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# SOME ASPECTS CONCERNING STRAWBERRIES FREEZING USING LIQUID NITROGEN

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***Abstract:*** *This paper presents some aspects concerning strawberries freezing using liquid nitrogen: duration of the process, freezing capacity, advantages and disadvantages of this modern method. Quick freezing of food products in a cryogenic freezer consist in the use of evaporation latent heat of the liquid nitrogen, as well as of the sensible heat of the vapors, whose temperature increase up to final temperature of the frozen product. The use of cryogenic freezing with liquid nitrogen and carbon-dioxide is regarded as the "centuries revolution" in the food area.*

***Key words*:** *strawberries, freezing, liquid nitrogen*

## 1. Introduction

Freezing is the favorite modern mean for best preservation of nutrient properties of a large number of alimentary products, ensuring long term preservation.

Direct contact freezing using liquids (nitrogen or $CO_2$), is done either by sinking the product in a cold liquid or by spraying the product with this liquid.

The liquid can evaporate or not, but in either cases, the method has the main advantage of a great improvement of the heat transfer coefficient between the product to be frozen and the refrigerant.

Using cryogenic systems one can avoid the large investment required for a compression refrigeration system, using only from time to time cold delivery in the shape of the liquefied cryogenic fluid.

## 2. Require Freezing Time

Freezing is the process by which most of the water from the cellular liquid and the water from a product's tissues (capillary vases, intercellular spaces) is turned into ice. Water crystallization temperature ranges between -1…-5°C, at which 60…75% of the whole water content turns into solid. The process must be continued afterwards by subcooling the product to a final temperature of -18 -25°C, at which 90…95% of the water content turns into solid. Thermal core temperature is a main indicator of the end of the freezing process as it can be with maximum 3 5°C higher than the products' storage temperature.

International Institute of Refrigeration established the following conditions: final temperature of the products thermal core ≤ -15°C, average final temperature ≤ -18°C.

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Freezing process of a food product is a typically transient heat and mass transfer process. Transfer phenomenon are complex due to the phase change of the solidifying water and of the transport properties of the product (thermal conductivity, specific heat.

Computing methods use some simplifying hypotheses which allow establishing some simple calculus relations for the freezing duration (according to Plank):

- all the heat is drawn from the product at the freezing point temperature;
- the products are homogenous and Isotropic;
- the cooling surroundings has a constant temperature;
- the product has already been cooled down to the freezing temperature.

For a spherical shape product, freezing duration can be determined using Plank's formula [3]:

$$\tau_{cg} = \frac{\rho \cdot l_{cg}}{t_{cg} \cdot t_{mII}} \cdot \left( \frac{r_0^2}{6 \cdot \lambda} + \frac{r_0}{3 \cdot \alpha} \right) [\mathrm{s}] \qquad (1)$$

where:
$t_{cg}$ = -0,7 [ºC] - freezing temperature;
$t_{mII}$ = -150 [ºC] - cooling surrounding temperature (zone II);
$\alpha$= 530 [W/m$^2$K] - convection coefficient;
$r_0$ = 0,0075 [m] - sphere radius;
$l_{cg}$ = 280,4 [kJ/kg] - freezing latent heat of the product;
$\rho$ = 921 [kg/m$^3$] - product density;
$\lambda$ = 1.35 [W/mK] - thermal conductivity of the product;

$$\tau_{cg} = 28.53 \ [\mathrm{s}]=0,5 \ (\mathrm{min})$$

For freezing using liquid nitrogen the values for $\alpha$ are between 35 [W/m$^2$K] (vapor precooling area) and 525…535 [W/m$^2$K] (nitrogen liquid spraying area).

Total duration of the freezing process is:

$$\tau = \tau_r + \tau_{cg} + \tau_{sr} \ [\mathrm{s}] \qquad (2)$$

where:
$\tau_r$ [s] - primary refrigeration duration;
$\tau_{cg}$ [s] - freezing duration;
$\tau_{sr}$ [s] - product duration subcooling;

Primary refrigeration duration can be computed from the following relation:

$$\tau_r = \frac{m \cdot c}{\alpha \cdot s} \cdot \ln \frac{t_i - t_{mI}}{t_f - t_{mI}} \ [\mathrm{s}] \qquad (3)$$

where:
m = ρV [kg] - product mass;
$\rho$ = 921 [kg/m$^3$]; $V = \frac{4 \cdot \pi \cdot r_0^3}{3}$ [m$^3$]

$$m = 1000 \cdot \frac{4 \cdot \pi \cdot 0,0075^3}{3} = 0,00174 \, \mathrm{kg}$$

$c$ = 3.852 [kJ/kg]- product's specific heat;
$\alpha$ = 35 [W/m$^2$K] - convection coefficient;
$s = 4\pi r_0^2$ = 0,000706 [m$^2$] - product's external surface;
$t_I$ = 25 [ºC] - product's initial temperature;
$t_f$ = -0,7 [ºC] - product's final temperature;
$t_{mI}$ = -60[ºC]-cooling surrounding temperature (zone I);
$\tau_r$ =90.92 [s] =1,5[min]

The duration for subcooling of the frozen product to the final average temperature ($t_{mf}$) can be calculated using Plank's relation:

$$\tau_{sr} = 933 \cdot c_m \cdot n \cdot \left| \lg \frac{t_{cg} - t_{mIII}}{t_m - t_{mII}} - 0,0913 \right| \cdot \left( \frac{2 \cdot r_0}{\alpha} + \frac{r_0^2}{\lambda} \right) \cdot \frac{1}{3,6} \ (h) \qquad (4)$$

where:
$c_m$ = 1,88 [kJ/kgK] - frozen product average specific heat;
$n$ - dimensionless coefficient, whose values depends on the Biot dimensionless group, defined by:

$$Bi = \frac{\alpha \cdot \delta}{\lambda} \qquad (5)$$

where $\delta = r_0$.

*Values for the dimensionless coefficient n vs. Bi* Table 1

| Bi | 0.2 | 0,25 | 0,5 | 1,0 | 2,0 | 4,0 | 10 | ∞ |
|---|---|---|---|---|---|---|---|---|
| n | 1.232 | 1,21 | 1,188 | 1,156 | 1,112 | 1,06 | 1,02 | 1,00 |

Bi = 0,19 ≈ 0,2 ⇒ n = 1,232

$t_{cg}$ = -4 [ºC] - freezing final temperature;
$t_{mIII}$ = -80 [ºC] - cooling surrounding temperature (zone III);
$t_m$ = -18 [ºC] - thermal core final temperature of the product;

$\tau_{sr}$ = 0.0162 [h]=58,32 [s]=1 (min)

Freezing process total duration is:
$\tau_c$= 3 [min]

## 3. Freezing Capacity

For freezing strawberries was used cryogenic freezer using liquid nitrogen designed and built by the author. Strawberries are placed in a plastic wrapping with the dimensions:
- L x W x H (mm):160x100x70;
- wrapping volume: 0,00112 $m^3$;
- strawberries radius: r=7,5 mm;
- the number of the strawberries in a box: $n_c$= 240

V- volume occupied by the strawberries in a box .

A sketch with strawberries displacement in a box is shown in Fig.1.

$$V = \frac{4 \cdot \pi \cdot r^3}{3} \cdot n_c = 0{,}000424 \text{ [m}^3\text{]} \qquad (6)$$

The weight of a box of strawberries:

$m=\rho \cdot V=921 \cdot 0{,}000424=0{,}39$[kg]

The boxes will be placed on a single row, as shown in Fig. 2:

$\tau_p$ = 11,76 [s]
$\tau_p$ - time in which the product covers a distance equal to the length of the box;

$\tau_n = \tau_c + (n-1)\tau_p$ (6)

Number of frozen boxes hourly is:

$$n = 1 + \frac{\tau_n - \tau_c}{\tau_p} = 291{,}125 \text{ [boxes /hour]} \qquad (7)$$

The quantity of strawberries freezed hourly

$$m_t = n \cdot m = 113.53 \text{ [kg/h]} \qquad (8)$$

The actual quantity of strawberries freezed hourly:

$$m_r = \frac{160}{165} \cdot m_t = 110.098 \text{ [kg/h]} \qquad (9)$$

Hourly capacity for strawberries displaced in a single layer:

$$\dot{m} = \frac{110}{4} = 27.5 \text{ [kg/h]} \qquad (10)$$

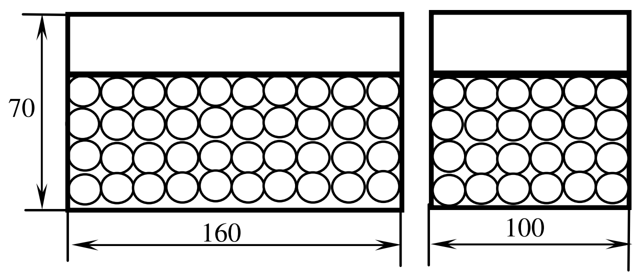


Fig. 1. *Strawberries displacement in a box.*

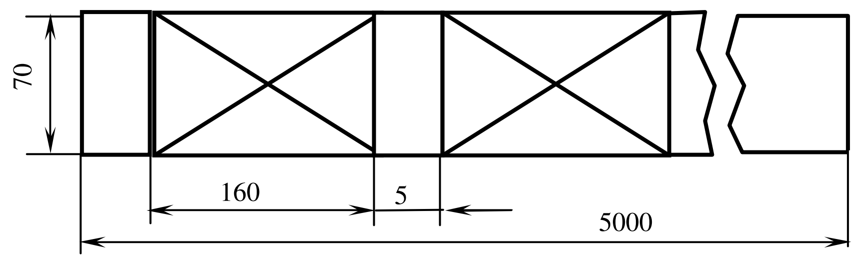


Fig.2 *Placed boxes.*

*Economical aspects on freezing methods* Table 2

| Objectives | UM | Freezing methods | | |
|---|---|---|---|---|
| | | fixed layer | fluidized bed | cryogenic fluids |
| Investment costs | % | 100 | 100 | 50…66 |
| Specific surface | $m^2$/t/h | 40…60 | 15…35 | 10…25 |
| Cooling need | $10^3$ kcal/t | 110…130 | 110…130 | 90…95 |
| Required energy | kWh/t | 110…130 | 100…120 | - |
| Manual labor | % | 67…470 | 100…2000 | 90…97 |

## 4. Conclusions

In order to make a comparison, in the following table are shown some economical parameters [4].

The main **advantages** of liquid nitrogen freezing are:

- simple design, small space required and easy cleaning
- short startup and freezing times,
- reduced weight losses,
- investment costs are with 50% smaller than for vapor compression systems, and there are no maintenance costs involved,
- the system can be used for various food products with no modifications,
- movable freezers can be designed.
- the liquid nitrogen is obtained as a auxiliary product in oxygen manufactory.

The main **disadvantage** of this freezing method is the high cost of liquid nitrogen, but considering that freezing cost accounts only for 5,3% of the product's price, one may disregard this disadvantage.

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