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THE STUDY OF THE HEAT AND MASS TRANSFER FOR THE FLUIDIZATION FREEZING OF PRODUCTS.
II. PRACTICAL ASPECT

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Abstract

The freezing by fluidization of the granular products is a complex process of heat and mass transfer in inconstant conditions. This paper describes the thermodynamics of granular products freezing and reviews heat and mass transfer coefficient calculation methods.

Keywords*: heat and mass transfer, granular vegetables, convection coefficient, freezing time*

Introduction

The freezing by fluidization of granular vegetables is a complex process of mass and heat transfer in non-stationary state. For the classification of the mass and heat transfer the granular product submitted to freezing by fluidization is defined as a two-phase mix with an intense mass and heat transfer in forced convection system. In this case the determined variables are numerous (Fricke, 2002).

Thus, for the definition of the process data regarding the geometry of the system, density, thermal conductibility, specific heat as well as the specific parameters regarding the change of the aggregation forms (solidification latent heat, etc.) is necessary.

It is considered a granular product (cube, rectangular or discs shaped pieces of carrot) submitted to freezing by fluidization with the following characteristics: thickness, $\boldsymbol{\delta}$; surface, **F**; volume mass, $\boldsymbol{\rho}$; specific heat, $\mathbf{c_p}$; thermal conductibility, $\boldsymbol{\lambda}$; freezing temperature, $\mathbf{t_c}$ and the freezing installation that interferes with the temperature of the environment and the convection coefficient, $\boldsymbol{\alpha}$ (Tofan, 2002).

During the freezing it is established a freezing front that advances from the surface of the granular product to its thermal center (figure1).

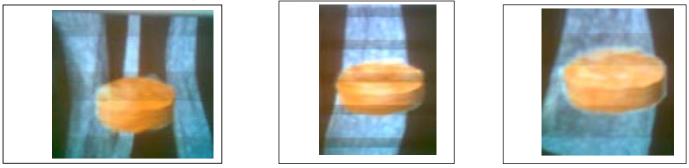


Figure1. Freezing front that advances from the surface of the granular product to its thermal center

In these conditions it takes place simultaneously an external thermal transfer by forced convection in non-stationary state and an internal transfer by diffusion (Bratu, 1961).

The external thermal transfer by forced convection is expressed by the relation:

$$Q = \alpha F\left(t_c - t_0\right) \qquad (1)$$

and the internal transfer by diffusion is expressed by the relation:

$$Q = \lambda F \frac{t_c - t_0}{x} \qquad (2)$$

The transfer of the quantity of elementary heat *d***Q** through a product that has the *d***x** thickness of the freezing front is materialized by the variation of the enthalpy.

$$dQ = \rho F dx dh \qquad (3)$$

The variation of the mass enthalpy *d***h** corresponds in this case to a simple state transformation. In these conditions, if the initial humidity of the product is **w** and **φ** is the proportion of frozen water, it can be written:

$$\Delta h = \varphi W l \qquad (4)$$

In the same time it takes place a mass transfer materialized by the loss in weight due to the partial dehydration of the product by the evaporation or the sublimation of the water from the surface of those in contact with the fluidization agent.

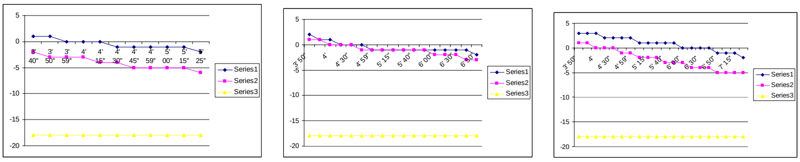
Experimental

The techniques used for the determination of the heat transfer coefficients can be split into three categories: measuring methods of temperature in a fixed state, measuring methods of the transitory heat transfer and measuring methods of the surface heat flux. Out of these three techniques, the most popular methods are the measuring techniques of the transitory temperature.

The transitory methods for the determination of the heat transfer coefficient imply the measuring of the temperature of the product during the freezing process. For that it is utilized the ScanLink 2.0 software.

Results and Discussions

In figures 2a, 2b, 2c, there are shown the curves that represent the variation in time of the temperatures from the surface of the project to its thermal center.



a b c

Figure 2. The temperature variation in the thermal centre of the product and in the product layer during the freezer fluidized bed
a) for the cube shape; b) the rectangular shape; c) the discs shape.
serie 1 – the temperature in the thermal center; serie 2 – the temperature at the surface of the product; serie 3 –the temperature of the agent

The transitory method for the determination of the heat transfer coefficient serves for the solving of the heat transfer in non-stationary state problem and of the calculation of the freezing time in the fluidic layer (Iliescu, 1982).

The mathematical relation that is at the basis of this method is:

$$\alpha = \frac{mc}{F\tau_{\exp}} \ln\left(\frac{t_i - t_0}{t_f - t_0}\right) \qquad (5)$$

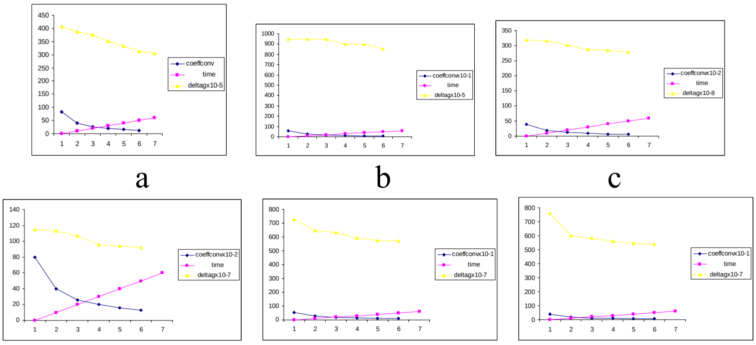
For the calculation of the losses in weight it is used the relation:

$$\Delta g = \frac{F\alpha_{calc}}{l}\left[\frac{h_s - h_a}{c_p} - \left(t_f - t_0\right)\right]\cdot\tau_{\exp} \tag{6}$$

After the calculus obtained results are presented in table 1 and figure 3.

Table 1. The experimental and calculated data

Shape $L\cdot l\cdot h$[mm]	$m\cdot 10^{-3}$ [kg]	c_p [J/kg]	F [m^2]	τ_{exp} [s]	t_i [°C]	t_f [°C]	t_o [°C]	α_{calc} [W/m^2K]	Δg [kg]
cube $8\cdot8\cdot8$	0.500	3725	0.064	1	4	- 1.4	- 18	23	0.0000129
cube $15\cdot15\cdot15$	2.947	3725	0.225	8	4	- 1.4	- 18	5	0.000079
rectangular $15\cdot8\cdot8$	0.945	3725	0.120	2	4	- 1.4	- 18	11	0.0000232
rectangular 20x10x10	2.316	3725	0.200	5	4	- 1.4	- 18	7	0.0000615
discs ($\Phi\cdot\delta$) $30\cdot6$	5.856	3725	0.180	2	4	- 1.4	- 18	47	0.000148
discs ($\Phi\cdot\delta$) $30\cdot8$	7.615	3725	0.240	4	4	- 1.4	- 18	23	0.000194

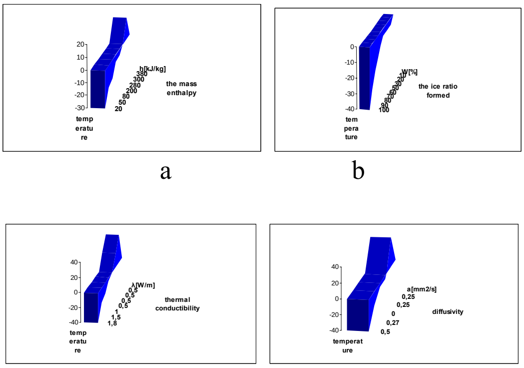


a b c

d e f

Figure 3. The thermal convection coefficient and the losses in weight by dehydration variation in the product layer during the freezer bed fluidized a,b) for the cube shape; c, d) the rectangular shape; e,f) the discs shape

During the freezing by fluidization process the thermo-physical properties of the product are changing (figure 4). As it results from the figure, the enthalpy of the frozen product drops as the freezing process advances and according to the quantity of freezable water.



a b

c d

Figure 4. The variation of the thermo-physical properties of the product during freezing

a) the variation of the mass enthalpy according to the temperature, b) the variation of the ice ratio formed according to the temperature, c) the variation of the thermal conductibility, d) the variation of the diffusivity.

The quantity of heat extracted from the product during the freezing depends very much upon the quantity of freezable water.

The quantity of formed ice increases as the temperature drops, as well as the thermal conductibility. The conductibility of the ice is four times higher than the conductibility of water, factor that plays an important role to the increase in the freezing speed. The thermal conductibility varies according to the nature of the product, temperature and the structural orientation of the tissues.

Conclusions

From the presented data it can be stated that due to the high speed of the air, the thermal convection coefficient is high, reaching 5 – 47 W/m^2 K, and it allows the realization of a quick freezing. In the case of the mass transfer, the losses in weight by dehydration are negligible.

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