Study of the temperature regime effect on the process of cheeses vacuum drying

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Abstract. Vacuum drying is a promising way to cheese processing. The heating temperature is the most significant factor in vacuum drying. The purpose of this work was the selection of temperature regimes of vacuum cheese drying. Experiments on vacuum drying of cheeses were conducted at different temperatures and heat flow density. It has been established that the temperature decrease rises significantly the duration of drying process. Increasing the drying temperature up to 60 °C and more leads to a decrease in the temperature gradient across the thickness of the layer of dried cheese. The organoleptic characteristics of dry cheeses have been found to be most appreciated at vacuum drying temperatures of 50 and 60 °C. Based on the conducted research, the influence of temperature and heat flow density on the process of vacuum cheeses drying was analyzed. The recommended temperature for vacuum cheeses drying is (60 ± 3) °C, the recommended value of the heat flow density is (7.36 ± 0.3) kW/m².

1. Introduction
Providing population with high-quality food has always been one of the most important tasks of the state policy. Providing population with high-quality food has always been one of the most important tasks of the state policy. Great interest in this issue is determined by social, economic and medical aspects; by a significant shortage of food resources, as well as by the constant action and the determining influence of nutrition on the population health and, of course, by the possibility of a significant correction of the situation, subject to the use of recommendations and practical conclusions of the nutrition science [1].

The fundamental result of the research in the nutrition field is the conclusion that in order to ensure better human life, it is important not only to provide it with an adequate amount of energy, but also to observe certain relationships between numerous irreplaceable nutrition factors, each of which plays a specific role in metabolism [2-7].

Dairy products taking into consideration to their biological value play an important role in the organization of population nutrition [8,9]. Cheese has a special place among dairy products. It is a con-
centrated easily digestible protein product with good organoleptic properties. The nutritional value of cheese is based on high concentration of proteins, fats, essential amino acids, calcium and phosphorus salts that are necessary for the normal development of the human body. Cheese is recommended for people of different ages and engaged in various types of occupation. Cheese is included in the diet of patients with diabetes, chronic hepatitis, liver disease, anemia.

2. Literature review
One of the most promising ways to cheese processing is vacuum drying [10]. This technology involves dehydration of the product under pressure below atmospheric, but above the triple point of water. Under reduced pressure, it is possible to lower the boiling point of moisture in the product, which allows carrying out the process at a relatively low temperature and eliminating thermal denaturation of the thermolabile components [11].

Dehydrated cheeses can be used, for example, in the production of bakery products, to supply certain areas of the country, the army, the fleet and expeditions. Dehydrated products, including cheeses, can be stored and distributed through the distribution network, using conventional storage facilities and vehicles. In addition, dehydration of food products reduces in mass and volume, having significant advantages in terms of their storage and placement compared with other methods of canning. All this suggests that dehydration can be an ideal method for storing cheeses.

Choosing a method and mode of drying it must be remembered that drying is not only the most complicated non-stationary process of heat and mass transfer, but also a technological process [12-14]. The dried product must have high quality indicators. Rational mode of drying is carried out with a minimum expenditure of heat and energy and consists in the maximum preservation of chemical and technological indicators of the product [15-17]. The implementation of such a mode is facilitated by the knowledge of the characteristics of the material being dried, the association of moisture with the material, and the theory of drying.

The most significant factor in vacuum drying is the heating temperature [18-20]. The choice of temperature for vacuum drying of cheeses is quite an important and serious task [21]. On the one hand, an increase in the temperature of the drying agent is one of the determining factors of the processing, on the other hand, excessive thermal effect on the cheese leads to spoilage of the finished product. Determination of the drying cheese temperature was carried out at constant values of heat load and residual pressure, but with different degrees of grinding and thickness of the dried layers.

The heat flow density (heat load) is an important parameter of the drying process as the temperature. The heat flow density is the amount of heat supplied from the heaters per area unit of the product being dried (kW/m²).

The rate of reaching the desired drying temperature depends on the magnitude of the heat load [22]. At small values of heat load, the duration of reaching the required temperature for drying cheeses increases, which increases the total duration of the drying process. Relatively large heat loads can lead to deterioration and spoilage of the dry product. The deterioration in quality is manifested in the burning of the surface layers, the melting of fat and the formation of dried layers on the cheese surface.

3. The subject of the study
The purpose of this work was the selection of temperature modes for vacuum drying of cheeses. The objects of research were cheeses of the following brands: Dutch, Kostromskoy, Poshekonskiy and Yaroslavskiy.

4. Materials and methods
In order to achieve this goal, experimental studies were carried out on vacuum drying of cheeses using an installation as shown in Figure 1.

This drying unit is universal and can be used for drying almost any raw material of plant and animal origin. The drying unit consists of a drying chamber, a desublimator, a vacuum pump, a chiller, and a regulation and measurement system. Infrared lamps are provided to supply heat to the product.
A mass sensor is placed under the product tray to register any change in the product mass during the drying process. Cheese drying was carried out at a residual pressure of 2-3 kPa.

In experimental studies, the drying cheese temperature was changed in the range from 30 to 80 °C with a step of 10 °C, the heat load in various experiments was equal to: 9.2; 8.28; 7.36; 6.44; 5.52; 4.6; 3.68; 2.76; 1.84; 0.92 kW/m².

When drying, the most susceptible to heat influence are layers on the surface of the product, from which moisture is removed first; therefore, the process of cheese vacuum drying was controlled by the temperature of the surface layer.

![Figure 1](image)

**Figure 1.** Scheme of an experimental vacuum drying unit: 1 – vacuum pump, 2 – working chamber, 3 – compressor, 4 – capacitor, 5 – liquid separator, 6 – desublimator, 7 – receiver, 8 – vacuum gauge, 9 – thermostatic expansion valve

Organoleptic evaluation of dry cheeses was carried out according to 3 indicators - taste with smell, color and consistency. The maximum organoleptic score is 30 points, including 15 points for taste and smell, 10 points for consistency, and 5 points for color.

5. Results and discussions
The duration of the vacuum drying process of the studied cheeses with varying degrees of grinding and thickness of the dried layers is given in Table 1.

Basing on the conducted research it was established that if the drying temperature decreases, a significant increase in the duration of dehydration occurs. By reducing the drying temperature from 80 to 70 °C, from 70 to 60 °C, from 60 to 50 °C, the duration of the drying process increases on average by 18-25%. By reducing the drying temperature from 50 to 40 °C, from 40 to 30 °C, the duration of the process reduces by 16–30%.

**Table 1.** Duration of vacuum cheese drying at a low second heating temperature, minutes

| Drying temperature, °C | Layer thickness, mm | Cheese variety       |
|------------------------|---------------------|----------------------|
|                        |                     | Dutch | Kostromskoy | Poshekhonskiy | Yaroslavskiy |
| 60                     | 10                  | 250   | 260        | 240          | 250         |
|                        | 20                  | 320   | 330        | 310          | 320         |
| 70                     | 10                  | 220   | 220        | 210          | 210         |
|                        | 20                  | 280   | 290        | 270          | 290         |
| 80                     | 10                  | 210   | 190        | 210          | 190         |
|                        | 20                  | 260   | 260        | 270          | 260         |
When the drying temperature decreases below 50 °C, the duration of the vacuum drying process increases to 7-8 hours, and the cheese after drying has an increased mass fraction of moisture (Figure 2). The increased moisture content of dry cheese is explained by the ratio of residual pressure and drying temperature. Studies on the choice of the required temperature for vacuum drying of cheeses were carried out at residual pressures of 4-5 kPa. At residual pressures of 4 and 5 kPa, the temperature of saturation with water vapor (boiling point) is 28.97 and 32.89 °C respectively.

Figure 2. The dependence of the mass fraction of moisture in cheese on temperature of vacuum drying

At a temperature of 30 °C, the temperature in the drying chamber does not exceed the saturation temperature at residual pressures of 4–5 kPa. At a drying temperature of 40 °C, a saturation temperature of 8-10 °C is observed. However, at 40 °C, the mass fraction of moisture in cheeses “Dutch”, “Kostromskoy”, “Poshekhonskiy” and “Yaroslavskiy” is greater than the ones at drying temperatures of 50, 60, 70 and 80 °C.

Figure 3 shows the temperature curves on the surface and in the thickness of the “Yaroslavskiy” cheese at vacuum drying temperatures of 80, 70, 60, 50, 40 and 30 °C. The thickness of the dried layer is 20 mm, the temperature in the thickness of the cheese was registered by a thermal sensor installed in the geometric center of the dried sample, i.e. at a depth of 10 mm.

At a drying temperature of 30 °C, the central layers reach 30 °C after 400 minutes. At drying temperatures of 40, 50, 60, 70 and 80 °C, the central layers are heated to a predetermined temperature in 340, 215, 160, 140 and 120 minutes, respectively. Increasing the drying temperature to 60 °C and more leads to a decrease in the temperature gradient across the thickness of the layer of dried cheese.

Organoleptic characteristics of dry cheeses had the highest scores at vacuum drying temperatures of 50 and 60 °C (28-29 points). When the temperature rises to 80 °C, the following disadvantages are observed in dry cheeses: loss of fat mass fraction to 4–5% of the total mass; uneven drying of cheese by volume; “Poshekhonskiy” cheese performs burning of the surface layers (total organoleptic evaluation decreased to 23-24 points). It should be noted that at 70 °C some cheeses had high enough quality indicators and minimal fat loss of 2-3%; however, to reduce the risks associated with the deterioration of the quality of dry cheese products, required drying temperature for “Dutch”, “Kostromskoy”, “Poshekhonskiy” and "Yaroslavskiy" cheeses is (60 ± 3) °C.
Figure 3. Temperature curves of "Yaroslavskiy" cheese vacuum drying

Table 2 shows the values of the mass fraction of moisture and fat of cheeses before and after drying at 60 °C. Losses of fat mass fraction do not exceed 1.6%.

Table 2. Mass fraction of moisture and fat in cheeses before and after drying

| Cheese variety     | Mass fraction, % |          |          |          |
|--------------------|------------------|----------|----------|----------|
|                    | before drying    | after drying | before drying | after drying |
| Dutch              | 43,0±1           | 3,7±0,2   | 46,6±0,7 | 45,0±0,5 |
| Kostromskoy        | 44,0±1           | 3,9±0,3   | 45,2±0,5 | 44,7±0,5 |
| Poshekonskiy       | 41,5±1           | 3,9±0,2   | 45,8±0,5 | 44,5±0,5 |
| Yaroslavskiy       | 42,0±2           | 4,3±0,3   | 47,0±0,9 | 45,5±0,7 |

The mass transfer equation is known:

\[ q_m = -a_m \cdot \gamma_o \cdot \nabla u - a_m \cdot \gamma_o \cdot \beta \cdot \nabla t = q_{nu} + q_{nt} , \]  

(1)

where \( a_m \) – coefficient of mass diffusivity, kg/(m·h);
\( \gamma_o \) – unit weight of dry material, kg/m³;
\( \nabla u \) – moisture content gradient (\( \nabla \) – Hamilton operator);
\( \delta \) – thermogradient coefficient, 1/°C;
\( q_{mu} \) and \( q_{mt} \) – moisture flows, kg/(m²·h);
\( \nabla T \) – temperature gradient, °C/m.

Consideration of the equation (1) and the curves of the distribution of temperatures and moisture mass fractions shows that during vacuum drying of cheeses the transfer of moisture up to the surface occurs due to a humidity gradient; while the temperature gradient, on the contrary, inhibits the transfer of moisture. In this case:

\[
q_m = q_{mu} - q_{mt}.
\]  

The difference in cheese humidity is created by the evaporation of moisture from the surface. During the drying process, the difference in humidity in the central and peripheral zones of the material increases. Alignment of moisture by volume of cheese begins at the end of the drying process.

Basing on the conducted research data, the required temperature for vacuum cheese drying was determined, which is \((60 \pm 3)\) °C.

Further studies were carried out on the vacuum drying of cheeses with different heat flow densities. Figure 4 shows the graphs of the drying cheese duration depending on the value of the heat load.

![Figure 4](image_url)

**Figure 4.** Dependence of the duration of vacuum cheese drying on the heat load: 1 - “Dutch”; 2 - "Poshekhwonskiy"

The required value of temperature and heat load should ensure high quality indicators of dry cheese products, the minimum duration of the drying process, as well as high efficiency of the process. The energy consumption of the vacuum cheese drying process was evaluated by using the unit cost of heat per 1 kg of removed moisture.

The specific heat consumption for removing 1 kg of moisture from different varieties of cheeses with a low second heating temperature is shown in Figure 5.

The minimum heat consumption per 1 kg of removed moisture is observed with a thermal load of 7.36 and 8.28 kW/m² for all cheeses. When a decrease in the heat load in the range from 8.28 to 3.68 kW/m² is, an increase in the specific heat consumption occurs. With an increase in heat load up to 9.2 kW/m², an increase in the cost of heat is also observed. At 8.28 kW/m², the cost of heat is minimal, but dry cheese has thermal damage and reduced organoleptic evaluation (26–27 points). Therefore, there we took \((7.36 \pm 0.3)\) kW/m² as the required heat load for heating.

It should be noted that the specific costs of heat depend on a large number of factors: drying temperature, heat load, thickness of the layer being dried, degree of grinding, physical and chemical parameters (mass fraction of moisture and fat).
Figure 5. Specific heat consumption depending on the heat load:
1– “Dutch”; 2– Kostromskoy; 3– “Poshekhonskiy”; 4– “Yaroslavskiy”

6. Conclusions
Thus, based on the conducted research, we analyzed the influence of temperature and density of the heat flow on the process of vacuum drying of cheeses. The recommended temperature for vacuum cheese drying is (60 ± 3) °C, the recommended value of the heat flow density is (7.36 ± 0.3) kW/m². The presented research results may be useful to food industry workers, technologists and research workers.

References
[1] Paoli A, Tinsley G, Bianco A and Moro T 2019 The influence of meal frequency and timing on health in humans: The role of fasting *Nutrients* 11 (4) 719
[2] Bogatyrev A N, Pryanichnikova N S and Makeeva I A 2017 Natural food products - health of the nation *Food industry* 8 26-29
[3] Anfinogenov V A 2019 To the question of the role and characteristics of a healthy nutrition *National Health* 1 27-29
[4] Safonova E E, Kharitonova E V and Timoshenko I A 2016 Nutrition industry and the role of functional food products in the population food safety *Modern science: current problems of theory and practice* 4 79-83
[5] Melnikova O F 2016 Role of nutrition in maintaining human health. *Science Time* 10 (34) 200-204
[6] Nile S and Park S 2014 Edible berries: bioactive components and their effect on human health *Nutrition* 30 (2) 134-144
[7] Nyberg M, Olsson V, Ormman G, Pajalic Z, Andersson H S, Blücher A, Lindborg A-L, Wendin K and Westergren A 2018 The meal as a performance: Food and meal practices beyond health and nutrition *Ageing and Society* 38 (1) 83-107
[8] Andreev V 2018 Dynamics and trends of development of dairy product categories in Russia and the world. *Milk processing* 7 (225) 30-31
[9] Panasenko L M, Kartseva T V, Leonova N V and Zadorina-Khutornaya E V 2017 Dairy products in the nutrition of children with insufficient vitamin D supply *Russian Bulletin of Perinatology and Pediatrics* 62 (4) 113-118
[10] Ermolaev V A 2014 Kinetics of the vacuum drying of cheeses *Foods and Raw Materials* 2(2) 130-139
[11] Ermolaev V A 2018 Research of vacuum drying peculiarities of wild berries *Bio Interface Research in Applied Chemistry* 8 (4) 3483-3489
[12] Wojdylo A, Figiel A, Lech K, Nowicka P and Oszmianski J 2014 Effects of convective and vacuum-microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries Food and Bioprocess Technology 7 829–841
[13] Mannanov U, Mamatov Sh and Shamsutdinov B 2016 Research and study mode vacuum infrared drying vegetables Austrian Journal of Technical and Natural Sciences 3-4 38-41
[14] Zeng M, Bi J, Chen Q, Liu X, Wu X and Jiao Y 2015 Weibull distribution for modeling microwave vacuum drying of kiwifruit slices and its application Journal of Chinese Institute of Food Science and Technology 15 (6) 129-135
[15] Ermolaev V A, Yakovchenko M A and Kosolapova A A 2017 Selection of effective technological parameters of vacuum drying of hard cheeses Bulletin of Krasnoyarsk State Agrarian University 1 (124) 114-119
[16] Baslar M, Kilicli M, Toker O S, Sagdic O and Arici M 2014 Ultrasonic vacuum drying technique as a novel process for shortening the drying period for beef and chicken meats Innovative Food Science and Emerging Technologies 26 182-190
[17] Li Y-H, Li Y-N, Li H-T, Qi Y-R, Wu Z-F and Yang M 2017 Comparative study of microwave-vacuum and vacuum drying on the physicochemical properties and antioxidant capacity of licorice extract powder Powder Technology 320 540-545
[18] Lope J, Vega-Galvez A, Bilbao-Sainz C, ChiouBor-Sen Uribe E and Quispe-Fuentes I 2017 Influence of vacuum drying temperature on: Physico-chemical composition and antioxidant properties of murta berries Journal of Food Process Engineering 40 (6) 124-128
[19] Duan K, Zhu W, Chen Q, Chang J and Liu B 2014 Moisture content and temperature variation characteristics of cut tobacco during variable temperature drying Tobacco Science and Technology (4) 20-25
[20] Liu T-X and Tan M-Z 2015 The effect of different drying temperatures on the transformation of polyphenols and volatile aroma components in Pu-erh tea Modern Food Science and Technology 31 (4) 264-271
[21] Rodionov D A, Lazarev C I, Polyanski K K and Ekkept E B 2019 Ultrafiltration concentration of whey in a pilot plant of the tubular type Proceedings of Voronezh State University of Engineering Technologies 2 (80) 41-46
[22] Shahov S V, Saranov I A, Sadibaev A K, Malibekov A A, Litvinov E B and Gruzdev P B 2019 A study of the forms of moisture in canola by the method of thermogravimetric analysis Proceedings of Voronezh State University of Engineering Technologies 1 (79) 27-31