Study of the process of infrared drying of lactic starter cultures

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Abstract. An assessment of the current state of the Russian lactic starter market is given, which reflects the dependence on imported raw materials mainly from European manufacturers. To reduce dependence and ensure food security during the sanction period, the scientific and technical community of the Russian Federation has been set with a task to create technologies that allow obtaining high-quality lactic starter cultures and fermented products based on them. The article discusses the drying of lactic starter culture to increase storage terms and conditions. An important point in the dehydration process is the preservation of biologically active substances (lactic acid organisms, bifidobacteria) in the starter dry residue. The basic technologies of starter culture drying are considered, an alternative technology of IR radiation with the use of membranous electric heaters is proposed. The experimental kinetic dependences and the equation of the drying process of lactic starter cultures were obtained on the manufactured laboratory stand. Laboratory tests of the dried starter culture showed full compliance of the content of biologically active substances with the starting material, GOST RF and a high degree of recoverability, which indicates the feasibility of developing IR radiation technologies and introducing them into the processing of lactic and lactic acid raw materials.

1 Introduction

To date, the lactic starter market is going through one of the most difficult periods. According to various economic publications, the import share of lactic starter cultures in the Russian Federation at the end of 2021 is about 88%, which characterizes the industry as import-dependent. The capacity of the entire market is estimated at about 10 billion rubles, but domestic producers account for only 1.2 billion rubles, or 12%. There are very few large companies engaged in the production of lactic starter cultures. As of 2021, there are only 7 such companies registered. According to Rosstat, the import of lactic starter cultures in the Russian Federation is constantly increasing every year, but since 2018 there is a tendency to this indicator decrease (Fig. 1).

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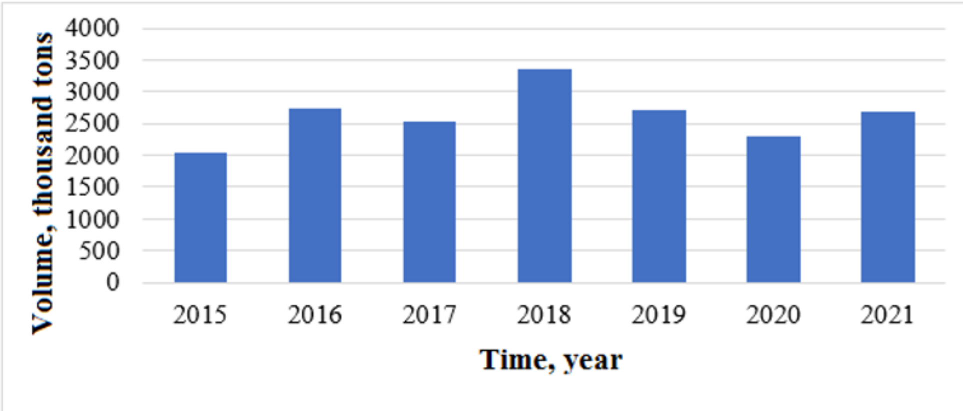

Fig. 1. Dynamics of import of lactic starter cultures by volume.

The main suppliers of lactic starter cultures in the Russian Federation are European countries (Italy and Denmark). Reducing dependence on European raw materials is a priority for the development of the dairy industry within the food security framework. The need to create domestic technologies that make it possible to obtain a high-quality product and compete with foreign companies is especially relevant in 2022. During the period of severe sanctions restrictions, the lactic starter market, more than ever, needs both a scientific-technical and economic breakthrough [1].

The production of dairy starter cultures is a rather complex technological process consisting of many stages. The product is perishable, therefore it requires special low-temperature storage conditions (from +2°C to +6°C); nevertheless, even if they are observed, the shelf life of the finished product is not long (up to 14 days), which determined a new vector of the dairy industry development - dry starter cultures as an innovative probiotic product. High biochemical activity allows their direct introduction into milk. One of the most important stages of obtaining the final product is the drying stage.

Drying allows to reduce significantly the volume of the prepared product. Starters in dry form are ten times smaller in volume than in liquid form, and does not require special storage equipment. Enterprises save a large amount of resources thanks to this storage method. During drying process, it is necessary not only to reduce the volume, but also to preserve all beneficial microorganisms, as well as to prevent pathogenic microflora development. Therefore, it is important to choose the optimal dehydration process parameters, allowing to get a high-quality product. Currently, two drying methods are widely used: convective and conductive [2,3].

These technologies have a number of disadvantages that affect the final product quality. This is due to the high process temperature, while local overheating of the product occurs, which is equal to a decrease in quality. If to try to reduce the temperature, in this case, the efficiency of these drying methods decreases, as a result, electricity consumption increases significantly. Today IR drying is of particular interest, due to the use of dark low-temperature radiation generators, or due to the organization of oscillating modes by lighter generators. Another advantage of IR radiation is the insecticide properties, thanks to which the development of pathogenic microflora is prevented, which makes it possible not to use additional disinfection measures during the drying of lactic starter cultures. [4-7].

2 Materials and Methods

According to the drying kinetics, the dehydration process occurs according to a certain pattern (Fig. 1) [8-10].

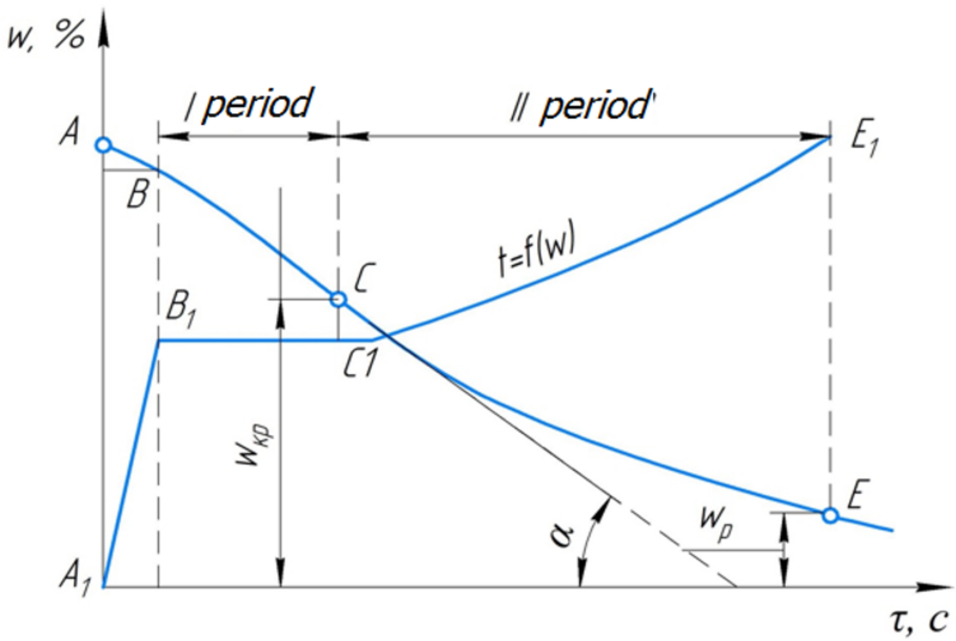

Fig. 2. Drying curve describing the process of product dehydration.

A typical drying curve consists of several sections corresponding to different drying periods. After the period of warming up the material to the drying temperature (section A_1B_1), a period of constant drying rate (I period) occurs. During this period, the temperature of the material takes a value equal to the wet thermometer temperature t_m (segments (B_1C_1).

During the period of constant drying rate, the heat supplied to the material is spent on the free moisture evaporation. The period of constant drying rate is represented by a straight line with a constant inclination angle tangent (BC segment). This period continues until the first critical moisture w_{kp} is reached. Starting from w_{kp}, there comes a drooping speed period (period II). In this period, the decrease in the moisture content of the material is expressed by the CE curve.

During the period of decreasing speed, the bound moisture is removed and the material temperature increases along the curve from C_1E_1. At the end of drying, the moisture content of the material asymptotically approaches the equilibrium moisture w_p. When the equilibrium moisture is reached, the removal of moisture from the material stops. At this moment, the material temperature reaches a value equal to the temperature of the coolant surrounding the material (point E_1). Nevertheless, it takes considerable time to achieve equilibrium moisture. The drying rate is a change in moisture content per time unit: $\frac{dw}{d\tau}$, %/h [8].

For practical use, it is interesting to obtain the main points for the product under study, these points can determine the main parameters of drying, primarily the period duration. Depending on the period, the temperature of exposure to the drying object may be different. When removing free moisture, the temperature may not significantly affect the destruction of biologically active components, respectively, it may be higher than the limit value, which will contribute to the process intensification. Nevertheless, when the second period is reached, the temperature should be lowered to the limit values, since the removal of bound moisture begins, which means that the molecular structure of some substances in the product may be destroyed, as a rule, biologically active useful substances die first, for lactic starter cultures these are primarily lactic acid organisms and bifidobacteria.

To study the drying of lactic starter cultures with the use of IR radiation, studies have been carried out, including two stages. The first stage included studies of the drying kinetics and obtaining process control points, according to the theoretical curve (Fig. 2). The second stage included a study of qualitative indicators of dry lactic starter culture in a specialized laboratory.

As a study product, a lactic starter was selected by the production company JSC "Group of Companies "Russian Milk", produced under the trademark "First Taste". According to the data on the packaging and technical specifications (TU 10.51.52-008-51469499-2019) it follows that this is a fermented milk product intended for direct consumption, it includes: normalized milk, fermentation starter of lactic acid bacteria, B.Adolescentis bifidobacteria concentrate, vitamin complex (A, E, D_3, B_6). The number of lactic acid organisms is not less than $1\cdot10^8$ CFU/g, the number of bifidobacteria is not less than $1\cdot10^6$ CFU/g. Nutritional value (content in 100 g of the product): protein – 3.0 g, fat – 1.0 g, carbohydrates – 4.0 g. The energy value is 37 kcal [11].

For the first stage, a laboratory stand was made, its appearance and block diagram are shown in Figure 3.

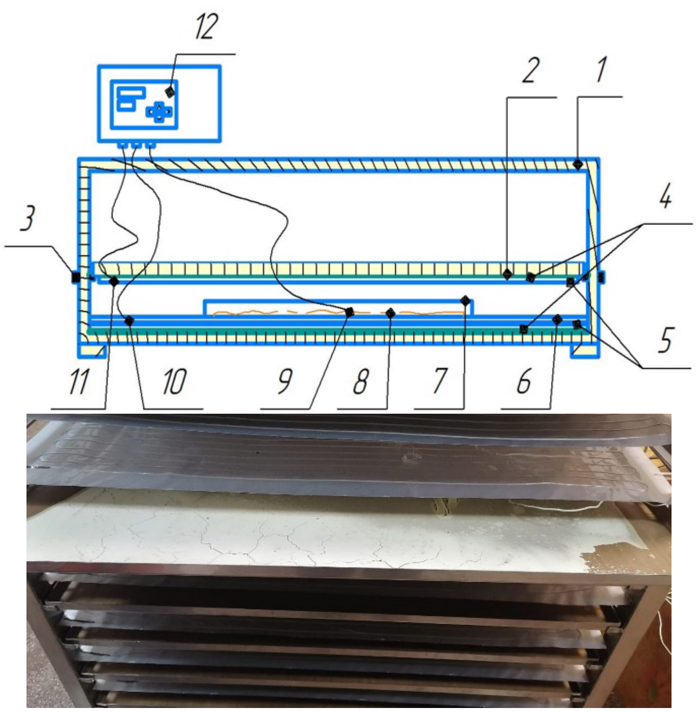

Fig. 3. Appearance and block diagram of the laboratory stand: 1 – housings; 2 – caps; 3 – bolts for adjusting the cap height; 4 – insulation with a reflective surface; 5 – membranous electric heater; 6 – fluoroplastic; 7 – molds for product pouring; 8 – lactic starter (product); 9 – product temperature sensor; 10 – temperature sensor of membranous electric heater, installed at the bottom of the unit; 11 – temperature sensor of the membranous electric heater installed on the cap; 12 – temperature meter-controller.

In the laboratory stand, previously published research results were considered, in which it was proved and justified:

1. Application as an IR radiation generator of low-temperature membranous electric heaters for drying food raw materials containing biologically active components, including for liquid and pasteous media [4,12];
2. The emitter and the reflector between which the product is located must be active – this will ensure a uniform distributed exposure to IR radiation, which will contribute to the drying process intensification [13];
3. It is necessary to install a fluoroplastic substrate between the liquid product and the membranous electric heater, thereby avoiding the adhesion of the product to the surface of the membranous electric heater during dewatering, and the fluoroplast optical properties will contribute to the drying process intensification by increasing the radiation flux density [14].

To obtain the drying kinetics curve using IR radiation, OVEN TRM-138 temperature and moisture control meter and Owen OPC Server software were used [15]. During the experiment, the drying process was controlled by the temperature of the membranous electric heaters 10 and 11 (Fig. 3). The temperature of the film electric heater was maintained at 40°C with a hysteresis of 1°C, which corresponds to the limit value for lactic starter culture, at which the destruction of microorganisms and bacteria is excluded [16]. The temperature of the product 9 did not participate in the drying process control, but the values of this parameter were fixed at intervals of 5 minutes, in the end they will determine the convergence with the theoretical curve.

The product moisture during the drying process was determined using the moisture analyzer "Elviz-2C", for which samples were taken at regular intervals during the entire drying process and moisture measurements were made for each.

The second stage involved comparing the content of bifidobacteria and lactic acid microorganisms in the initial liquid material of the lactic starter and in the dried material of the lactic starter. Samples for laboratory testing were delivered to the FBHI Center for Hygiene and Epidemiology in the Chelyabinsk Region to obtain quantitative indicators of the content of bifidobacteria and lactic acid microorganisms in accordance with GOST.

3 Results and Discussion

According to the results of the experiment, the dependences of the drying process of the lactic starter are obtained, according to which the main points of the curve for this product are determined (Fig. 4).

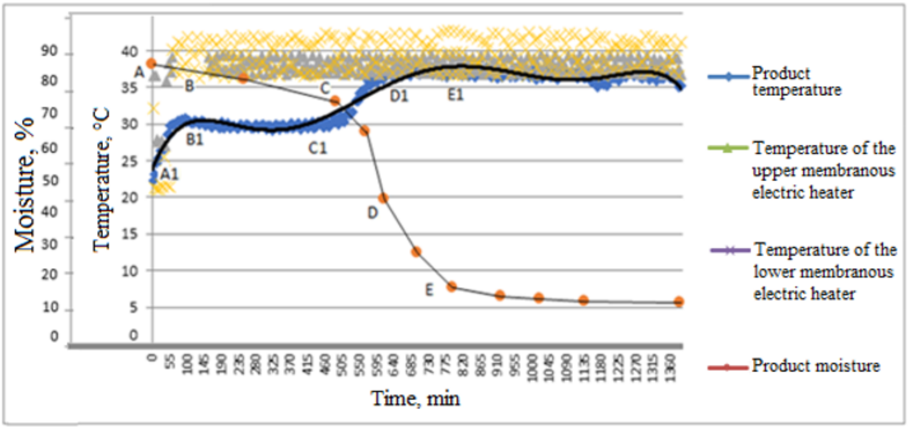

Fig. 4. Temperature and moisture content characteristics of the drying process of lactic starter culture.

The segment A_1B_1 corresponds to the product heating. This stage is characterized by rapid heating of the product to a temperature of 30°C for 1 hour 20 min. Then comes the I period of constant drying speed, at which the temperature of the product practically does not change over time (segment B_1C_1). This stage takes place at a steady temperature during the heating process equal to 30°C and lasts 7 hours and 15 minutes. This period continues until the first critical moisture is equal to 77.8%. Then the II period begins, marked by the segment C_1D_1. This period is characterized by a more abrupt heating of the product to a heater temperature equal to 37°C. In this section, it can be seen that the temperature at point D_1 has reached the temperature of the electric heater and practically does not change in the future; nevertheless, to complete the drying process of lactic starter cultures, it is most rational to continue the drying process to point E_1, since the product when it reaches point D_1 has a high moisture content, about 20%, but in the future the moisture indicator decreases exponentially.

By processing the obtained experimental values, polinomial approximation, an equation of the sixth degree (1) for the temperature curve of the product (lactic starter) was obtained:

$$y = -1E\text{-}14x^6 + 3E\text{-}11x^5 - 3E\text{-}08x^4 + 1E\text{-}05x^3 - 0{,}0025x^2 + 0{,}222x + 23{,}669 \qquad (1)$$

This equation will be useful when designing algorithms for automatic control systems for the drying of lactic starter cultures in a drying plant using low-temperature membranous electric heaters.

Samples of dried and initial liquid lactic starter material delivered to the laboratory center of the FBHI Center for Hygiene and Epidemiology in the Chelyabinsk Region, where, according to regulatory documents and GOST, results on the content of bifidobacteria and lactic acid microorganisms were obtained (Table 1).

Table 1. Results of laboratory tests of lactic starter culture samples.

No.	Defined indicators	Result measuring unit	Test result	Acceptable level value	ND on test methods
	Liquid lactic starter				
1	Bifidobacteria	KOE/cm^3	more than 1,1x10^6	less than 1x10^6	GOST 33491-2015
2	Lactic acid microorganisms	KOE/cm^3	more than 1,1x10^8	more than 1,1x10^8	GOST 10444.11-2013
	Dry lactic starter				
1	Bifidobacteria	KOE/cm^3	more than 1,1x10^6	less than 1x10^6	GOST 33491-2015
2	Lactic acid microorganisms	KOE/cm^3	more than 1,1x10^8	more than 1,1x10^8	GOST 10444.11-2013

From the results obtained (Table 1), it follows that in the sample of liquid lactic starter culture, the content of lactic acid microorganisms corresponds to the declared indicators on the manufacturer's packaging according to the technical specifications 10.51.52-008-51469499-2019, and the content of bifidobacteria exceeds this indicator.

In the sample of dry lactic starter, the content of lactic acid microorganisms and bifidobacteria are identical in comparison with the indicators of the initial material of liquid lactic starter.

4 Conclusion

The process of drying lactic starter cultures with the use of an infrared low-temperature membranous electric heater allows to get a high-quality dry product, while preserving biologically active nutrients, which is confirmed by laboratory tests.

The obtained kinetic dependences of the drying process and the equation for the product temperature curve can become the starting point for the development of drying plants for liquid and paste-like materials, as well as for the design of algorithms for automatic control of the dehydration process, which in the future can become the basis for the use of artificial intelligence in technological processes using IR radiation.

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