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THE STUDY OF HEAT AND MASS TRANSFER WHEN FREEZING BY FLUIDIZATION OF PERISHABLE FOOD PRODUCTS. PART I. THEORETICAL BACKGROUND

Mihaela Gabriela Chirila, I. Tofan
Dunarea de Jos Unversity-Galati, Faculty of Engineering Sciences, The Freezing and Air-Conditioning Technique 47 Domneasca Street, 800008-Galati, Romania,
ioan_tofan@yahoo.com; chrl_mihaela@yahoo.com.uk

Abstract

During the freezing process by fluidization the heat and mass transfer varies, the different parts of the product being in various stages of cooling. The freezing speed influences the heat and mass transfer, and the mechanism of forming the ice crystals respectively and, in the end, the quality of the frozen product destined to consumption.
***Keywords**: fluidization, heat transfer, mass transfer, freezing, quality.*

Introduction

The heat transfer is the science of irreversible spontaneous processes of heat propagation in space and it represents the heat exchange between two bodies, two regions of the same body as a result of the temperature difference between the two.

The heat exchange observes the principles of thermodynamics: the first principle of thermodynamics that expresses the law of energy preservation, and the second principle of thermodynamics, that settles the natural direction of heat propagation, always from the higher temperature source to the lower temperature one (Ştefãnescu,1983).

By mass (or substance) transfer one understands the passing of a component from a phase into another or within a phase, phenomenon which occurs due to the tendency of one or more components in a homogenous mixture to move to zones of higher concentration to those of lower concentration; the driving force of the mass transfer is, therefore, the deficiency of concentration and the process of transfer continues until a phase dynamic balance is achieved, when the concentration of the component between the two phases has homogenized (Alexandru,1990).

Theoretical background

With a view to the freezing by fluidization, the product is introduced in the freezing by fluidization installation (figure 1), in which the air temperature is of - 35°C , the relative air humidity is of 90%, and the coefficient of air recirculation, by means of extremely high fan power, is of approximately 250/h (Mihalca, 1980).

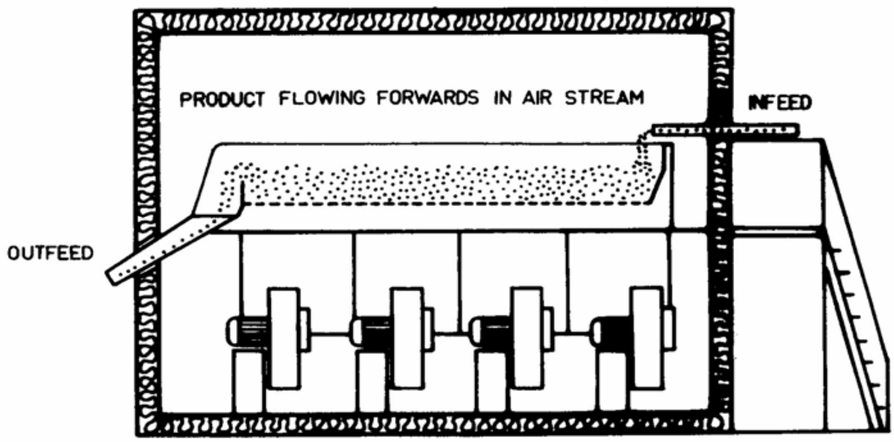

Fig. 1. – The freezing installation in fluidized bed of granular perishable products

The heat transfer in fluidized bed is made:

- between the solid particles and the fluid, during various operations of heat retrieval without mass transfer or during operations with mass transfer (drying, freezing, etc.);
- between the fluidized bed and a surface of inner heat exchange;
- between different points within the bed.

Hypotheses of working conditions in fluidized bed:

- the granular product(strawberries, peas, cherries, raspberries, etc.) which is being frozen has a uniform temperature in the beginning and cools down at a constant temperature;

- the thermal transfer coefficient between the surface of the granular product and the fluidization agent is uniform and constant;
- thermal conductivity and the specific heat of the frozen and unfrozen body is constant;
- density does not vary alongside the temperature during the freezing process;
- the released latent fluidization heat defines the freezing point.

Stages of freezing in fluidized bed (figure 2):

- the pre-cooling of the granular product;
- the freezing;
- the cooling of the frozen product up to the final storing temperature (-18°C)

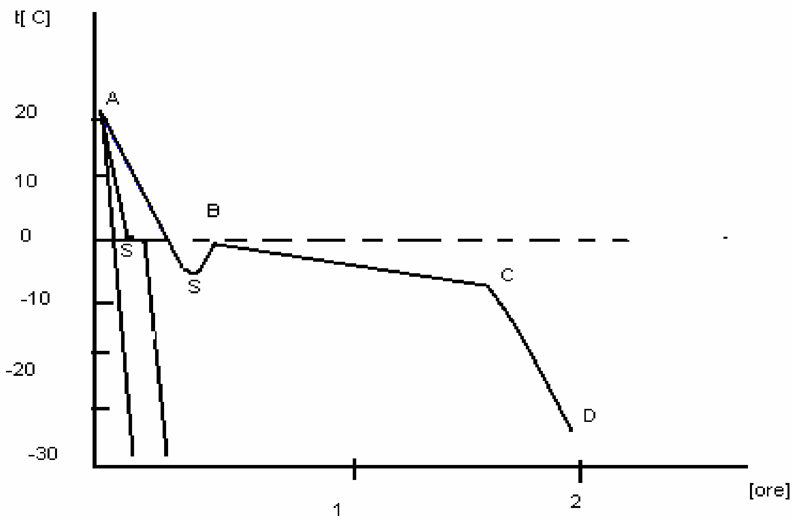

Fig. 2. – The variation of the product temperature during the freezing in fluidized bed (Tofan, 2002)

At the flow through a granular layer the variation of the pressure drop is influenced by the Reynolds number (figure 3). Between the A and B points, the granular bed is steady. In the B point, the weight of the fluid is balanced. Between the B and C the bed is unstable, the particles move placing themselves in such a way that resistance to the fluid should be minimum. In the C point the optimum position of the particles which are still in contact has been obtained. Above this point the particles start moving freely but they still touch themselves frequently up to the D point. When the speed of the agent increases and the D point is surpassed, the particles are still in free suspension. The C point is the so-called fluidization point.

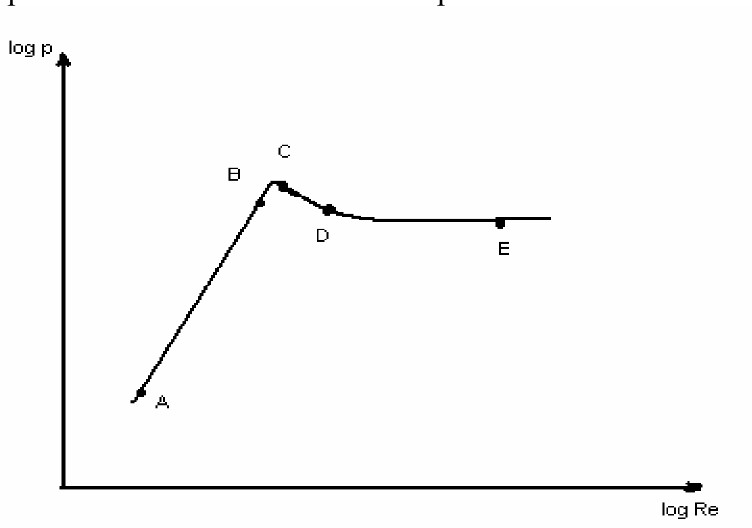

Fig. 3. – The variation of the pressure drop with the Reynolds number, at the flow through a granular bed (Tofan, 2002)

The heat exchange in the product frozen at the time τ is described with equation 1:

$$dQ = \frac{k(\theta_1 - \theta_2)d\tau}{x} \qquad (1)$$

where: x- the thickness of the product frozen by fluidization at the time τ;

θ_1– the freezing point of the product, and θ_2 is temperature of the fluidization agent respectively;

k- the thermal conductivity of the frozen product;

The eliminated heat used to freeze the dx thickness of the product is well described with relation 2:

$$k(\theta_1 - \theta_2)\frac{d\tau}{x} = L\rho dx \qquad (2)$$

where: L- the latent fluidization heat.

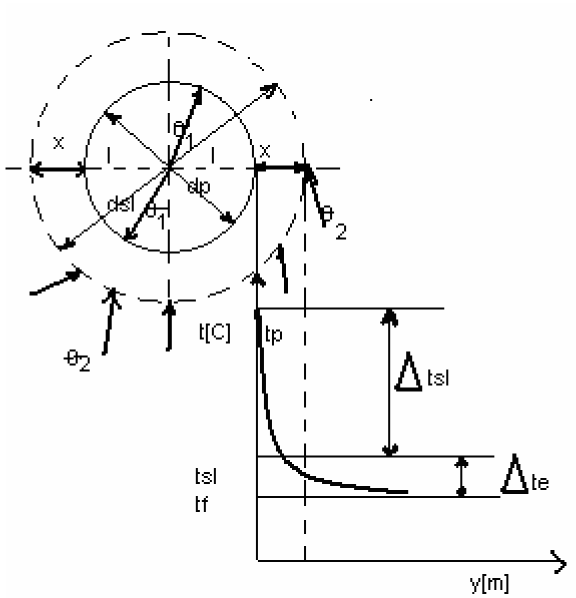

Fig. 4. – The temperature variation during the thermal transfer from the solid particle to the fluidization agent (Chiriac, 1982) (Δt_{sl} – the variation of temperature in the layer-limit; Δt_e – the variation of temperature in fluid; t_p – the temperature of solid particle; t_f – fluid temperature; d_{sl} – the diameter of layer-limit)

Integrating with the conditions at the limit:

- $\tau = 0$; $x = 0$;
- $\tau = \tau_f$ (figure 4); x = l (the shortest distance from the surface to the thermal core [m])

is obtained the new form of equation 2:

$$k(\theta_1 - \theta_2)\tau_f = \frac{L\rho l^2}{2} \qquad (3)$$

In equation 3, *l* is the shortest distance from the surface to the thermal core, [m].

The thermal conductivity, k for the food products can be estimated with the empirical equation 4:

$$k = 0{,}25m_c + 0{,}155m_p + 0{,}16m_f + 0{,}135m_a + 0{,}58m_m \qquad (4)$$

where: m stands for the mass fraction,
the indices: c-carbohydrates; p- proteins, f- fatty acids; a-ash; m-humidity.

The mass transfer is done in two ways: by molecular diffusion and by turbulent diffusion (convection).

The mass transfer by molecular diffusion in a mixture is the result of the overlapping the effect of three processes:

- common diffusion, produced by the difference in concentration;
- thermal diffusion, based on the Soret effect, according to which the higher mass molecules tend to move towards the lower temperature regions producing a temperature gradient;
- pressure diffusion, caused by the pressure differences.

The direction of the mass transfer is pointed from the zone with higher concentration or pressure to the lower concentration or pressure zone, as the minus sign in Fick's equation written for the diffusion of component A into the z direction

$$q_{m,Az} = -\rho D_A \frac{dg_A}{dz} \qquad (5)$$

The convective mass transfer (or by turbulent diffusion) implies the substance transport between a surface and a moving fluid. The mechanism of convective mass transfer also needs molecular diffusion mass transfer. As in the case of molecular diffusion, the turbulent diffusion occurs in the direction of the reduction of the concentration difference.(Ştefãnescu, 1983).

The mass transfer in the freezing process by fluidization takes place at the same time with the heat transfer on the BC landing section (figure 3) when there takes place the turning of liquid water into ice crystals inside the product. The size of the ice crystals depends on the freezing speed (Ştefãnescu, 1983).

The chilling, the chilled products and the cold storage imply low temperatures, lower rate of biochemical changes in foods, slower microbial growth. The freezing or frozen storage is done at very low temperatures, and means very low water activity, biochemical changes and the microbial growth is stopped.

The nutritive value and the flavor of food are well preserved; undesirable structural changes may take place. The water inside the product begins to crystallize the moment the temperature of the cellular juice reached the freezing point specific to the respective product; and, when the balance temperature has been reached, one can notice that not the whole water quantity inside the product has been turned into ice.

During the slow freezing process there is formed a smaller number of big irregular ice crystals. During the rapid freezing process there is formed a larger number of small regular crystals. The mass transfer happens when changing the aggregation state of the component with the highest concentration.

Conclusions

The quantitative knowledge of the heat transfer is necessary to the thermal dimensioning of the fluidization devices. Creating hydrodynamic conditions favourable to the convective transport and the widening of the contact surface by decreasing the dimensions of the solid particles are two main ways by which the fluidization intensifies the fluid-particle heat transfer.

It could be used successfully for foods of irregular shape. It is ideal for freezing in fluidized beds: Air at – 20°C to – 40°C and the velocity is of 6 m/s for fluidization. Also, freezer burns (dehydration of the food surface) should be avoided. Fluidized bed freezers are widely used for peas, berry fruits, cherries, potato slices, pepper and carrot cubes, green beans and many other fruits and vegetables.

Terminology

Mass	m	kg
Time	τ	s
Temperature	t, T, θ	°C, K

Heat	Q	J
Speed	w	m/s
Pressure	p	N/m^2
Density	ρ	kg/m^3
Internal energy	u	J/kg
Enthalpy	h	J/kg
Specific heat	c	J/kg°C
Dynamic viscosity	η	Ns/m^2
Kinematical viscosity	ν	m^2/s
Thermal conductivity	λ(k)	W/m°C
Thermal diffusivity	a	m^2/s
Convection coefficient	α	$W/m^2°C$

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