Electrotechnology of animal colostrum defrosting in two-resonator microwave installations

M Prosviryakova1,*, I Ershova2, O Mikhailova3, G Novikova1, D Tarakanov4 and G Samarin5

1Department “Information, Communication Technologies and Communication Systems”, Nizhny Novgorod State Engineering and Economic University, 22 a Oktyabrskaya Street, 606340, Knyaginino, Russian Federation
2Laboratory of Electrophysical Influence on Agricultural Objects and Materials, Federal Scientific Agroengineering Center VIM, 5 Institute Passage, 109428, Moscow, Russian Federation
3Department ‘Electrification and Automation”, Nizhny Novgorod State Engineering and Economic University, 22 a Oktyabrskaya Street, 606340, Knyaginino, Russian Federation
4Department “Labor Protection and Life Safety”, Nizhny Novgorod State Engineering and Economic University, 22 a Oktyabrskaya Street, 606340, Knyaginino, Russian Federation
5Department of Energy Supply of Agriculture, State Agrarian University of the Northern Trans-Urals, 7 Republic Street, 625003, Tyumen, Russian Federation

*E-mail: ProsvirykovaMV@ngieu.ru

Abstract. The article is devoted to the development of the plants for defrosting and heating animal colostrum. The idea is that the plant should contain two cavities that provide different levels of an ultra-high frequency electromagnetic field exposure on colostrum, which differs in the aggregate state. A laboratory sample of the plant with conical cavities having a common perforated base was constructed. With the help of the plant the technological parameters of cow colostrum defrosting and heating were processed. Analyzing the developed installations with two resonators, from the point of view of the implementation of the main technological criteria, a design with quasi-stationary toroidal resonators connected by a common perforated base is proposed as the most effective. In the condense parts of both cavities, a high-voltage electric field is fed, which is sufficient for a low-temperature bacterial contamination reduction of the fodder product.

The use of an installation for defrosting and heating colostrum of animals on farms in rural area will reduce the heating time, preserve the useful properties of colostrum.

1. Introduction

Traditional equipment for colostrum defrosting does not allow full preserving the nutrition value of animal colostrum due to the process duration [1-4]. The principle of its operation is to provide a water bath to submerge plastic bottles with frozen raw materials. The speed of colostrum defrosting and heating is 40-90 minutes, which does not allow full preserving the colostrum nutrition value [5-7].

The purpose is that the plant should contain two cavities that provide different doses of exposure to the ultrahigh frequency electromagnetic field (UHF EM field) on colostrum, which differs in the aggregate state. One cavity is designed for defrosting colostrum at a temperature from -15 to 0 °C, the
other cavity is designed for heating up to +38 °C. The cavities are supposed to separate the solid and liquid phases of the raw material at a temperature equal to one of the phase transformation. This follows from the analysis of the colostrum dielectric characteristics; the nature of its changes is the opposite at negative and positive temperatures [8-10]. So, the factor of colostrum dielectric losses, at a temperature from -10 to 0 °C, increases from +4 to +27 °C, i.e. the power absorbed by the raw material during defrosting increases several times. When the colostrum is heated from 0 to +38 °C, on the contrary, the dielectric loss factor decreases, i.e. the absorbed power decreases while temperature increases, which means the heating process is longer than the defrosting, so it is necessary to provide a different dose of UHF EM field exposure in the second cavity. Only the separation of these processes in different cavities will drastically reduce the duration of the entire technological process and will preserve the nutrition value of animal colostrum.

To implement the purpose, it is necessary:

1. To justify the design of the resonant cavities of the microwave plant of continuous-flow action for animal colostrum defrosting and heating at reduced operating costs compared to the basic colostrum defrosting.
2. To make laboratory sample of the microwave plant to adjust its theoretically justified operating modes, which ensures the preservation of the colostrum nutrition value after defrosting and heating.

The scientific novelty is represented by the design of cavities of radio-hermetic multigenerator microwave plants of continuous-flow action, which allow implementing the technology of colostrum defrosting and heating while preserving its nutrition value in accordance with the nature of changes in the raw materials dielectric characteristics at a frequency of 2450 MHz in the range of negative and positive temperatures [7].

The authors propose several installations, the novelty of which is confirmed by patents. This allows farmers to choose a suitable installation design for thawing and heating colostrum of animals.

2. Materials and methods

To study the effectiveness of the structure implemented in the metal, cow colostrum with a fat content of 4.5-6.4%, a density of 1.06-1.05 g/cm³ and an acidity of 50 °T was taken from clinically healthy cows in JSC “Bazinskoe” Nizhny Novgorod region. Colostrum was selected according to GOST. On the farm, the volume of thawed raw materials reaches up to 10 thousand liters per year. The method used. The raw materials were frozen to -10 °C in special plastic bags in the form of briquettes with a size of 2x4x2 cm. The temperature of the raw materials in the microwave electromagnetic field was controlled by a Testo 925 pyrometer (Germany), the distribution of heat flow over the surface of the raw materials was controlled by a FLIRi335 thermal imager (Flir Systems, USA, Sweden). The dose control of the microwave electromagnetic field exposure to raw materials was carried out on the basis of measurements of the electric field strength near the laboratory sample at a frequency of 2450 MHz by the electromagnetic radiation meter – PZ – 31 (Russia). The research methods are described in detail in other works of the authors listed on elibrary.ru. We have modeled the resonators in the CST STUDIO SUITE (Dassault Systemes) program.

3. Results and discussion

Taking into account the following requirements, the authors have developed continuous-flow microwave installations with various non-traditional resonators for thawing and heating colostrum of animals.

The criteria for a flow-through microwave installation for the implementation of the technology of defrosting and heating of colostrum of animals are as follows:

1) the variability of the plant efficiency when using low power air cooled magnetrons which have the emitters directed to the cavities;
2) the uniformity of frozen colostrum defrosting from -15 to 0 °C in one cavity and heating of liquid colostrum to +38÷(+40) °C in the other one;
3) low-temperature colostrum disinfection due to the high electric field strength in the cavities;
4) different doses of UHF EM field exposure for colostrum defrosting in one cavity and its
reheating in another one;
5) radio leak resistance of the plant.

Taking into account such criteria, continuous-flow microwave installations with various
unconventional resonators for defrosting and heating of colostrum of animals have been developed.

The authors analyzed the features of the developed non-traditional cavities of different structural
designs.

A microwave plant with a ring cavity makes it possible to separate the processes of defrosting and
reheating of animal colostrum due to compartments formed using dielectric perforated plates as figure
1. The cavity provides the in-phase waves addition. The ring cavity performs the function of a shield
and a traveling wave field is set up in it. The disadvantage is that the exposure dose remains constant
in both units.

![Figure 1](image1.png)

**Figure 1.** The design of a microwave plant with a ring cavity: 1 – inlet nozzle, 2 – ring
cavity, 3 – dielectric perforated disc, 4 – magnetrons, 5 – ball valve, 6 – below
cutoff waveguide.

![Figure 2](image2.png)

**Figure 2.** The design of a microwave plant with a biconic cavity: 1 – container for frozen
raw materials, 2 – finned rollers, 3 – biconic cavity, 4 – magnetrons, 5 – dielectric
perforated disc, 6 – gear rim, 7 – drive sprocket, 8 – electric drive, 9 – cylindrical
container, 10 – electric heating tube, 11 – below cutoff waveguide, 12 – drain
valve for colostrums, 13 – dielectric scraper.

Microwave plant with the biconic cavity is demonstrated in figure 2. In the center of the cavity
there is a perforated dielectric disk in a gear rim, which separates the liquid fraction of colostrum from
the frozen raw materials. The disadvantage is that the dose of UHF EM field exposure is the same in
both cones.

Microwave plant with prismatic cavities as figure 3 is assembled from three hexagonal prismatic
cavities arranged in tiers. The lower faces of the first tier are perforated and are the faces of the
corresponding prismatic cavities 7, 10, having a common face. Dissectors 6 are located near each
emitter. At the joints of the lower faces of the second tier prismatic cavities, there are slits 8 for
draining defrosted colostrum. The rotating finned rollers 2 are located inside the loading container.

A microwave plant with coaxially arranged spherical and cylindrical cavities makes it possible to
separate the processes of cow colostrum defrosting and heating, due to the placement of a cylindrical
perforated rotating cavity inside a spherical cavity as figure 4. The disadvantage is that there is no
uniform distribution of EM field in the spherical cavity due to the location of the cylindrical one inside it.

**Figure 3.** Microwave plant with prismatic cavities: 1 – container for raw materials loading, 2 – finned rollers, 3 – upper prismatic cavity, 4 – magnetrons, 5 – perforated cavity faces, 6 – dissectors, 7, 10 – lower prismatic cavities, 8 – prisms slits for product draining, 9 – electric drive.

**Figure 4.** The design of a microwave plant with coaxially arranged spherical and cylindrical cavities: 1 – receiving container, 2 – magnetrons, 3 – spherical cavity, 4 – cylindrical perforated rotating cavity, 5 – stationary base stands, 6 – additional magnetron, 7 – fluoroplastic plug, 8 – below cutoff waveguide with a ball valve, 9 – fluoroplastic shaft.

The microwave plant with non-traditional resonators as figure 5 consists of an internal 2 and an external shielding 14 cylinders arranged coaxially.

**Figure 5.** The microwave plant with non-traditional resonators: 1 – non-ferromagnetic semi-cylinders, 2 – non-ferromagnetic internal cylinders, 3 – dielectric plates, 4 – emitters, 5 – upper and lower cavities tiers, 6 – non-ferromagnetic perforated disc, 7 – perforated cavities bases, 8 – lower base of the shield cylinder, 9 – ball valves, 10 – storage container, 11 – major ball valve, 12 – fan, 13 – perforated part of the shield cylinder lower base, 14 – external shield cylinder, 15 – upper base of the shield cylinder, 16 – intermediate container, 17 – ball segment, 18 – scraper, 19 – receiving container.
In the inner ring space, non-ferromagnetic semi-cylinders 1 are installed with slits in the side surfaces along the entire height. The cylinder 14 is divided into upper and lower tiers 5 by means of perforated bases 7. In the separated halves of the inner cylinder 2 there are emitters. Advantages are the possibility to carry out the technological processes of cow colostrum defrosting and heating in separate cavities with different specific power and exposure duration to UHF EM field; the combining the cavity with the function of a shield; the ability to provide standing waves in several cavities from a single emitter. The disadvantage is the design complexity.

The microwave plant with conical cavities as figure 6 and a common perforated base provides a dosed effect of UHF EM field on frozen and heated colostrum separately. The magnetrons are located near the base with a shift so that some emitters are directed to the upper cavity, and others – to the lower cavity.

![Figure 6](image)

**Figure 6.** The microwave plant with conical cavities: (a) laboratory sample; (b) technological design: 1 – truncated conical cavities, 2 – non-ferromagnetic perforated base stand, 3 – ball valve, 4 – scraper, 5 – magnetrons.

For the performance test, the proposed design was made in metal as a laboratory sample. Frozen briquetted colostrum was loaded into the unit of no more than two wave penetration depths size (3 cm) are loaded through the truncated top of the upper cavity, where colostrum is defrosted at a single dose of UHF EM field exposure. Next, the liquid colostrum fraction seeps through the perforated non-ferromagnetic base into the lower cavity, where it is exposed to the UHF EM field effect of a different dose. The cones vertices are truncated at the level of the critical section, where there is a complete waves reflection towards the base of the cone, so there is no radiating from the truncated open ends. This ensures the electromagnetic safety of a continuous-flow plant without a shielding body.

In the cavities, the raw material is exposed to UHF EM field in different effective doses, colostrum is defrosted from -10°C to 0°C in one cavity and heated to +38÷(+40)°C in another one, where a high electric field strength is created for low-temperature colostrum disinfection. Using the created laboratory sample as figure 6 (a), the technological parameters of processing cow colostrum with a fat content of 4.5-6.4% were corrected (figure 6 (b)). Effective modes of defrosting and heating of cow milk are: duration of exposure is 12 min; power of generators is 3.2 kW; plant capacity is up to 40 kg/h; energy costs for the technological process are 0.175 kWh/kg, temperature change of raw materials from -10 °C to +38÷(+40) °C.

The microwave plant with quasi-stationary toroidal cavities as figure 7 contains two vertically mounted quasi-stationary toroidal upper and lower cavities docked with a common perforated base. A dielectric mixing mechanism is installed above the perforated base. In the central part of the upper cavity, the discharge screw of the grinding mechanism is installed. A dielectric plate is installed in the condensing part of the lower cavity. Magnetrons are installed on the cavities surfaces with a shift of
120 degrees in the area of their condensing parts. In the condensing parts of both cavities, a high-voltage electric field is set up, sufficient for a low-temperature bacterial contamination reduction of the fodder product.

![Figure 7](image)

**Figure 7.** The microwave plant with quasi-stationary toroidal cavities: (a) general view; (b) technology scheme: 1 – grinding mechanism, 2 – discharge screw, 3 – knife and grill, 4 – upper cavity, 5 – lower cavity, 6 – ball valve, 7 – lower cavity condensing part, 8 – dielectric plate with no bottom, 9 – magnetrons on the lower cavity surface, 10 – magnetrons on the upper cavity surface, 11 – common perforated base of both cavities, 12 – upper cavity condensing part; 13 – mixing mechanism.

### 4. Conclusion

The implementation of electrical technology in a two-resonator installation is possible, which is proved by the manufacture of one of the structures in metal. Tests of the plant showed the following results: colostrum is thawed in a gentle mode, evenly with the preservation of feed value. Effective modes of defrosting and heating of cow milk are: duration of exposure is 12 min; power of generators is 3.2 kW; plant capacity is up to 40 kg/h; energy costs for the technological process are 0.175 kWh/kg, temperature change of raw materials from -10 °C to +38+/+(+40) °C.

This will allow farmers of rural area to choose a suitable installation design for thawing and heating colostrum of animals. The economic effect of using a microwave plant is achieved by reducing operating costs at the level of 250,000 RUB a year with the amount of product 3600 l/year.

### 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. *J. Food Eng.* **234** 15 doi: 10.1016/j.jfoodeng.2018.04.009

[2] Tushar G, Huacheng Z, Ashim K and Kama H 2015 Microwave drying of spheres: Coupled electromagnetics-multiphase transport modeling with experimentation. PartII: Model validation and simulation results. *Food Bioprod. Process.* **6** 326 doi: 10.1016/j.fbp.2015.08.001

[3] Donglei L, Juming T, Patrick D, Frank L and Zhongwei T 2016 Analysis of electric field distribution within a microwave assisted thermal sterilization (MATS) system by computer simulation. *J. 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. Therm. Sci.* **153** 106344 doi: 10.1016/j.ijthermalsci.2020.106344

[5] Campañone L A and Zaritzky N E 2005 Mathematical analysis of microwave heating process. *J. 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. *Int. J. Heat and Mass Trans.* 55(13) 3800 doi: 10.1016/j.ijheatmasstransfer.2012.02.065

[7] Novikova G V, Mikhailova O V, Prosviryakova M V, Tikhonov A A, Tarakanov D A, Dulepov D E and Kirillov N K 2020 Installations for defrosting and warming colostrum in continuous mode: *IOP Conf. Ser.: Earth Environ. Sci.* 604 012007 doi:10.1088/1755-1315/604/1/012007

[8] Kumar C, Joardder M, Farrell T, Millar G and Karim M 2016 Mathematical model for intermittent microwave convective drying of food materials. *Dry. Technol.* 34(8) 962 doi: 10.1080/07373937.2015.1087408

[9] 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

[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. *Int. J. Heat Mass Tran.* 140 440 doi: 10.1016/j.ijheatmasstransfer.2019.06.017