below 10 F. Distilled water can be frozen with temperature as low as 6 F.

Brine velocity has a marked influence on freezing time and should not exceed about 35 fpm. Brine movement is caused by the *hydraulic gradient, best designed for about 1¼ to 1½ in.* in the tank length. This permits submergence of water in the ice cans below the brine level. It is important to maintain brine movement, insuring a temperature as nearly uniform as possible. A variation of not more than ½ F deg is desirable, though 1 F deg is permissible.

Uniform rate of ice harvesting on exact time schedule is likewise necessary for maximum yield. The rate of ice freezing drops rapidly as the ice becomes thicker. An 11 × 22 in. can holding 320 lb of water in 12 F brine will make 280 lb of ice in 24 hr and consume an additional 14 hr to freeze the 40 lb balance.

When brine *agitation is moderate,* 15 to 25 fpm, the total freezing time for US standard cans, 11 in. thick, may be expressed by Equations 1 and 2 from:

$$\theta = \frac{7a^2}{32 - t} \qquad (1)$$

$$\theta = \frac{wn}{2{,}000} \times 24 = \frac{3wn}{250} \qquad (2)$$

where

θ = total freezing time for the block, hours.
a = thickness of ice block, inches.
t = temperature of brine, Fahrenheit.
n = number of cans per ton of ice produced in 24 hours.
w = weight of ice block, pounds.

Equation 3 is obtained by combining Equations 1 and 2 and solving for the brine temperature.

$$t = 32 - \frac{583.3a^2}{wn} \qquad (3)$$

Thus, with a given plant, the daily output is a function of the brine temperature only.

The number of cans per ton is the usual unit for rating tank capacity. It indicates the number of cans that are working to produce one ton of salable ice per 24 hr day, when ice is harvested uniformly. The number of cans per ton establishes the necessary brine temperature for a given daily output.

Table 1 .... Normal Number of 300-lb Cans Required per Ton of Ice per Day (Based on 30 fpm brine velocity)

Average Brine Temp, F	11½×22½ in. Can		11×22 in. Can	
	Number	Freezing Time, Hr	Number	Freezing Time, Hr
22	22.5	81	21	75.6
20	19	68.4	18.0	64.8
18	16	57.6	15.5	55.8
16	14.5	52.2	13.5	48.6
15	13.6	48.6	12.5	45.0
14	12.5	45.0	11.5	41.4
13	12	43.2	11	39.6
12	11.5	41.4	10.5	37.8
11	11	39.6	10	36.0
10	10.5	37.8	9.5	34.2
9	10	36.0	9.0	32.4
8	9.5	34.2	8.5	30.6

Table 1 shows observed ice can performance when various brine temperatures are maintained in tanks designed for 300-lb cans, with all can water below the brine level. Fig. 1 is a chart prepared by Rasori for calculation of freezing tank performance when the can width is not less than twice the ice block thickness. In tanks with a high brine velocity, the constant 7 in Equation 1 reduces to 6.3 for 11 × 22 in. cans.

Warm water in 11½ × 22½ size ice cans will cool in the brine tank at a heat transfer rate of 50 Btu per (sq ft) (hr) (F deg) up to the time when ice first forms on the can sides. Ice first appears when the water reaches 40 F with 14 F brine and at 38 F with 18 F brine. In 14 F brine, water will drop from 70 to 40 F in 15 min, but chilling thereafter down to 32 F will require an additional 40 to 50 min. The extent of both brine and water turbulence will influence the cooling rates to a marked extent.

Can Ice Freezing Time

The freezing time (Equation 1) applies principally to standard American freezing cans with dimensions of 11 × 22 in., or approximations to them. For block thicknesses above 12 in. or below 10 in., Equation 1 should not be used because: (1) it assumes that all resistance to heat flow is dependent

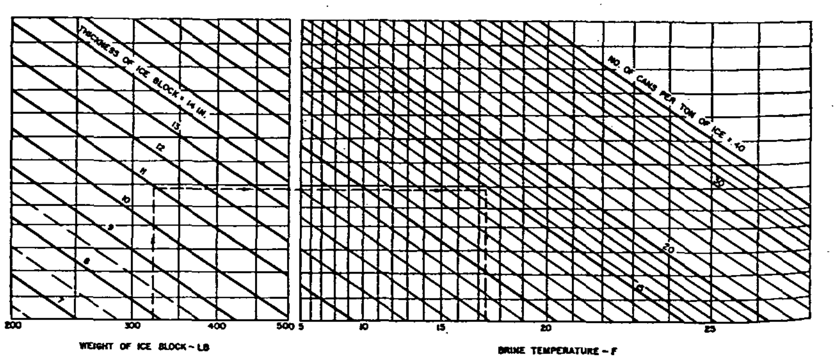
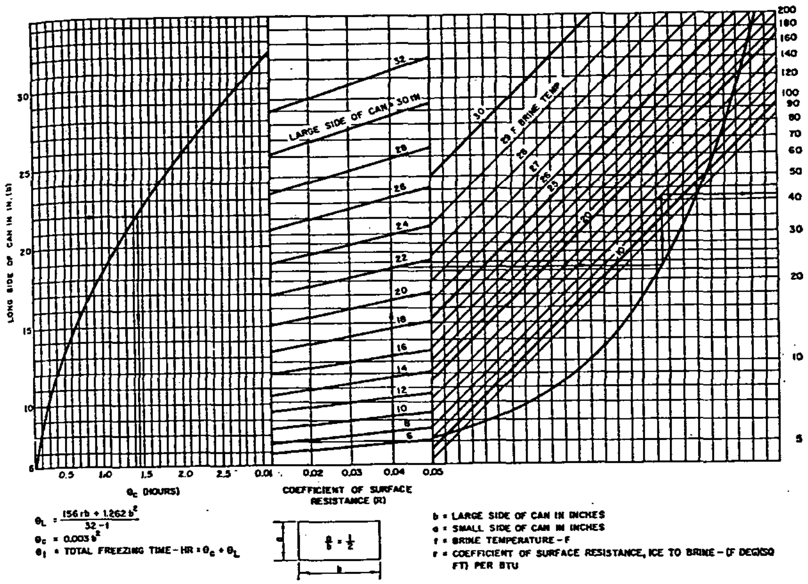


Fig. 1 .... Freezing Tank Performance



* For rectangular cans with sides a/b in ratio of 1:2 ($a \times$ ½b).

Fig. 2 .... Freezing Time for Can Ice*

upon ice thickness, whereas the resistance actually consists of (*a*) ice resistance (thickness), and (*b*) surface resistance (from brine to ice), which is independent of ice thickness; and (2) it does not take into consideration the flow of heat across the narrow sides of the can, which becomes increasingly important as the shape of the can approaches a square.

Equation 4 is more exact for rectangular cans having a ratio of sides a/b = ½, where a = short side and b = long side of can. Fig. 2 shows a graphical solution of Equation 4.

$$\theta_t = \frac{156rb + 1.262b^2}{32 - t} + 0.003b^2 \qquad (4)$$

where

θ_t = total freezing time, hours.
r = coefficient surface of resistance, brine to ice, (F deg) (hr) (sq ft) per Btu.
b = Long side of can, inches.

The value of r varies with brine velocity. For very high brine velocities $r = 0.02$; for ordinary ice tanks with relatively slow moving brine $r = 0.04$.

To the freezing time established, it is necessary to add a reasonable time for the core pulling and refilling operation, varying in time from ½ to 1 hr.

BRINE COOLING

The cooling of brine in ice tanks is accomplished by various kinds of evaporators. Modern tanks use either open end shell-and-tube horizontal coolers, trunk coils, or verti-flow or raceway coils. *The older coil types appear to find acceptance in* the new small tanks using low pressure refrigerants.

An enclosed cooler external to the tank may be used only when the brine is pumped from one end of the brine tank and discharged into an agitator at the opposite end. The thermal efficiency of this system is not equal to that of the usual design.

Typical freezing tank coil designs, until about 1925, had 1¼ or 2 in. black steel pipe coils arranged in single vertical stands running longitudinally and set up between each row of cans, along the tank sides and center partition. Pipe coils were also arranged in various vertical and horizontal circuits, with 1¼ in. pipe more commonly used. Vertical stands 8 and 10 pipes high, containing 180 to 200 ft per ton of daily ice capacity were usual. More efficient tanks of the 10 pipe class used 240 to 310 ft of 1¼ in. pipe per ton of daily ice production.

Open shell-and-tube coolers and trunk evaporators provide a large circulating brine volume in a single-pass operation. The cooling range at best does not exceed ½ to 1 F deg establishing the variability of brine temperature in the tank. Tanks of over 30 tons are usually divided into multiple sections so as to insure small temperature ranges. Brine velocities vary between 3 and 5 fps through the shell cooler tubes, in order to keep the cooler diameter reasonable and agitation hp low. In shell-and-tube coolers, heat transfers of 60 to 80 Btu per (sq ft) (hr) (F deg) may be procured, with brine tem-