RESEARCH IN HEAT TRANSFER PROCESS DURING FREEZING BERRIES

Ilze Beitane, Aivars Aboltins, Anita Blija, Uldis Gross, Sigita Boca, Imants Skrupskis
Latvia University of Agriculture
ilzebeitane@inbox.lv

Abstract. Good quality is one of the main problems in every stage of freezing berries and fruits. 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 and fruits. Fresh raspberries, red currants and black currants grown in Latvia were used in the research. 10.0 cm thick bulk frozen berry layer was chosen for studying the freezing and storage 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 the heat flow was approbated. Theoretical calculation of the heat flow process is described. It is necessary to investigate suitability of different cultivars for freezing and influence of freezing to the quality of final product. Experimentally verified results will help explain and predict physical processes in berries during the freezing and storage process. The research shows that the influence of the temperature has to be differentiated – if one can ignore the influence of the temperature 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. Specific cultivars were chosen with already stated chemical content. By processing the experimental data the following thermo-physical parameters of frozen berries are obtained which further help theoretically more precisely mathematically simulate both the process of storage and thawing of frozen berries. The said researches provide additional information on the process kinetics of frozen food products, mass transfer in them, as a result of what it enables more precise projecting of their quality change.

Key words: freezing, storage, berries, heat flow.

Introduction

Frozen storage is one of the methods for long – term preservation of soft berries. Freezing as a physical process is connected with product internal moisture transforming into ice as a result of temperature falling under the freezing point. Freezing has to be done quickly. Experience shows that only few products demand very quick freezing. They are fruit and berries the quality of which is largely influenced by the freezing rate [1; 6]. Therefore, for each kind of product appropriate conditions have to be chosen for freezing, as well as the state of products before freezing has to be taken into consideration to diminish the harmful influences on their quality to the minimum.

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. In the research the most attention is paid to the heat release coefficient. With the decrease in temperature of heat dissipation into environment, the freezing time shortens almost proportionally but the freezing expense increases. The heat release coefficient at a relatively thin product layer reduces the freezing time. In thin friable berry layers the convection of air through a layer, heterogeneity of the medium and differences between the thermal conductivity of air and berries must be taken into account. However, the thermo-physical parameters of berries and fruits are still poorly described in scientific literature.

Water disappearing in the biological system during the temperature decrease changes the thermo-physical properties of the product. Different descriptive theoretical models of freezing and storage processes can be found in literature [4; 5].

Analyses of professional literature [7] and the results of the experiment enable to conclude that transformation of water into ice is one of the most important aspects of freezing because water and ice possess different thermo-physical properties.

As the research showed [6], 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 heat processing of whole cells, the most important change of initial consistency is in the penetrability of the cell membrane.

The aim of the research is to study heat transfer processes during the freezing process of berries grown in Latvia.

Materials and methods

The research object: fresh and frozen raspberries, red currants and black currants grown in Latvia. Specific cultivars were chosen with already stated chemical content in technical ripeness. Two cultivars of red currants were used in the experiments: "Red Dutch" and "Vierlander" (currant-1, currant-2); blackcurrant cultivar – "Titania"; Raspberries – "Rubin".

The actual berries freezing temperature was -25 ºC ... -30 ºC, the storage temperature was -20 ºC, the layer thickness was 100 mm. For determination of the layer density the weight-volume method was used. For experimental heat flow research, the equipment for heat flow measurement at the Department of Physics of the Latvia University of Agriculture (LLU) was used. It consists of a horizontal freezing chamber with a steady temperature (-30 ºC) and a computerized wireless measuring system with heat flow sensors and thermocouples for temperature measurements.

During the process, the machine was adjusted to measure the heat conductivity parameters of the frozen berries samples. For this task, a sample holder of thermo-isolating material was made. The measurements were performed, placing the frozen berries into a foam sample holder which was placed inside the cold chamber. Under the sample of berries, there was a 0.3 mm metal plate placed for insurance of the continuity of the temperature T_2. It was fixed by the thermocouple. Straight above the sample, another metal plate was placed for keeping and fixing the continuity of the higher temperature T_3. On the warmer metal plate, symmetrically to the sample, the heat flow q_1, q_2 measuring sensor was placed (Fig. 1). Above the "warmer" plate and the q_2 sensor, an additional plate of thermo-isolating material was placed to supply negative temperature for the sample.

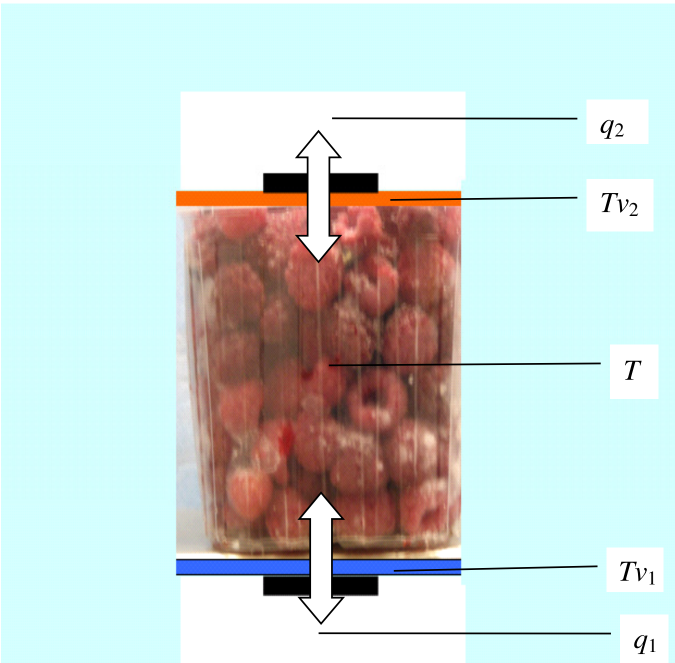

Fig. 1. **Experimental scheme for determination of heat conductivity coefficient of frozen berries**

Results

The research shows that the influence of the temperature has to be differentiated – if one can ignore the influence of the temperature 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 the heat flow and temperature (Fig. 2 and 3) 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.

The mathematical model considers the first stage of thawing, which is warming of frozen products until the melting point. In the first approximation it could be described as warming of the infinite layer with a definite height (*H*) in the air (warming from sides is not taken into account).

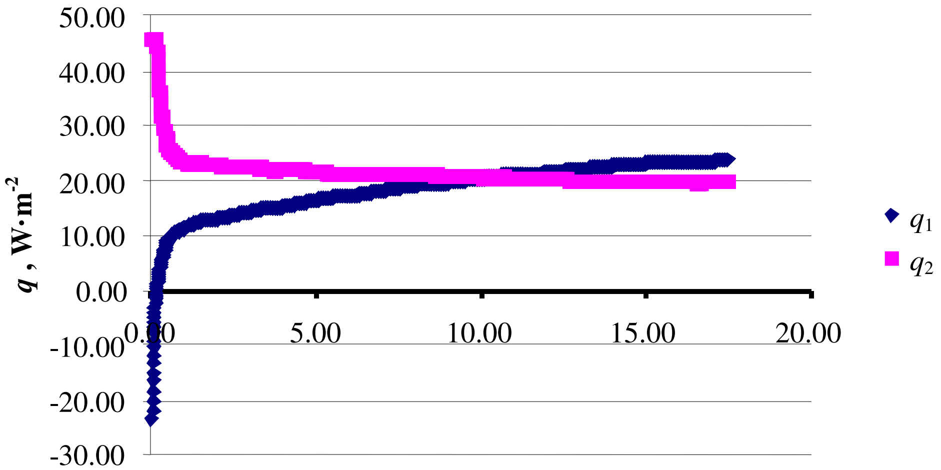

Fig. 2. **Heat flow q_1, q_2 changes in frozen black currant**

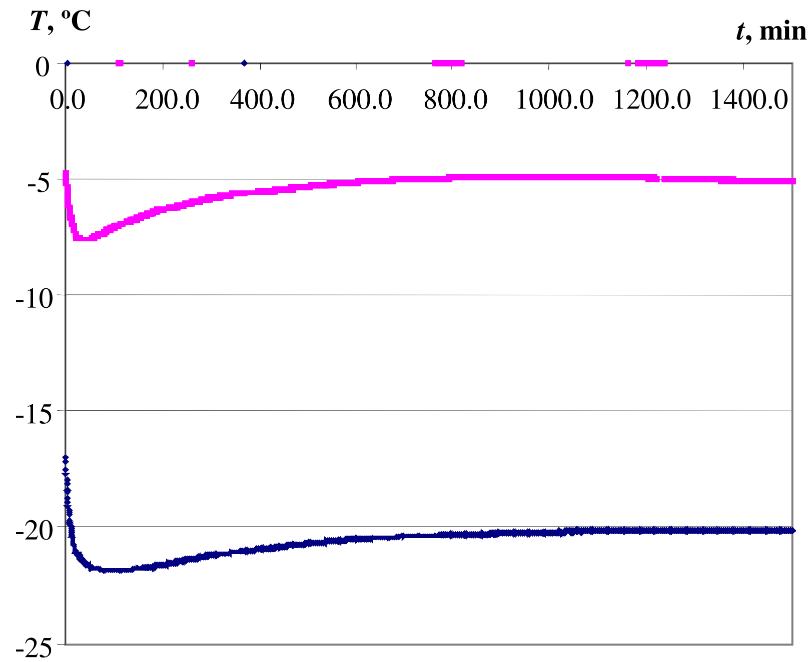

Fig. 3. **Change of temperature *T* of raspberry sample surfaces during the process time *t***

In the stage while the product is in a frozen condition, we will not consider mass transfer processes in this approximation. Heat exchange is an unstationary process and unstationary thermal conductivity equation in an infinite layer is taken as basis:

$$\frac{\partial T}{\partial \tau} = a\frac{\partial^2 T}{\partial x^2}, \tag{1}$$

where T – temperature, ºC;
τ – time, s;
a – temperature conductivity coefficient, $m^2 \cdot s^{-1}$;
x – co-ordinate axis where the process takes place.

For complete definition of the mathematical physics problem, the initial condition is necessary

$$T\big|_{t=0} = T_1, \tag{2}$$

where T_1 – initial temperature of the currant layer.

The boundary conditions are (bottom and top of the layer)

$$T\big|_{x=0} = T_2 \tag{3}$$

$$T\big|_{x=H} = T_3, \tag{4}$$

To solve the problems (1)-(4) we use the variable separation method (by Fourier) and the solution of (1)-(4) is

$$T(x,t) = \frac{2T_1}{\pi} \sum_{n=1}^{\infty} \frac{1-(-1)^n}{n} \cdot \exp(-(a\frac{\pi \cdot n}{H})^2 t) \sin\frac{\pi \cdot n \cdot x}{H} + \frac{T_3 - T_2}{H} x + T_2 \tag{5}$$

By deriving the obtained expression (5) after x, theoretical expression of flow distribution can be obtained

$$\frac{\partial T(x,t)}{\partial x} = \frac{2T_1}{H} \sum_{n=1}^{\infty} (1-(-1)^n) \cdot \exp(-(a\frac{\pi \cdot n}{H})^2 t) \cdot \cos(\frac{\pi \cdot n \cdot x}{H}) + \frac{T_3 - T_2}{H}.$$

In its turn $\frac{\partial T(x,t)}{\partial x} = \frac{q}{\lambda}$.

At stationary situation ($t \to \infty$) $\lambda = \frac{q \cdot H}{T_3 - T_2}$.

By processing the experimental data the following thermo-physical parameters of frozen berries are obtained which further help theoretically more precisely mathematically simulate both the process of storage and thawing of frozen berries (see Table 1). These parameters will allow determining processes more precisely taking place on the boundary surface layer of frozen berries, as well as determine the temperature conductivity coefficients for different kinds of frozen berries.

Table 1

Calculated thermo-physical parameters of berries

Sample type	ρ, kg·m^{-3}	λ, W·(m·K)$^{-1}$
Currant-1	558	0.084
Currant-2	610	0.087
Black currant	438	0.072
Raspberry	419	0.079

The product temperature conductivity increases with ice crystals forming. So, simultaneously the specific heat diminishes and heat conductivity increases. The decreasing temperature of the products and growing of the temperature conductivity stops with finishing of ice formation.

Determination of the precise freezing temperature for each product type enables to create conditions for effective use of the technological process in temperature ranges where the most unfavourable quality changes affecting the berries take place. By the temperatures below the freezing point, the influence on fruit heat physical indicators cannot be taken into consideration.

Discussion

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 were 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 [3].

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.

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 the production expenses increase.

From the sample during the change of temperature by using the method of smallest squares the relaxation time τ characteristic to the process is searched which enables to obtain theoretical temperature changes of the sample in time. Researches in the difference in temperatures show that after 10000 seconds it becomes constant. It can be concluded that the dynamic phase of the process has finished. Consequently, the heat flow through the sample also should become constant which unfortunately is not so. During further process of sample warming, the significance of parasitic heat conductivity processes through the insulation material increases. Therefore, for determination of the relaxation time τ characteristic to the process data up to 10000 seconds are used.

In low temperatures particles of frozen products are in a concentrated amorphous state because liquid is concentrated under the influence of freezing, but plasticity is imparted by unfrozen water. Under the common storage temperatures the product physical condition is provided by the particle properties and their influence on ice thawing [1].The lower the temperature of the heat dissipation into environment and the higher the heat release coefficient, the shorter the freezing time. The rate of freezing is essentially influenced by the temperature of heat dissipation into environment and the heat release coefficient. 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 [2; 5].

The said researches provide additional information on processes kinetics of frozen food products, mass transfer in them the result of what enables more precise projecting of their quality changes [6].

Researches will make possible usage of the yield of local berries produced at local climatic conditions. Their use in nutrition will eliminate the seasonal character and imbalance. Therefore, scientific researches and practical measures are necessary in searching for advanced storage and preservation methods where freezing takes an important part.

Conclusions

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