DESUBLIMATION OF STEAM ON A CYLINDRICAL SURFACE

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Abstract: The operation of the sublimation unit is largely determined by the mode of operation of the desublimation unit. The buildup of ice, during the process of dewatering the material, on the surface of the desublimator-evaporator of the refrigerating machine leads to an increase in thermal resistance between the vapor-air phase and the boiling refrigerant.

Keywords: temperature, desublimation, thermal resistance, refrigerant.

Introduction

The heat flow to the refrigerant is transmitted through a layer of ice (frost) whose thickness is a function of the time of the process. An increase in thermal resistance due to ice chilling leads to an increase in the desublimation temperature (vapor-ice phase transition) at a constant boiling temperature of the refrigerant, which, other things being equal, leads to a decrease in the freezing rate and, consequently, the entire sublimation process. If the desublimation temperature is kept constant, the boiling point of the refrigerant will decrease, which leads to additional energy consumption (due to a decrease in the refrigeration coefficient.

Materials and methods

We were tasked to calculate the temperature field during sublimation on a cylindrical surface. Desublimator is taken as an endless cylinder consisting of two layers: a layer of ice and a tube of the evaporator itself. The heat exchange between the shell of the frozen layer of ice and the medium occurs according to the Newton-Richmann law. Our task is to determine the temperature in this system.

The energy equations are written as:

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

where $i=1$ for the frozen layer and $i=2$ in the thickness of the evaporator wall.

In the first case, the value R changes within $R_0 < R \le \xi$, ξ – the coordinate of the frozen layer at the moment of time τ. a_1 and a_2 – thermal conductivity coefficients of the frozen and boundary layers, respectively m^2/s; T – temperature, K; τ – time, s.

Taking the process of crystallization symmetric and the edge effect is insignificant, and then equation (1) for the frozen layer is simplified to the form:

$$\frac{\partial T_i}{\partial \tau} = \frac{a_1}{R}\frac{\partial}{\partial R}\left(\frac{R\partial T_1}{\partial R}\right). \quad (2)$$

The boundary conditions we write in the form:

$$T(\xi,\tau) = T_{kp};\ \ T(\infty,\tau) = T_c; \quad (3)$$

$$\alpha_1\left(T_C - T_\xi\right) = \lambda_2 \frac{dT_2}{dR} + 4\rho \frac{d\xi}{d\tau}; \tag{4}$$

$$T\left(R_\partial, 0\right) = T_0 \ : \frac{\partial T}{\partial R}\Big|_{n=3} = -\frac{\alpha}{\lambda_1}\left(T_3 - T_c\right). \tag{5}$$

The solution of equation (2) with boundary conditions (5) can be solved by the operational Laplace method [1]. The type of solution in our case will be written in the form:

$$\frac{T_c\left(R,T\right)-T_0}{T_c - T_0} = 1 - \sum_{n=1}^{\infty} A_n I_0\left(\mu_n \frac{R}{R_1}\right)\exp\left(-\mu_n^2 F_0\right), \tag{6}$$

where the temperature amplitude A_n is defined as:

$$A_n = \frac{2I_1\left(\mu_n\right)}{\mu_n\left[I_0^2\left(\mu_n\right) + I_1^2\left(\mu_n\right)\right]} = \frac{2Bi}{I_0\left(\mu_n\right)\left[\mu_n^2 + Bi^2\right]}, \tag{7}$$

for large values $Bi \to \infty$, μ_n are the roots of the Bessel function of the first kind of zero order $I_0\left(\mu_n\right)$, then:

$$A_n = \frac{2}{\mu_n I_1\left(\mu_n\right)}, \tag{8}$$

$I_1\left(\mu_n\right)$ Bessel function of the first kind of the first order.

For small values $\beta_i \to \infty$, the amplitude A_n tends to 1 (except for the value $A_n = 0$ except $A_1 = 1$).

Then the solution (6) can be written in the form:

$$\frac{T_1\left(R,T\right)-T_0}{T_c - T_0} = 1 - I_0\left(\sqrt{2Bi}\,\frac{R}{R_1}\right)\mathrm{e}^{-2BiF_0} \tag{9}$$

The temperature distribution in the thickness of the wall of the evaporator - desublimator is described by equation (2), where the temperature value T_2, the boundary conditions are written in the form:

$$T\left(\mathrm{R}_0, \tau\right) = T_{кип};\ T\left(\mathrm{R}_1, \tau\right) = T_\xi;\ T\left(0, \mathrm{K}\right) = T_0, \tag{10}$$

we have boundary conditions of the first kind.

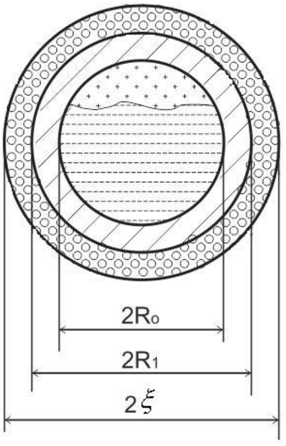

Fig. 1. *Representation of the vaporizer pipe in section*

The solution in this case is written in the form:

$$T_2(\mathrm{R},\tau)=\frac{\pi^2}{2}\sum_{n=1}^{\infty}\frac{k_n^2 I_0^2(k_nR_1)V_0(k_nR)}{I_0^2(k_nR_0)-I_0^2(k_nR_1)}\cdot\int_{R_0}^{R_1} RT_0V_0(k_nR)\,dR\cdot e^{-ak_n^2\tau}, \quad (11)$$

where $V_0(k_nR)-$is the Bessel function of the second kind of zero order. The roots $\mu_n=k_nR_0$, $R_1/R_0=m$ and $F_0=\frac{a\tau}{R_0^2}$ are determined from the characteristic equation:

$$I_0(\mu)Y_0(m\mu)-I_0(m\mu)Y_0(\mu)=0. \quad (12)$$

The obtained solutions of temperature distribution in the system. The pipe in the pipe describes the non-stationary process of heat exchange in this system complicated by the phase transition. The process of sublimation, and, consequently, of desublimation is quite long, we have the value of the Fourier criterion, tending to infinity. Therefore, the freezing process can be considered quasi-stationary (the phase transition zone moves.

The temperature at the interface of the condenser (ice) and the outer surface of the evaporator - desublimator is determined from equation (6) and (11) by setting the coordinate value R_1.

Putting the value of the temperature distribution (6) into equation (4), we obtain the rate of increase of desublimate:

$$L\rho\frac{d\xi}{d\tau}=-\lambda_1(T_c-T_0)\sum_{n=1}^{\infty}A_n\exp\left(-\mu_n^2F_0\right)\frac{d}{dR}\left[I_0\left(\mu_n\frac{R}{R_0}\right)\right]. \quad (13)$$

Sublimation in stationary mode greatly simplifies the process of condensation in the desublimator.

In this case, the speed of freezing ice in the installation can be written in the form:

$$\frac{\xi^2}{x}\left[\frac{2}{\alpha,\xi}+\frac{1}{2\lambda_л}\left(\ln\frac{\xi}{R_1}-1\right)+\frac{1}{4x_m}\ln\frac{R_1}{R_0}+\frac{1}{2\alpha_2 d_2}\right]=\frac{\Delta t\tau}{x\pi 4\rho}, \qquad (14)$$

where $T-$ is the temperature, K; $a-$ thermal diffusivity, m^2/s; $\tau-$ time, s; $L-$ phase transition heat, $\frac{J}{kg}$; $\rho-$ specific density, $\frac{kg}{m^3}$; $\alpha-$ heat exchange coefficient, $\frac{W}{m^2\cdot K}$; $\lambda-$ heat transfer coefficient, $\frac{J}{m\cdot K}$; $\xi-$ condensate coefficient, m; R_1 and R_2 the geometric dimensions of the evaporator chiller, m.

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