SIMILARITY OF DESUBLIMATION PROCESSES

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Based on a diffusional mathematical model of the processes of desublimation from binary gaseous mixtures, dimensionless similarity numbers are obtained. The effect of these numbers and the parameters contained in them on the thickness and density of a cryogenic precipitate is investigated by numerical methods.

Introduction. The effect exerted by operational parameters of the process of desublimation on the thickness and density of a cryogenic precipitate was investigated experimentally for certain substances, especially for water, rather comprehensively in [1]. However, the formation of the cryogenic precipitate has received little study for the majority of substances that can be isolated from gas mixtures by the method of desublimation.

The main object of the present work was to consider the effect exerted by the substance parameters on the thickness and density of the cryogenic precipitate.

The reason for the formation of a loose layer in the process of desublimation is the same for all of the substances: instability of the plane crystallization front in the presence of a concentration gradient of a desublimating admixture in a boundary layer. This makes it possible to describe the processes of desublimation of various substances by a single mathematical model.

Model. For carrying out the analysis, we can adopt the approach suggested in [2]. With the additional assumption of the linear distribution of temperature over the precipitate layer thickness, the process is described by the system of equations

\[
\frac{dP_{cr}}{dt} = \frac{MD}{1.1RTsh} \left( \frac{dP_{sat,ad}}{dT} \right) \frac{T_s - T_w}{h} ;
\]

\[
\frac{d}{dt} (\rho_{cr}h) = \frac{\beta M}{RT_f} (P_{ad,f} - P_{ad,sat,ad}) ;
\]

\[
T_s = \frac{\alpha T_f + \frac{\lambda_{cr}}{h} T_w + r \frac{d}{dt} (\rho_{cr}h)}{\frac{\lambda_{cr}}{h} + \alpha}.
\]

To calculate the effective thermal conductivity, we can use averaged relations not associated with specific substances [3, 4]

\[
\lambda_{cr} = f (\rho_{cr} , \rho_{ice} , \lambda_{ice} , \lambda_f) .
\]

The saturated vapor pressure curve can be approximated by the relation

\[
P_{sat,ad} = \text{const} \exp \left( \frac{-Mr}{RT} \right) .
\]
A comparison made in [4] for the results of a calculation by the model suggested and the model proposed in [2] and experimental data shows that the simplified model is suitable for the analysis of the process.

Separation of Dimensionless Similarity Numbers. Introducing the dimensionless quantities

\[ \rho_{cr}^* = \frac{\rho_{cr}}{\rho_{ice}}; \quad h^* = \frac{h}{h_{max}} \]

where

\[ h_{max} = \frac{\lambda_{ice} (T_{sat,f} - T_w)}{\alpha (T_f - T_{sat,f})} \]

is the maximum possible thickness of a crystalline layer under the given conditions of heat transfer (in our opinion, this definition of the dimensionless thickness seems to be more convenient for the analysis than \( h^* = \frac{h}{\lambda T_f} \) [5] since in our case the limiting values of the dimensionless density and thickness are normalized to unity);

\[ T^* = \frac{T - T_{sat,f}}{T_{sat,f}}; \quad \lambda_{cr}^* = \frac{\lambda_{cr}}{\lambda_{ice}}; \quad \lambda_f^* = \frac{\lambda_f}{\lambda_{ice}} \]

we transform the system of equations (1)-(5):

\[ T_s^* = \frac{T_w^*}{T_{w} - \frac{T_{sat}^*}{T_{sat,f}} \left( 1 - \frac{\lambda_{cr}^*}{h^*} + K_T \left( 1 - \exp \left( \frac{K_p}{\lambda_{cr}^*} \frac{T_s^*}{1 + T_s^*} \right) \right) \right)}; \]

\[ \frac{d\rho_{cr}^*}{dt^*} = K_p \lambda_f^* \left( 1 - \rho_{cr}^* \right) \left( T_s^* - T_w^* \right) \left( T_f^* \right)^2 \exp \left( K_p \frac{T_s^*}{1 + T_s^*} \right) \]

\[ \frac{d(h^*)}{dt^*} = -\frac{T_f^*}{T_w^* (T_f^* + 1)} \left( 1 - \exp \left( K_p \frac{T_s^*}{1 + T_s^*} \right) \right) \]

\[ \lambda_{cr}^* = f(\rho_{cr}^*, \lambda_f^*) . \]

In the resulting system of equations all the characteristics of the substance are concentrated in four dimensionless numbers:

\[ t^* = \frac{\alpha^2 D \rho_{ad,f} T_f^*}{\rho_{ice} R T_{sat,f}^* \lambda_f^* \lambda_{ice}} \]

is the dimensionless time;

\[ K_T = \frac{r D \rho_{ad,f} M}{R \lambda_f T_f^* (T_f - T_{sat,f})} = \frac{r D \rho_f}{\lambda_f T_f^* T_{sat,f}} \]

characterizes the ratio of heat of the phase transition to the convective component of heat inflow;

\[ K_p = \frac{Mr}{R T_{sat,f}^2} \]