CONTROLED FREEZING OF LIQUID ENVIRONMENT IN FRAGILE TARE

Ivanov L.
Cartofeanu V., Melenciuc M., Istratii D.

Technical University of Moldova

A special interest in mass transfer processes represent the conditions under which has place the phase transfer. As a rule those are liquid – vapor for high intensive heat processes, or moisture freezing, when all substance thermo physical parameters change and the process itself is non stationary. In practice, very often while storing liquid canned products in fragile tare in unheated warehouses, while transporting them, when uncontrolled heating systems disconnection has place, occurs freezing and depressurization of tare and as result product spoilage. From our point of view, while transporting in cold weather different kind of liquid products, by truck or by train, it is of high importance to create special conditions for controlled freezing of those products (like different juices). One should create such heat transfer conditions, between the canned product and the environment, under which liquid freezing will occur on the bottom and on the lateral surfaces of the tare. Heat outflow, caused by thermal conductivity (conductive heat transfer), will dominate over convective one, in the tare itself, due to the difference of product temperatures on the bottom and on the surface. Anomalous water density properties in temperature diapason 0 – 4°C, in natural conditions, lead to ice layer creation on the surface, which after future amplification of the process creates a high pressure inside the liquid product and as result brings to tare depressurization.

To impose the right conditions for a safe freezing of a part of the liquid product, one should have enough knowledge about temperature field distribution inside stored object. To perform the needed calculation, we'll take the tare as cylindrical, which is more specific for our food industry. The phase transfer has place in a narrow liquid – ice zone, thermo physical properties are changing leaping while transferring from phase to phase, and are stable in one phase. Energy equation for the cylinder can be written down like this:

$$\frac{\partial T_i}{\partial \tau} = a_i\left(\frac{\partial^2 T_i}{\partial R^2} + \frac{1}{R}\frac{\partial T_i}{\partial R} + \frac{\partial^2 T_i}{\partial Z^2}\right) \quad (1)$$

Bottom and lateral surfaces are cooling. The boundary conditions in this case will have the form:

$$T(R, Z, O) = T_0 \quad (2)$$

$$T(R_0, Z, \tau) = T_\xi \quad (3)$$

$$\left.\frac{dT}{dZ}\right|_{Z=l} = 0 \quad (4)$$

$$\left.\frac{dT_1}{dR}\right|_{R=R_0} = -\frac{\alpha}{\lambda_1}(T_s - T_m) \quad (5)$$

$$\left.\frac{\partial T}{\partial Z}\right|_{Z=0} = -\frac{\alpha}{\lambda_1}(T_s - T_m) \quad (6)$$

$$\lambda_2 \frac{dT_2}{dR} - \lambda_1 \frac{dT_1}{dR} = L\rho \frac{d\xi}{d\tau} \quad (7)$$

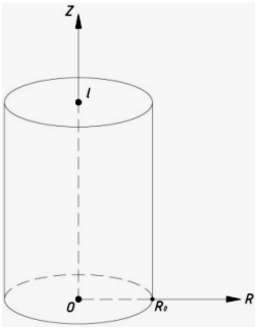

Fig. 2 Cylinder scheme for a cylindrical form tare.

The diapason of parameters changes

$$0 \le R \le R_0; \quad 0 \le Z \le l$$

Equation (1) solution with boundary conditions (2) and (6) will be written in next form:

$$\frac{T_1 - T_m}{T_0 - T_m} = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} A_{n_1} A_{m_2} I_0\left(\mu_{n_1}\frac{R}{R_0}\right)\cos\mu_{m_2}\frac{Z}{l} exp\left[-\left(\frac{\mu_{n_1}^2}{R_0^2} + \frac{\mu_{n_2}^2}{l^2}\right)\right]a\tau \quad (8)$$

where $A_{n_1}, A_{m_2} -$ constant coefficients.

$$A_{n_1} = \frac{2Bi_1}{I_0(\mu_{n_1})\left[\mu_{n_1}^2 + Bi_1^2\right]}; \; A_{m_2} = \frac{(-1)^{m+1} \cdot 2Bi_2\sqrt{Bi_2^1 + \mu_{m_2}^2}}{\mu_{m_2}^2\left(Bi_2^2 + Bi_2 + \mu_{m_2}^2\right)}$$

Indexes 1 and 2 refer to lateral and bottom surfaces.

$$I_0(R) = \sum_{m=1}^{\infty} \frac{(-1)^m}{m!\,\Gamma(V + m + 1)}\left(\frac{1}{2}Z\right)^{2m}$$

If Z argument shows high values, then Bessel function of first order is written abreast:

$$I_0\left(\mu_{n_1}\frac{R}{R_0}\right)=\frac{1}{\sqrt{2\pi\mu_{n_1}\frac{R}{R_0}}}e^{\mu_{n_1}\frac{R}{R_0}}\left(1+\frac{1}{8\mu_{n_1}\frac{R}{R_0}}+\frac{9}{128\mu_{n_1}^2\frac{R^2}{R_0^2}}+\cdots\right.$$

where $\mu_{n_1}, \mu_{m_2} -$ radicals of characteristic equations obtained from boundary conditions (5)and (6).

$$tan\,\mu=-\frac{\mu}{\frac{\alpha}{\lambda}R_0-1}$$

In our case the problem as three–layered: tare's shell, ice layer on the inside surface and liquid phase. Equation (1) shows temperature distribution in the thickness of membrane packaging, in frozen ice layer, where heat transfer is exclusively conditioned by thermal conductivity. In liquid phase, the main role forming temperatures field is played by convective heat transfer.

Heat transfer equation for final sizes cylinder is written in this form:

$$W_R\frac{\partial T_\xi}{\partial R}+W_Z\frac{\partial T_\xi}{\partial Z}=a_3\left(\frac{\partial^2 T_\xi}{\partial R^2}+\frac{1}{R}\frac{\partial T_\xi}{\partial R}+\frac{\partial^2 T_\xi}{\partial Z^2}\right) \quad (9)$$

Liquid phase movement equation can be written as for symmetric case:

$$W_R\frac{\partial W_R}{\partial R}+W_Z\frac{\partial W_R}{\partial Z}=V\left(\frac{\partial^2 W_R}{\partial R^2}+\frac{1}{R}\frac{\partial W}{\partial R}-\frac{W_R}{R^2}+\frac{\partial^2 W_R}{\partial Z^2}\right) \quad (10)$$

$$W_R\frac{\partial W_Z}{\partial R}+W_Z\frac{\partial W_Z}{\partial Z}= \\ =(1-\beta\Delta T)\frac{g}{\rho}-\frac{1}{\rho}\frac{\partial P}{\partial Z}+V\left(\frac{\partial^2 W_Z}{\partial R^2}+\frac{1}{R}\frac{\partial W_Z}{\partial R}+\frac{\partial^2 W_Z}{\partial Z^2}\right) \quad (11)$$

where $a -$ thermal conductivity coefficient, $[m^2/s]$;
$T -$ temperature, $[K]$;
$W_R, W_Z -$ flow's velocity in R and Z coordinates, $[K]$;
$\nu -$ cynematic viscosity, $[m^2/s]$;
$\rho -$ products density, $[kg/m^3]$;
$\beta -$ coefficient of thermal distribution.

Because of anomalous density, unfreezing water flow goes up from bottom and lateral surfaces. Inside gravitational field we can neglect mixing along the radius. Hydrodynamic problem resolution is complicated by mass – heat transfer with phase transfer, which is a difficult problem even with the inducted simplification. However to obtain the necessary conditions for a safe freezing one could insert some additional assumptions being guided by thermo physical processes having place in the object. The heat flow outputted by the conductive heat transfer, in the bottom part of the tare, and partially by the convective heat transfer on the lateral surfaces, the closest to the bottom, should be higher than the heat transfer from above. The convection of the liquid phase is caused by temperature difference of 0 – 4°C, this value is maximal and along with heat transfer process development, at 0°C environment temperature, it will only decrease.

This way solving equations (11) and (9) and supposing the viscosity insignificant (light flow velocity), the *Z* axe temperature distribution, can be written like this:

$$T = T_{cr} e^{\frac{2}{3}\sqrt{2(1-\beta\Delta T)gZ^3}} \quad (12)$$

where $\beta -$ coefficient of liquid volumic distribution;
$T_c -$ liquid phase temperature, $[K]$;

If using higher mentioned assumptions in freezing ice on the bottom, one should consider the next inequality:

$$\lambda_1 \frac{dT}{dx}\bigg|_{Z=0} \geq \alpha_1 \left(T_c - T_{cr} e^{\frac{2}{3}\sqrt{2(1-\beta\Delta T)gL}}\right) \quad (13)$$

While environment temperature T_m lowers over time, in the considered cooling period (in the interval of 4°C to 0°C), the inner convective heat transfer will weaken, because of the fading temperature gradient between the bottom and the surface, resulting in moisture freezing in the thickness of the product itself. Wherein the bottom and the lateral surface will be covered with a thicker layer of ice, and when ice on the surface will appear, upon further freezing, it will be pushed and the liquid will flow in the buffering zone.

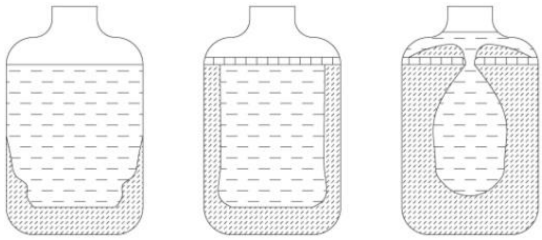

Fig. 2 Ice deposing phases (moisture freezing)

Complying with conditions (13), give us the opportunity to safely freeze the moisture of a liquid product, without depressurizing the tare.

Bibliographic references

1. Лыков А.А., «Теория теплопроводности», M 1967;
2. Карслоу Х.С., Ерег Д., «Теплопроводность твердых тел», M 1964, с. 484;
3. Bernic M., Ivanov L., et al., „Container pentru păstrarea recipientelor de sticlă cu lichide în condiţii de îngheţ”, Brevet de invenţie MD 3429 C2, 2007.11.30;
4. Гордеев Ю., Иванов Л., Потапов Н., Бологa М., «Емкость для хранения жидкости в условиях замерзания», А.С. 1507933.