This article considers the mechanism by which ice melts in salt solutions. Experimental data were used to determine the coefficients of mass transfer from dissolved NaCl to the melting surface during natural convection and forced movement and when air was bubbled through the solution.

The melting of any substance when its melting point is reduced by contact between the liquid and a solid is of great interest. Special cases of this phenomenon include the melting of ice in salt solutions and the melting of iron in iron–carbon melts. These processes are defined by two equations: the mass-transfer equation and the heat-transfer equation. Although both phenomena belong to the same class, they differ from one another. When ice melts, substances dissolved in the water do not form a solid solution with the ice, while carbon dissolved in molten iron is capable of forming a solid solution with the latter. This introduces some difference into the course of the processes. We will consider only the first case in the present article.

We construct the salt-balance equation at the melting surface:

\[ \beta (C_p - C_s) = w_m C_p. \]  

(1)

The left-hand side of the equation represents the amount of salt reaching the melting surface by diffusion. The right-hand side represents the amount of salt necessary to maintain a concentration \( C_s \) at the boundary between the liquid phase and the melting surface. Similarly, we write the heat-transfer equation:

\[ \alpha (t_p - t_s) = \dot{W}_{int} q_m. \]  

(2)

From Eqs. (1) and (2) we obtain

\[ t_p - t_s = t_0 \left( \frac{C_p}{C_s} - 1 \right), \]

or

\[ \frac{t_p - t_s}{C_p - C_s} = \frac{t_0}{C_s}, \]

(3)

where

\[ t_0 = \frac{\beta q_m}{\alpha}. \]  

(4)

If \( t_0 \) is known, Equation (3) contains two unknowns: the salt concentration \( C_s \) and the temperature \( t_s \) at the boundary with the melting surface. We will assume that these quantities are associated with the liquidus curve for the equilibrium state of the ice–salt solution system. Equation (3), together with the liquidus curve, then enables us to determine the values of these quantities.

We can give graphic interpretation of the solution of this equation. We mark off points A and B, indicating the solution temperature (A) and the unknown melting-surface temperature (B), on the ordinate of the equilibrium phase diagram for the system (Fig. 1), which corresponds to the salt concentration in the
solution $C_p$. The point $O$ where a line passing through point $B$ and parallel to the abscissa intersects the liquidus defines the salt concentration in the solution at the boundary with the melting surface $C_s$. We continue lines $AO$ and $BO$ to their intersection with the ordinate, which corresponds to a salt concentration of zero. This yields points $A'$ and $B'$. From the similarity of the triangles $AOB$ and $A'O'B'$, we have

$$\frac{AB}{OB} = \frac{A'B'}{OB'}.$$  \hfill (5)

It follows from our construction that

$$AB = t_p - t_s,
OB = C_p - C_s,
OB' = C_s.$$  \hfill (6)

i.e.,

$$\frac{t_p - t_s}{C_p - C_s} = \frac{A'B'}{C_s - C_s}.$$  \hfill (7)

It can be seen from a comparison of Eqs. (7) and (3) that the segment $A'B'$ equals the quantity $t_0$.

This construction gives us a graphic interpretation of the process and facilitates solution of Eq. (3).

The melting rate is determined by the coefficient of heat transfer from the solution to the melting surface and by the temperature difference in the solution far from this surface and at the boundary with it. The first quantity is governed by hydrodynamic factors, while the latter is determined by the solution temperature and $t_0$. If the heat-transfer constant and $t_0$ are known, the melting rate can be calculated.

The above relationships can be utilized for experimental determination of the coefficients of mass transfer. For this purpose, it is necessary to determine the melting point of the solid experimentally and to calculate the heat-transfer coefficient from the melting rate. We find $t_0$ by using the liquidus curve and calculate the mass-transfer coefficients $\beta$ from Eq. (4).