THE RESEARCH OF HEAT TRANSFER PROCESS DURING FREEZING OF BERRIES

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Abstract

Good quality is one of the main problems in every stage of freezing berries. On the basis of worked out functional analysis of freezing, it is possible to optimize regulation possibilities of heat processes for a particular kind of berries. Raspberries, red currants and black currants were used in the research. 10.0 cm thick bulk frozen berry layer was chosen for studying the freezing process. The freezing dynamics of berries is characterised by temperature measurements in a layer and on its surface. As a result of the research the developed equipment for the measurements of heat flow are approbated. It is necessary to investigate suitability of different cultivars to freezing and influence of freezing to quality of final product. Experimentally verified results will help to explain and predict physical processes in berries during freezing.

Key words: freezing, temperature, berries, heat transfer

Introduction

Freezing as a physical process is connected with products inner moisture transforming into ice as the result of the temperature diminishing under the freezing point. With the decrease of temperature the chemical and microbiological processes in the product slow down. Therefore for each kind of product appropriate conditions have to be chosen for freezing, as also the state of products before freezing has to be taken into consideration to diminishing to the minimum the harmful influences on their quality.

Freezing has to be done quickly. But one should not overestimate the benefical influence of a high rate of freezing on the quality of the product. Experience shows that only few products demand very quick freezing. They are fruit and berries whose quality is largely influenced by the freezing rate (Kampuse, 2003). The freezing rate, in its turn, is essentially influenced by the temperature of heat dissipation into environment, the thickness of the product layer and the heat release coefficient. The research devotes the most attention to the heat release coefficient. With the decrease in temperature of heat dissipation into environment, freezing time shortens almost proportionally but the freezing expense increases. The heat release coefficient at a relatively thin product layer diminishes the freezing time.

Water disappearing in the biological system during the temperature decrease changes the thermo-physical properties of the product. The main and almost the only reason for the changes of thermo-physical properties in the product is the transformation of the free water into ice, because water and ice possess different thermo-physical properties.

When freezing foodstuff, changes in their physical-chemical and biochemical properties are individual and depend on the nature of the product and the freezing process conditions but basically there are great similarities. The aim of the research is to study the heat transfer processes during freezing of berries grown in Latvia.

Materials and Methods

Research object: fresh and frozen raspberries, red currants and black currants grown in Latvia. Specific cultivars were chosen with already stated chemical content. Two cultivars of red currants were used in the experiments (currant-1, currant-2).

Actual berries freezing temperature was –2…–30 °C, the layer thickness was 100 mm. For the determination of the layer density weight-volume method was used. For experimental heat flow research, the equipment for heat flow measurement at the Department of Physics of Latvia University of Agriculture (*LLU*) was used. It consists of a horizontal freezing chamber with a steady temperature (-30 °C) and a computerized wireless measuring system with heat flow sensors and thermocouples for temperature measurements (Figure 1).

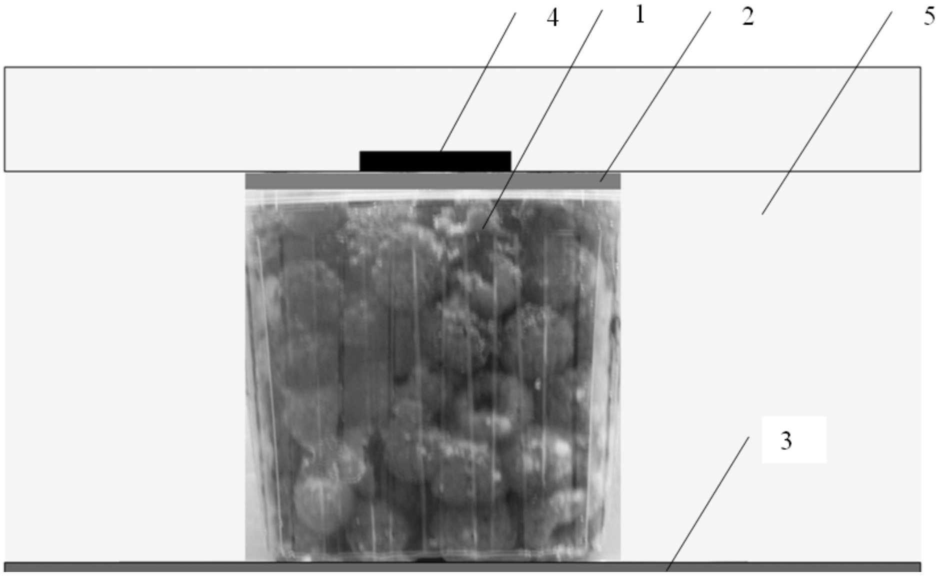

Figure 1. Scheme of the experiment for determining the heat conductivity coefficient of frozen berries

1 – berry sample, 2 and 3 – metal plates, 4 – sensor for heat flow measurement, 5 – thermo-isolating material

During the project, the machine was adjusted to measure the heat conductivity parameters of frozen berries samples. For this task, a sample holder of thermo-isolating material was made. The measurements are performed, placing frozen berries into a foam sample holder which is placed inside of the cold chamber. Under the sample of berries, there is a 0.3 mm metal plate placed for the insurance of the continuity of the temperature T_1. It is fixed by the thermocouple. Straight above the sample, another metal plate is placed for the keeping and the fixing of the continuity of the higher temperature T_3. On the warmer metal plate, symmetrically to the sample, the heat flow q measuring sensor is placed. Above the "warmer" plate and the q sensor, an additional plate of thermo-isolating material is placed to supply a negative temperature for the sample.

Results and Discussion

The research shows that the influence of the temperature has to be differentiated – if one can ignore the influence of the teperature on the specific heat and heat conductivity of fresh fruit, then regarding the enthalpy of frozen products, the temperature is one of the main factors. After the placement of the sample, fast change of temperature (Figure 3) and heat flow (Figure 4) in time period can be observed. It stabilizes in approximately 1000 minutes (~16 hours). With this, we can consider that stationary temperature distribution in the sample is set. At the stationary temperature distribution its change takes place in one dimension. In figure 2 heat flow through the sample is described by the Fourier equation:

$$q = \lambda \frac{\partial T}{\partial x}, \qquad (1)$$

where:

q – heat flow, W/m^2;
λ – heat conductivity coefficient, W/(m·K);
$\frac{\partial T}{\partial x}$ – temperature gradient, K/m.

This leads to the heat conductivity coefficient of the layer:

$$\lambda = \frac{q\partial x}{\partial T} = \frac{qd}{T_3 - T_1} \quad (2)$$

where;

d – thickness of the sample, m,
T_1 – the lowest temperature, ^oK,
T_3 – the highest temperature, ^oK.

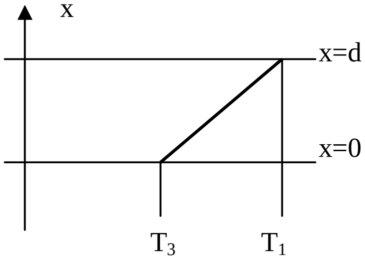

Figure 2. Distribution of temperature in the sample in a stationary situation

Data of the temperature distribution and heat flow after the set of stationary distribution with sample thickness d=0.1 m are used in the calculations. Results are summarized in the Table 1.

Table 1

Thermo-physical parameters of berries

No.	Sample type	p, kg/m^3	λ, W/(m K)
1	Currant-1	558	0.084
2	Currant-2	610	0.087
3	Black currant	438	0.072
4	Raspberry	419	0.079

The research proved that the increase of the product thickness over 20 cm and the increase of the heat release coefficient above 90 W/(m^2 K) almost do not influence hastening of the freezing process.

As the research showed (Kampuse, 2003), cell destruction is obvious in raspberries, i.e. berries with thin parenchyma walls and big intercellular space. These berries contain 84–89% water and 5–10% sugar of the total weight. It promotes the formation of big ice crystals. It is especially important to take into consideration the supplying of reversibility of the technological process. It was observed that in the heat processing of whole cells, the most important change of initial consistency is in the penetrability of the cells membrane.

The products temperature conductivity increases with ice crystals forming. So simultaneously specific heat diminishes and heat conductivity increases. The decreasing temperature of the products and growing of temperature conductivity stops with ice forming finishing. Analyses of professional literature (Skrede, 1996) and the results of the experiment enable to conclude that the transformation of water into ice is one of the most important aspects of freezing.

All these factors are taken into consideration in the research. The most attention is paid to the heat release coefficient. With the decrease of temperature of the heat dissipation into environment, the length of freezing shortens almost proportionally but production expenses increase. The determination of the precise freezing temperature for each product type allows one to create conditions for the effective use of technological process in temperature ranges where the most unfavourable quality changes affecting the berries take place. In temperatures below the freezing point, its influence on fruit heat physical indicators cannot be taken into consideration.

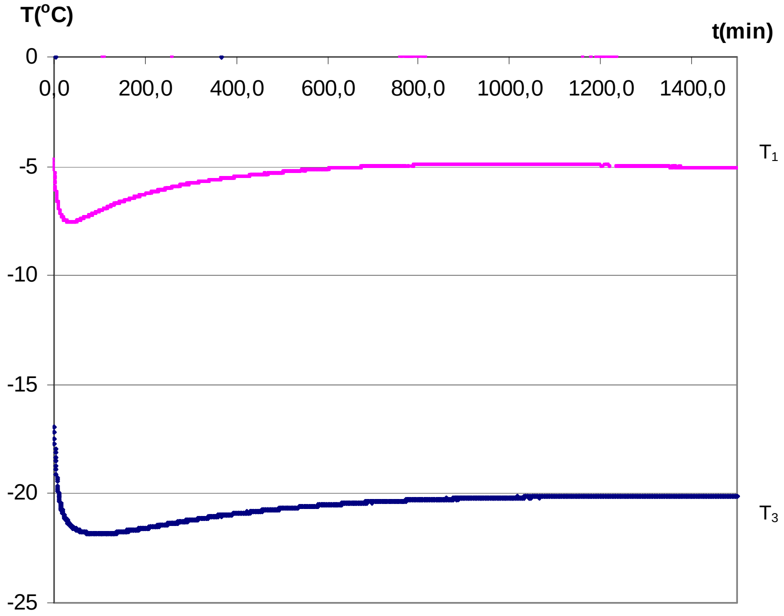

Figure 3. Change of temperature of the raspberry sample surfaces

In the heat calculations of the freezing process, the determined heat of the frozen products is used with the latent heat of ice formation (Wang, 1990). In technical calculations, the ice heat conductivity coefficient is asummed 2.22 – 2.33 W/(m K).

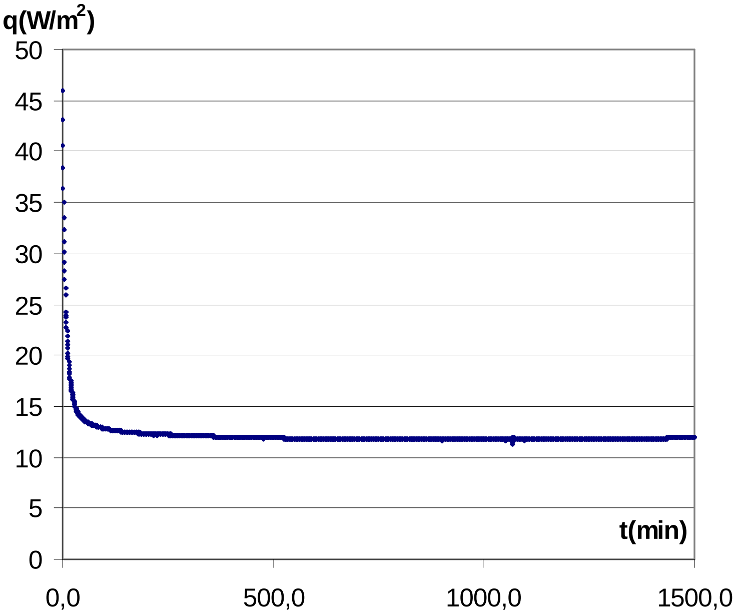

Figure 4. Change of heat flow through the raspberry sample

The heat conductivity coefficient of foodstuff containing 70–80% water including fruit and berries is determined by the general formula. During the research, evidence for the hypothesis on the ruling role of the temperature in the freezing processes was established. Also discoveries and new information was gained on the freezing processes that are mutually interconnected. It secures scientifically practical evidence for some technological developments of qualitative improvement in berry freezing methods and their usage range.

Conclusion

1. The lower the temperature of the heat dissipation into environment and the higher is heat release coefficient, the shorter is freezing time.

2. The rate of freezing is essentially influenced by the temperature of the heat dissipation into environment and the heat release coefficient.

3. The increase of the heat conductivity of the product by the decrease of the temperature is practically over when the water begins to turn into ice.

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