

Conference Paper

Analysis of Shrinkage Phenomena in the Process of Cheese Vacuum Drying

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Abstract

The work is devoted to the study of the shrinkage phenomena during the vacuum dehydration of the cheese varieties “Sovetskiy” and “Gollandskiy”. During the research, the dependences of the cheese shrinkage coefficient on the initial mass fraction of moisture were obtained. It was found that when the mass fraction of the cheese moisture increases, an increase in the shrinkage coefficient of the product occurs. The greatest increase in the cheese shrinkage coefficient is observed when the mass fraction of moisture is more than 50%. It was established that with increasing temperature and heat load, the moisture content on the cheese surface rapidly decreases, while in the central layers it changes more slowly. Shrinkage at elevated temperatures is less; however, dry cheese has a large mass fraction of moisture. It was found that an increase in the difference in the mass fraction of moisture between the inner and surface layers is accompanied by an increase in the difference between the actual shrinkage and possible shrinkage corresponding to the amount of liquid removed. The coefficients of shrinkage in the volume of the “Sovetskiy” and “Gollandskiy” cheese varieties were calculated: they lie in the range of 0.017–0.004 and 0.006–0.003, respectively. The dependences of the cheese shrinkage coefficients on the drying layer thickness, shape and size of grinding were obtained.

Keywords: cheeses, vacuum drying, shrinkage

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1. Introduction

It is well known that the size and volume of most materials are reduced in any drying process. This phenomenon is called material shrinkage [1, 2]. For example, during convective drying, vegetables, fruits, and cereals give significant shrinkage, decreasing in volume 3-4 times [3, 4]. Most materials (peat, grain, leather, dough, bread, etc.) shrink throughout the drying process. However, a number of materials (clay, ceramic masses and some other materials) shrink during a period of constant speed. In this case, the

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shrinkage ceases at approximately critical moisture content if the gradient of moisture content inside the material is small. Other materials (wood, coal) shrink only in the period of falling speed; it starts at the critical moisture content [4, 5].

Particular interest presents the study of shrinkage processes during vacuum drying, which is one of the most promising technologies for dehydration of food products - vegetable, meat, dairy (including cheese).

2. Methods and Equipment

The aim of this research was to study the process of vacuum drying on the effect of cheese shrinkage. The objects of research were cheeses of the following varieties: "Sovetskiy" and "Gollandskiy". The process of drying was carried out at a residual pressure of 2-3 kPa [6, 7].

Figure 1 shows a dependence graph of the cheese shrinkage coefficient on the initial mass fraction of moisture.

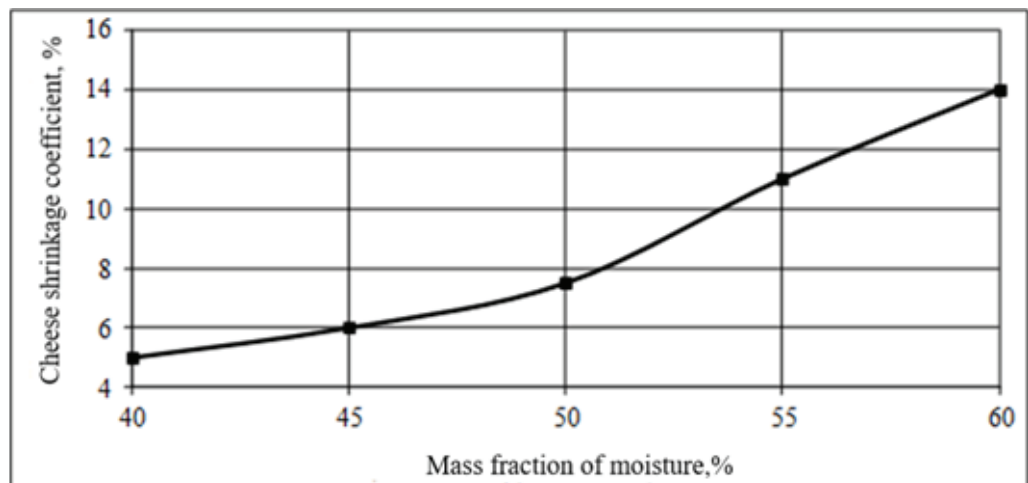


Figure 1: Dependence of the cheese shrinkage coefficient on the mass fraction of moisture

It is established that with an increase in the mass fraction of cheese moisture, an increase in shrinkage coefficients occurs. The greatest increase in the cheese shrinkage coefficient is observed when the mass fraction of moisture is more than 50%. A change in the mass fraction of cheese moisture from 40 to 50% leads to the shrinkage coefficient increase by 2.5%; from 50 to 60% - by 6.5%.

Figure 2 shows the dependence of the shrinkage coefficient on the initial mass fraction of cheese moisture in the drying process. According to the graphs presented in Fig. 2, the following dependence is established: when the mass fraction of cheese moisture increases, the shrinkage coefficient increases, as well.

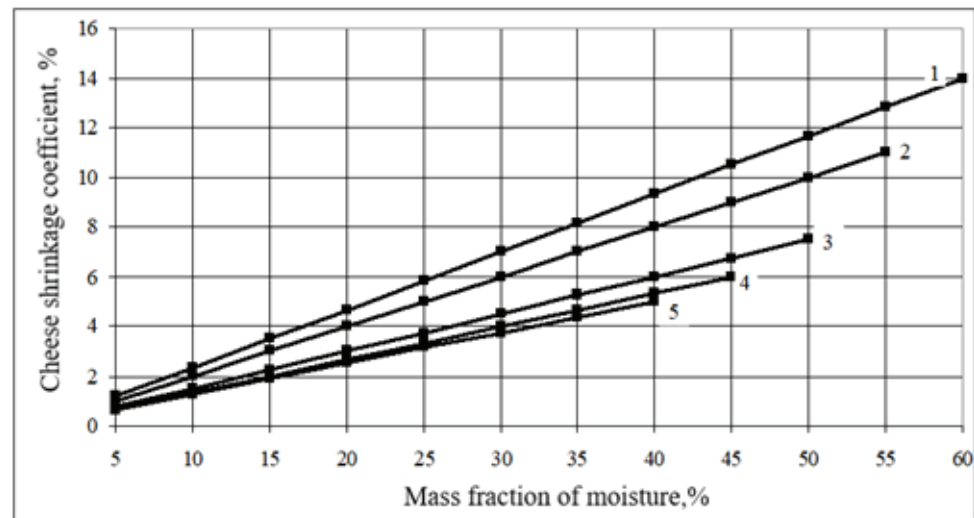


Figure 2: Dependence of cheese shrinkage coefficients on the initial mass fraction of moisture

If the linear size of the material [8, 9] (length, width, height) is denoted by l , a mass fraction of moisture – by W , it can be written as [10]:

$$l = l_0 \cdot (1 + \beta_l \cdot W), \tag{1}$$

where l_0 – linear size of the absolutely dry material;

β_l – coefficient of linear shrinkage that characterize the shrink rate of 1%,

that is $\beta_l = \frac{1}{l_0} \cdot \frac{dl}{dW}$.

Formula (1) is valid for relatively small gradients of moisture content inside the material. With a large moisture content gradient, the surface layers of the material will shrink faster than average ones do.

3. Results

Table 1 shows the moisture content of the cheese varieties “Sovetskiy” and “Gollandskiy” by a layer thickness of 20 mm. The data of moisture content for the cheese layer thickness of 20mm was obtained at the required temperatures, heat loads and residual pressure of vacuum drying of the cheese.

TABLE 1: Moisture content of cheeses by a layer thickness of 20 mm

Cheese	Moisture content, g of moisture /g of dry material			
	reaching the first critical point		reaching the second critical point	
	Surface layers	Center of a layer	Surface layers	Center of a layer
Sovetskiy	6–9	20–24	4–5	9–17
Gollandskiy	6–8	19–22	4–5	7–12

As the temperature and heat load increase, the moisture content on the cheese surface rapidly decreases, while in the central layers it changes more slowly [11–13]. The surface layers, which affect the size of the material, tend to contract not proportionally to the average moisture content, but approximately proportionally to the moisture content on the surface. Therefore, starting from a certain moisture content (mass fraction of moisture), shrinkage is almost not observed (Figure 3).

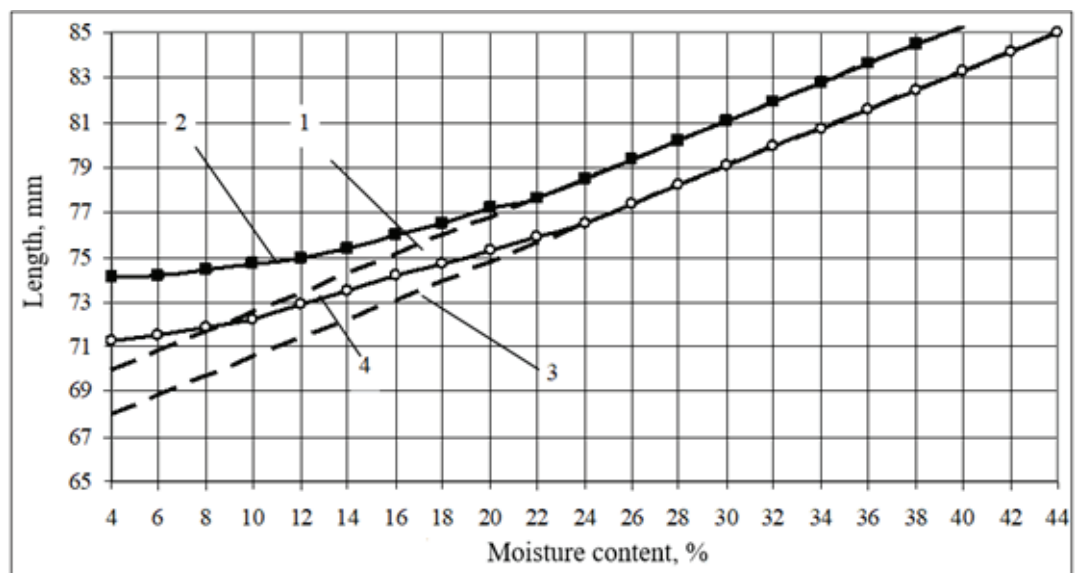


Figure 3: Curves of shrinkage for cheese varieties “Sovetskiy” (1, 2) and “Gollandskiy” (3, 4): 1 – $t=60^{\circ}\text{C}$; $q=5,52\text{ kW/m}^2$; $P=2-3\text{ kPa}$; 2 – $t=80^{\circ}\text{C}$; $q=5,52\text{ kW/m}^2$; $P=2-3\text{ kPa}$; 3 – $t=60^{\circ}\text{C}$; $q=7,36\text{ kW/m}^2$; $P=2-3\text{ kPa}$; 4 – $t=80^{\circ}\text{C}$; $q=7,36\text{ kW/m}^2$; $P=2-3\text{ kPa}$

The shrinkage curves of cheeses “Sovetskiy” 1 and “Gollandskiy” 3 were obtained at the required drying temperature of 60°C [14, 15]. The shrinkage curves 2, 4 were obtained at temperatures above the required value (80°C). At a suspended drying temperature, the surface layers quickly dry. The central layers have an increased mass fraction of moisture. Shrinkage at elevated temperatures is less; however, dry cheese has a large mass fraction of moisture.

An increase in the drying temperature leads to a decrease in the shrinkage coefficient, which is explained by an increase in the gradient of moisture content inside the material. If there is a gradient of the mass fraction of moisture, the surface layers tend to contract more than the inside layers. However, the reduction of surface layers is impeded by internal ones, the mass fraction of moisture of which is greater than surface ones. As a result, the shrinkage of the surface layers is less than that which should have corresponded to the moisture removed from them. Therefore, an increase in the difference in the mass fraction of moisture between the inner and surface layers

is accompanied by an increase in the difference between the actual shrinkage and the possible shrinkage corresponding to the amount of liquid removed [16].

4. Discussion

Thus, formula (1) is valid only for a small gradient of moisture content (mass fraction of moisture), when the moisture mass fraction u at any point in the cheese is approximately equal to the average mass fraction of moisture W ($u \sim W$). A more rigorous writing of formula (1) was suggested by A.V. Lykov [2, 4]:

$$l = l_0 \cdot (1 + \beta_l \cdot W). \quad (2)$$

For most materials, the relationship between body volume V and its moisture content is linear:

$$V = V_0 \cdot (1 + \beta_V \cdot W), \quad (3)$$

where B_V – the coefficient of volumetric shrinkage that is equal to the relative decrease in body volume with a change in moisture content by 1%, $B_V = \frac{dV}{V_0 \cdot dW}$;

V_0 – volume of the absolutely dry body.

A.V. Lykov proposed determining the coefficient B_V by two values V_1 and V_2 for mass fractions of moisture W_1 and W_2 , for example, before and after drying. Hence:

$$V_1 = V_0 \cdot (1 + \beta_V \cdot W_1) \quad (4)$$

$$V_2 = V_0 \cdot (1 + \beta_V \cdot W_2). \quad (5)$$

These equations can determine V_0 and β_V . Denoting the relative (in relation to the initial volume) shrinkage by δ , it is written as:

$$\delta = \frac{V_1 - V_2}{V_1} \quad (6)$$

then

$$\beta_V = \frac{\delta}{(W_1 - W_2) - \delta \cdot W_1}. \quad (7)$$

Table 2 shows the coefficients of volumetric shrinkage of cheese.

If the linear parameters of the cheeses vary from the mass fraction of moisture in relation (2), then we can find a simple relationship between β_V and β_l , as well as between β_l and β_S .

TABLE 2: Coefficients of volumetric cheese shrinkage

Cheese	Coefficient of volumetric shrinkage β_V
Sovetskiy	0.017–0.004
Gollandskiy	0.006–0.003

The area of the material sample is equal to multiplication of the product length l and its width L that is:

$$S = l \cdot L = l_0 \cdot L_0 \cdot (1 + \beta_l \cdot W)^2 = S_0 \cdot (1 + \beta_l \cdot W)^2, \tag{8}$$

where $S_0 = l_0 \cdot L_0$ – the area of the absolutely dry material.

When deriving the formula, it is assumed that the body is isotropic and shrinkage in length and width is the same. If $(1 + \beta_l \cdot W)^2$; then it is as follows:

$$S = S_0 \cdot (1 + 2 \cdot \beta_l \cdot W) = S_0 \cdot (1 + \beta_S \cdot W), \tag{9}$$

where $\beta_S = 2 \cdot \beta_l$ – the coefficient of area shrinkage equal to the doubled coefficient of linear shrinkage.

The area shrinkage coefficient can be determined by the formula:

$$\beta_S = \frac{\delta_S}{(W_1 - W_2) - \delta_S \cdot W_1}, \tag{10}$$

where $\delta_S = \frac{(S_2 - S_1)}{S_1}$ – relative area shrinkage.

The relationship between the volume of the material and the moisture content is written as follows:

$$V = V_0 \cdot (1 + \beta_V \cdot W)^3. \tag{11}$$

An approximate formula can be developed:

$$V = V_0 \cdot (1 + 3 \cdot \beta_V \cdot W) = V_0 \cdot (1 + \beta_V \cdot W), \tag{12}$$

where $\beta_V = 3 \cdot \beta_l$ – volumetric shrinkage coefficient that is equal to the tripled linear shrinkage coefficient.

5. Conclusion

Thus, the dependences of the cheese shrinkage coefficients on the thickness of the drying layer, the shape and size of grinding are obtained. When the drying layer thickness is from 10 to 30 mm, the cheese shrinkage coefficient, depending on the shape and size of grinding, is from 3 to 14%. With an increase in the mass fraction of

moisture in cheese, an increase in shrinkage coefficients occurs. It is determined that the shrinkage of cheese in both periods of vacuum drying occurs evenly. With an increase in the drying temperature above the required volume, the shrinkage coefficient decreases, this is explained by an increase in the gradient of the mass fraction of moisture inside the material.

Conflict of Interest

The authors have no conflict of interest to declare.

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