August 1969 Brief 69-10321

NASA TECH BRIEF

A Method for Predicting Interfacial Freezing of a Liquid Flowing Over a Cold Surface

A frozen layer can form in a flowing warm liquid when the liquid is in contact with a sufficiently cold surface. This occurs in some important engineering applications such as heat exchangers in which liquids are cooled by cryogenic coolants, castings formed in cooled molds, and in rivers where ice layers form in winter. Common to all these applications is the need to know how rapidly the frozen layer forms.

When a flowing liquid is frozen onto one side of a flat plate which is convectively cooled from the other side by another fluid, the relation between the thickness of the frozen layer and time is given by the following equation:

$$\tau' = -x' - \frac{1+R}{R} \cdot \ln(1 - x') - S\left\{ \frac{Rx'}{3(Rx' + 1)} \cdot \left[x' + \frac{R + 2}{R(R + 1)} \right] + \frac{3 + 3R + R^2}{3(1 + R)^2} \cdot \ln(1 - x') + \frac{\ln(Rx' + 1)}{3R(1 + R)^2} \right.$$

where

$$S = \frac{C_p(T_f - T_c)}{L} \; ; R = \frac{\frac{x_s}{k}}{\frac{1}{h_c} + \frac{a}{k_w}} \; ; x' = \frac{x}{x_s} \; ; \tau' = \frac{\tau h_l (T_l - T_f)}{\rho L x_s}$$

and

C_p = specific heat of frozen material

T_f, T_l, T_c = freezing temperature and temperatures of liquid and coolant

L, k = heat of fusion and thermal conductivity of frozen material

a, k_w = thickness and thermal conductivity of flat wall on which frozen layer forms

h_l, h_c = convective heat transfer coefficient for liquid and coolant sides

x, x_s = instantaneous and steady state thickness of frozen layer

τ = time

ρ = density

The x_s is calculated from the steady state heat balance where

$$h_l (T_l - T_f) = \frac{T_f - T_c}{\frac{x_s}{k} + \frac{a}{k_w} + \frac{1}{h_c}}$$

(continued overleaf)

Thus the instantaneous thickness of a frozen layer is found to be a function of specific heat, heat of fusion, temperatures, the frozen layer thickness at equilibrium, the thermal conductivity and heat transfer coefficient. The equation can be evaluated on a desk calculator.

The analytical predictions agree well with experimental measurements of the growth of an ice layer when water was flowed past a cold plate.

The method can be used to predict the (1) time needed to solidify plate type castings; (2) growth of ice covers on rivers and lakes; and (3) frozen layer formations in heat exchangers that tend to freeze.

Notes:

1. Documentation is available from:
   Clearinghouse for Federal Scientific
   and Technical Information
   Springfield, Virginia 22151
   Price $3.00
   Reference: TSP69-10321
2. Technical questions may be directed to:
   Technology Utilization Officer
   Lewis Research Center
   21000 Brookpark Road
   Cleveland, Ohio 44135
   Reference: B69-10321

Patent status:

No patent action is contemplated by NASA.

Source: J. M. Savino and R. Siegel
Lewis Research Center
(LEW-10813)