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Rapid freezing of ground meat: discrete heat transfer

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Abstract. The paper deals with the optimum conditions for quick freezing of ground meat by continuous and discrete heat transfer. We constructed curves of temperature changes and heat flux during quick freezing of semi-processed meats (ground beef). It was revealed that an increase in the heat flux and a reduction of freezing period by about 1.4 times occurs when the temperature of the cooling medium decreases from -20 C to -40C at air speed of 6 m/s. Comparative characteristics of the change in the freezing duration and the speed of the process by continuous and discrete heat transfer methods are shown. It is proved that with discrete heat transfer, the freezing period lasts 20 minutes, with continuous heat transfer it takes 26 minutes. The paper presents a thermograph and the kinetics of heat transfer during freezing under discrete mode conditions. The quality indicators of ground meat are considered depending on the conditions of heat transfer, as well as the change in the physical and chemical properties of the food after freezing and during storage.

1 Introduction

Quick freezing is an effective way to preserve the food quality as it retains most of the nutrients and taste**.** Quick-frozen foods can be stored for a long time and still retain their properties. This makes quick-frozen foods popular in nutrition [1]. Uninterrupted freezing includes production, storage, transportation and selling at low temperatures in order to maintain their quality and safety. Quick freezing is an important element of the chain, so the advances of quick freezing technologies are extremely important for the modern food industry [2].

To obtain flash-frozen foods the world food industry uses a wide range of methods and technologies found in a great variety of quick freezers [3]. The advances of freezing equipment and technology mean using quick-freezing equipment [4, 5]. Therefore, it is important to develop such a food processing technology that will allow obtaining the most effective indicators and parameters of the freezing process. The experience outlines the prospects for the development of freezing modular devices both with and without packaging [6].

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The aim of the paper is to determine optimum conditions for quick freezing of unpacked small-sized meat foods by discrete heat transfer.

2 Materials and research methods

We experimentally assessed and compared the thermo-physical processes of quick freezing. The study object was ground meat. Freezing was done by continuous and discrete heat transfer in the targeted range of temperatures and air speed.

We used mathematical methods for experiment planning. This made it possible to reduce the number of experiments and graphically show an assessment of the quantities that affect the freezing process [7].

Two parameters that characterize the process were taken as effective: heat flux– from the study object to the cooling medium (q, kW/m2) and time –freezing period (hours). Heat flux was the main efficiency criterion. Itis connected with energy costs. Freezing period was a secondary one.

The freezing was carried out in the air stream. The sample was an unlimited plate [8]. We measured the heat from both sides of the plate of the lower and upper surfaces, since the intensity of cooling is not the same. There were two main factors that affect the intensity of heat transfer during freezing in the air flow – air temperature t_a and air speed v_a**.**

When choosing the limits of the experiment, it was taken into account that at above -20°C, freezing will not be a fast one, even if the air velocity is increased. Lowering the temperature below -70°C is energy inefficient. Therefore, we considered temperatures ranging from -20°C to -70°C and air velocity from three to ten m/s.

The study object was ground beef made from chilled and chopped beef of the first category of nutritional status, in briquettes weighing 250g and 28 mm thick.

3 Results and discussion

The briquettes were placed on a metal tray and put in a freezing chamber with an initial temperature of 20°C (both meat and tray). The approach takes into account real production conditions. It is different from the method where small-piece foods were frozen on a metal line, which at the initial moment had a temperature below the cryoscopic point [9].

The cooling block includes an evaporator and fans that are staggered against each other. This arrangement of cooling devices and fans allows for two-way symmetrical air circulation. Thermocouples were attached to the sample (Fig. 1): one on the inner surface (thermocouple 5), another on the outer surface (thermocouple 1), three thermocouples at a distance of seven mm from the surface. In the chamber the temperature was -45°C.

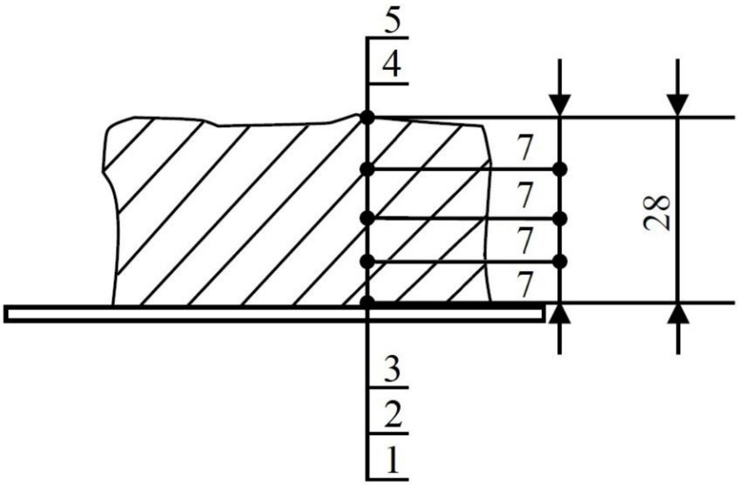

Fig. 1. Thermocouples in the study object

Sample temperature curves were drawn (Fig. 2) and the heat transfer kinetics was shown(Fig. 3).

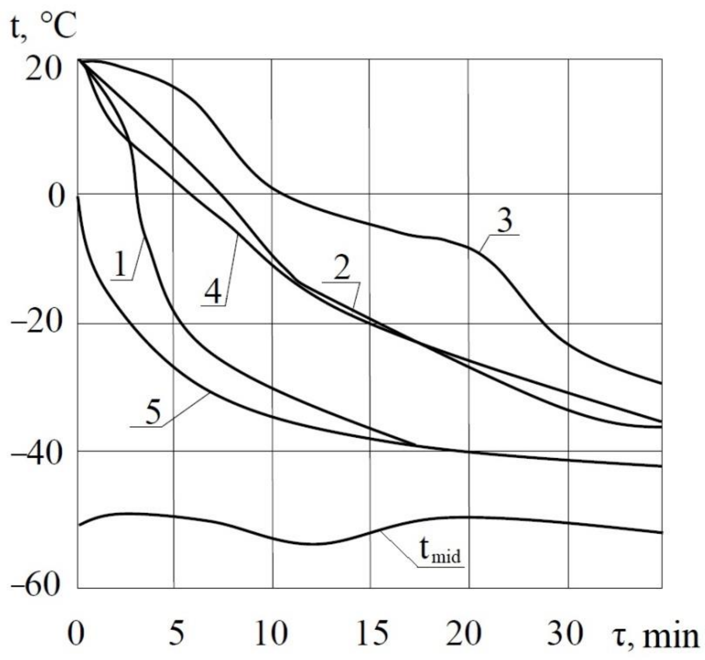

Fig. 2. Thermographs of temperature changes during freezing

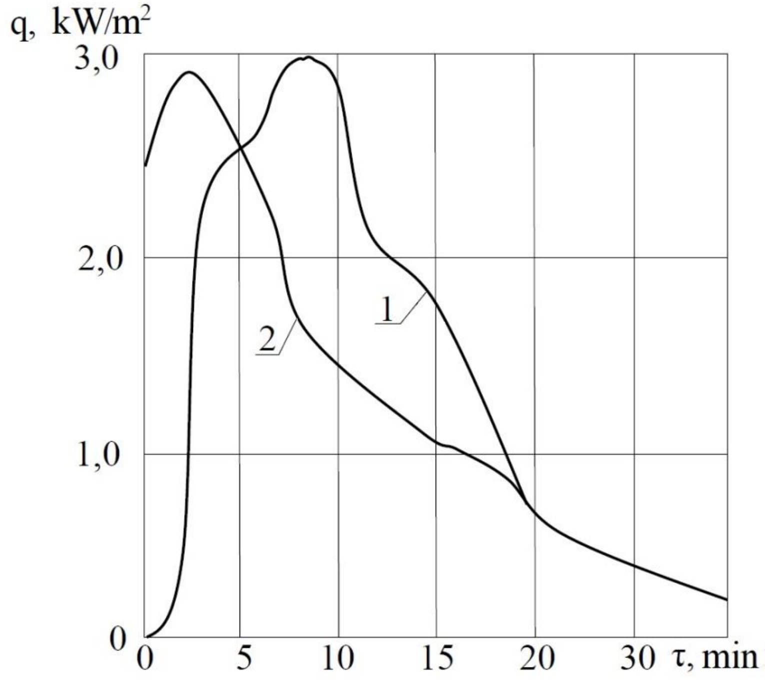

Fig. 3. Kinetics of heat transfer from the sample surface during freezing

The graphs show that the upper surface cools faster (Fig. 3, Curve 1). With a further decrease in temperature on the lower surface, the heat transfer becomes more intense and in 18 min the temperature levels off. Such heat transfer is symmetrical.

The main purpose of discrete heat transfer is to implement such external influence using air cooling, in which there will be a reduction in costs without worsening the food quality[10].

First, research was done to determine the most rational mode of continuous heat transfer. The optimum range of air circulation speeds in the contact zone with the foodwith continuous heat transfer is in the range from 4 m/s to 6 m/ s at air temperature up to -50 °C.

The experiment by discrete heat transfermethod was carried out in several stages.At the first stage, using the features of changing the process characteristics of continuous heat transfer**,** we made up a plan for the implementation of experiments in a four-module experimental setup.

Each section of the apparatus has an individual refrigeration supply and a system that provides air circulation with the specified parameters.

Table 1 presents the plan and experiment findings of rapid meat freezing under conditions of discrete heat transfer. Assuming that it might be difficult to calculate the duration of the process with sufficient accuracy for different modules, we repeated the experiment ten times.

The assessment was done in comparison with the most efficient mode of continuous heat transfer at -40 °C and 5 m/s. Process duration and speed were the main evaluation criteria.

Theresults of the first part indicate that when more intense conditions are created in module one**,** this has a lesser effect on reducing the process duration and speed.

From a thermophysical point of view, this can be explained by the fact that on the surface of the food the temperature reaches cryoscopicdegrees very quickly, forming a crystalline ‘barrier’ of a certain thickness. This significantly reduces the intensity of the temperature penetration into the inner layers of the product. Experiment 6 turned out to be effective at this stage, when less intense conditions were created in the first module, which then turned into an active effect of lower temperatures and high air speeds.

Table 1. The findings of the experiment

No.	Air parametersinmodules								Duration, min		Process speed $\omega \times 10^6$, m/s
	1st module		2nd module		3d module		4th module		Discrete heat transfer	Continuous heat transfer, -40 °C , 5 m/s	
	t_a, °C	v_a, m /s	t_a, °C	v_a, m/s	t_a, °C	v_a, m /s	t_a, °C	v_a, m /s			
First stage											
1	-50	6	-40	4	-35	6	-30	4	24	26	12.5
2	-40	6	-30	4	-40	6	-30	4	29.5	26	11.9
3	-30	6	-40	4	-50	6	-30	4	23,5	26	13.3
4	-50	4	-40	6	-30	4	-30	4	23	26	12.8
5	-40	4	-30	6	-40	4	-30	4	29	26	11.7
6	-30	4	-40	6	-50	4	-35	4	22	26	13.7
Secondstage											
7	-30	4	-50	6	-40	6	-30	4	22	26	14.0
8	-30	4	-50	4	-40	4	-30	4	23	26	13.7
9	-30	4	-50	6	-40	5	-30	4	20	26	14.2
10	-30	4	-50	4	-40	6	-30	4	22	26	14.0

The second part of the experiment was aimed at identifying the optimal combination of modules. Following the setting of experiments, the process was purposefully intensified in modules 2 and 3. In experiment 9, the minimum period was 20 min, while the duration with continuous heat transfer was 26 min.

Fig. 4 shows the experimental curves depicting what was happening in this experiment.

Under the conditions of discrete heat transfer, the freezing process was carried out in four modules, into which the frozen product was sequentially moved. InFig. 4 module boundaries are shown by time intervals, indicated from *I* to *IV*. Each module supported a separate low-temperature treatment mode. Mode parameters supported in the modules are presented in Table. 2.

Table 2. Low temperature processing modes supported in individual modules for discrete freezing mode

Module	*I*	*II*	*III*	*IV*
Temperature, °C	-30	-50	-40	-30
Air speed, m/s	4	6	5	4
Time spent in the module, min	6	6	6	2

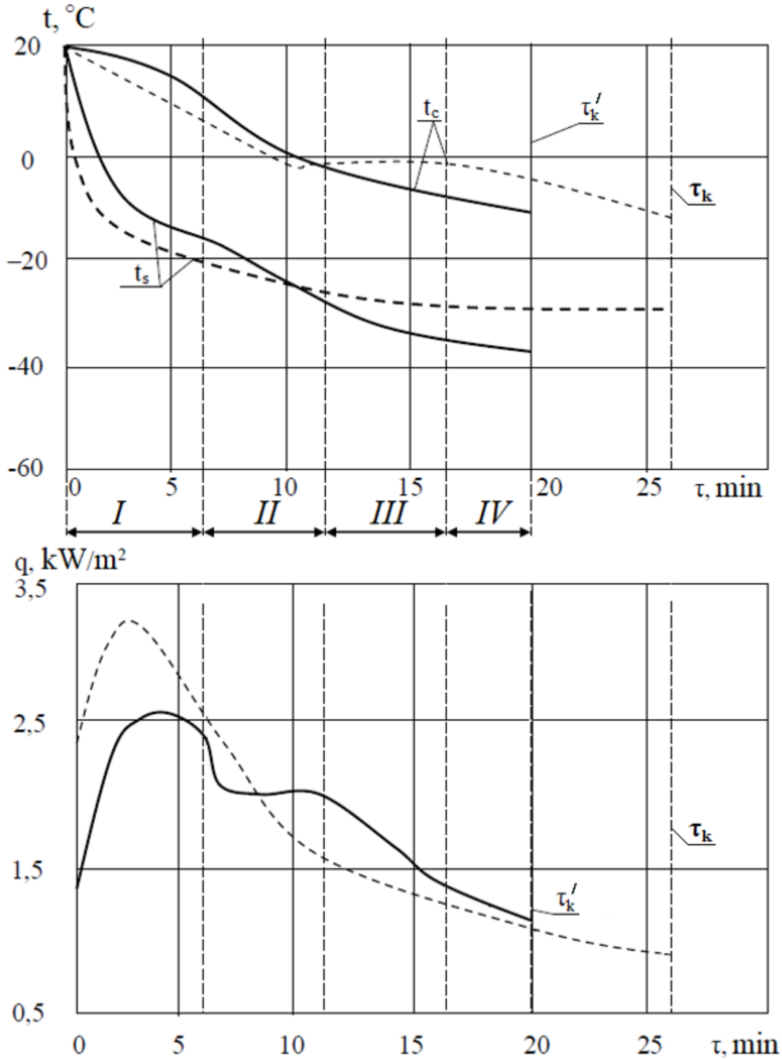

Fig. 4. Thermograph and kinetics of heat transfer during freezing under conditions of discrete mode in comparison with continuous heat transfer

A broken curve is a continuous heat transfer; a continuous curve is a discrete heat transfer

t_s is the temperature of the sample surface, t_c is the temperature of the sample centre,

τ'_k is the period of freezing at a discrete heat transfer ,τ_k is the period of freezing with continuous heat transfer.

Significantly less heat is removed in module 1 than in module 4. The temperature in the center and on the surface is significantly higher than in the control variant of fast freezing. In module 2, at -50°C and a maximum speed of 6 m/s, heat transfer is so effective that the temperature drops sharply not only on the surface, but also in the center of the food. This means that the bulk of the food successfully passed the period of water-to-ice phase transformation. This can guarantee maximum preservation of all the properties during long-term storage.

In Module 3 at -40 °C, the flow rate somewhat decreases, due to the fact that the heat transfer intensity is already falling, but the process is still quite intense.

Module 4 makes it possible to further reduce the speed and increase its temperature, since the heat load is minimal and the process of achieving an average volume temperature of -18 °C does not require intervention, since intensification by the convective method will no longer reduce significantly the process duration.

We also studied the qualitative characteristics of meat foods frozen under conditions of discrete heat transferand compared them with the quality of meat frozen under conditions of continuous heat transfer. Samples were thawed in air medium at 20°C, until + 1°C was reached in the center of the meat.

In defrosted meat we studied the mass fraction of moisture, water-binding capacity, solubility of protein fractions, weight loss after heat treatment, loss of meat juicedefrosted groundmeat, were determined. In the raw ground meat, the mass fraction of moisture, water-binding capacity, and protein solubility were determined. The findings are shown in Table 3.

Table 3. Quality indicators of ground meat depending on heat transfer conditions

Study object	Moisture W, %	Loss of meat juice during defrosting	Mass loss, %	
			after freezing	after heat processing
Raw ground beef meat	74.9			
Ground meat frozen by continuous heat transfer	73.4	0.5	2	26
In 30 days	72.3	1.7	3.7	32
In 60 days	70.8	1.9	5.6	40
Ground meat frozen by a discrete heat transfer	73.8	0.4	1.1	25
In 30 days	72.7	1.6	2.5	31.5
In 60 days	71.6	1.8	3.6	38

The findings indicate that during freezing in both heat transfer modes, the decrease in the mass fraction of moisture in minced meat is almost the same. This is due to the natural weight loss due to moisture evaporation. The loss is 0.97 - 1%, which does not exceed the standard freezing shrinkage. However, during storage there is a further decrease in moisture due to evaporation. The decrease is explained by the partial destruction of the protein-colloidal system, a decrease in the ability of proteins to retain moisture [11].

The findingsalso showed that the loss of meat juice with an increase in the duration of storage of frozen minced meat increases by about 1.2–1.4%. This is due to a decrease in the swelling of minced protein substances. The decrease in moisture in ground meat and the loss of meat juice in both freezing modes are almost the same.

Weight loss during freezing and during storage was about 1.2%, but during freezing under conditions of discrete heat transfer, they turned out to be somewhat lower than with continuous heat transfer. This is due to the shorter freezing period.

The freezing is accompanied not only by weight loss, but also by changes in the physical and chemical food properties [12].

We studied the solubility of protein fractions and water-binding capacity. The findings are shown in Table 4.

When frozen, the properties of sarcoplasmic proteins, including their solubility, practically did not change. The solubility of myofibrillar proteins during freezing and storage decreased by 9÷20%. In discrete heat transfer, the solubility of proteins is 1.5–2% less than in conditions of continuous heat transfer.

Table 4. Change in water-binding capacity and solubility of myofibrillar proteins after freezing and during storage

A study object	Water-binding capacity % to the raw meat	Protein solubility	
		sarcoplasmic	myofibrillar
Raw ground beef	100	100	100
Ground meat frozen by continuous heat transfer In 30 days In 60 days	84.9 68.8	98.2 98.0 90.8	88.1 85.1 80.0
Ground meat frozen by a discrete heat transfer In 30 days In 60 days	87.3 73.6	98.9 97.1 93.6	90.1 86.8 81.8

The dynamics of changes in water-binding capacity of the meat foods indicates a decreased ability to retain moisture. This is due to the decrease in moisture during storage. The rate of reduction of water-binding capacity is higher by 3.7% with continuous heat transfer.

4 Conclusions

The most optimum range of air circulation speeds ranges from 4 m/s to 6 m/s, at which the intensity of heat transfer increases. Lowering the air temperature below -50 °C is not advisable, since there is no significant reduction in the duration of freezing and the intensity of heat transfer.

In addition, if the air temperature is kept at -40 °C to -50 °C, then the freezing speed of the semi-finished meat food is in the range within12.5×10 -6 to 14.8×10^{-6} m/s, which corresponds to the concept of 'quick freezing'. The findings also demonstrate that with discrete heat transfer, the freezing period is shorter and takes 20 minutes. This can lead to cost reduction of the freezing process.

Quick freezing of the meat under the conditions of heat transfer did not give grounds to consider a significant change in the food quality. The findings indicate that discrete heat transfer, having advantages in reducing the freezing period, does not worsen the food quality, but improves it in some respects.

References

1. Grujić S, Grujčić M. Factors affecting consumer preference for healthy diet and functional foods. Foods and Raw Materials. 2023;11(2):259–271. https://doi.org/10.21603/2308-4057-2023-2-576
2. Arriaga-Lorenzo P, de Jesús Maldonado-Simán E, Ramírez-Valverde R, Martínez-Hernández PA, Tirado-González DN, Saavedra-Jiménez LA. Cold chain relevance in

the food safety of perishable products. Foods and Raw Materials. 2023;11(1):116–128. https://doi.org/10.21603/2308-4057-2023-1-559

3. Fryer PJ, Versteeg C. Processing technology innovation in the food industry. Innovation: Management, Policy and Practice. 2008; 10(1): 74–90. https://doi.org/10.5172/impp.453.10.1.74.
4. Korotkiy IA, Rasschepkin AN. Refrigerating: the state and perspectives of the industry in Russia. Dairy industry. 2022; 8: 6-8. DOI 10.31515/1019-8946-2022-08-6-8.
5. Buyanov ON, Buyanova IV. Calculation of the heat load on the modules of a combined type quick freezer. Bulletin of International academy of refregiration. 2016; 2: 63–66. https://doi.org/10.21047/1606-4313-2016-15-2-63-66.
6. Korotkiy IA, Sakhabutdinova GF, Shafray AV. Parameters affecting the duration of freezing of vegetable semi-finished foods frozen in a combined way. Food engineering and technology. 2017; 3(46): 108-113.
7. BuyanovO.N.. Effectiveness evaluation of the combined rapid freezing of biological objects / O.N. Buyanov., I.V. Buyanova // Bulletin of International academy of refregiration. – 2015. – № 4. – P. 44-48.
8. Korotkiy IA, Korotkaya EV, Rasschepkin AN, Sakhabutdinova GF. Freezing of minced meat in biopolymer package. Food engineering and technology. 2021; 51(1): 6-16. DOI 10.21603/2074-9414-2021-1-6-16.
9. Bredihin SA, Andreev VN, Martekha AN, Schenzle MG, Korotkiy IA. Erosion potential of ultrasonic food processing. Foods and Raw Materials. 2021; 9(2); 335-344. DOI 10.21603/2308-4057-2021-2-335-344.
10. Buyanov VO. Freezing of hard pressed chesses under conditions of regulated heat. Cheese and butter manufacturing. 2009; 4: 46-48.
11. Ishevskiy AL, Davydov IA. Freezing as food conservation method. Theory and practice of meat processing. 2017; 2(2): C. 43–59. https://doi.org/10.21323/2414-438X-2017-2-2-43-59.
12. Korotkiy IA, Rasshchepkin AN, Korotkaya EV, Sakhabutdinova GF. Improved freezing technology of minced meat products in biopolymer packaging material. ARPN Journal of Engineering and Applied Sciences. 2020; 15(21): 2547-2554.