian T K, Érica S S, Eduardo S F, Pedro E A, Sébastien C, Lionel B, Sudhir K S and Jorge A G 2020 Non-thermal effects of microwave and ohmic processing on microbial and enzyme inactivation: a critical review. *Current Opinion in Food Science* **35** 36 DOI: 10.1016/j.cofs.2020.01.004

[16] Wenjia Z, Donglei L, Juming T, Shyam S S, Barbara R, Huimin L and Fang L 2015 Dielectric properties and other physical properties of low-acyl gellan gel as relevant to microwave assisted pasteurization process. *J. of Food Eng.* **149** 195 DOI: 10.1016/j.jfoodeng.2014.10.014