III. Insulation

Expanded polystyrene has been used in packages that:

1. Keep product frozen; for example: meat, fish and medical specimens.
2. Maintain product below a critical temperature; foods, pharmaceuticals, and chemicals.
3. Prevent product freezing; chemicals, fish, plants, and medical supplies.
4. Minimize extreme temperature variations; sensitive instruments, electronics, live fish, plants, and flowers.

It has been effective in these uses because of its low thermal conductivity (Figure 44) and its insensitivity to lower temperature; physical properties change minimally at sub-freezing temperatures. Also, thermal conductivity decreases at lower average mean temperature (Figure 45). When comparing the efficiency of insulating materials the mean temperature, at which the data was developed, should always be stated.

Theoretically, with thermal conductivity data one can easily calculate the minimum thickness required for a particular level of package insulation by using the equation:

$$q = \frac{k\,a\,(t_1 - t_2)}{X}$$

Where q = heat loss, Btu/hour

k = thermal conductivity, Btu — in./hr — ft.^{2}/°F

a = area perpendicular to the flow of heat, square feet

$(t_1 - t_2)$ = temperature difference, °F

X = thickness, inches.

Product requirements determine "q", the permissible heat loss, for the anticipated temperature difference $(t_1 - t_2)$ and estimated area. With this information one can solve for X.

Unfortunately, it is not that easy. Quite frequently the permissible heat loss is very small, as for a product with low mass and low specific heat. It becomes even more critical if the temperature difference is large.

$$X = \frac{(t_1 - t_2)}{q} \quad \begin{matrix}\text{Large}\\ \text{Small}\end{matrix}$$

The thickness determined in this fashion can be prohibitive and unrealistic. Since in such a case a moderating agent (ice or dry ice) will be required, it is easier and more accurate to test a fabricated package with the moderating agent.

A package in which five pounds of ice melts completely in 30 hours at the anticipated average mean temperature has a "q", heat loss, of 24 Btu/hr.

Heat of fusion of ice = 144 Btu/hr

$$\frac{5 \text{ lbs} \times 144 \text{ Btu/lb}}{30 \text{ hr}} = 24 \text{ Btu/hr}$$

With this information one can determine the amount of ice required to maintain the product the desired length of time. The "Icing Guidelines" of Figure 46 were developed by the Bureau of Commercial Fisheries (Reference 12) by this method.

Figure 44

THERMAL CONDUCTIVITY, k MEAN TEMP. 75°F

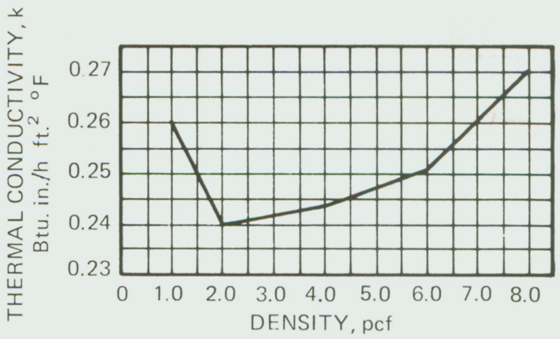
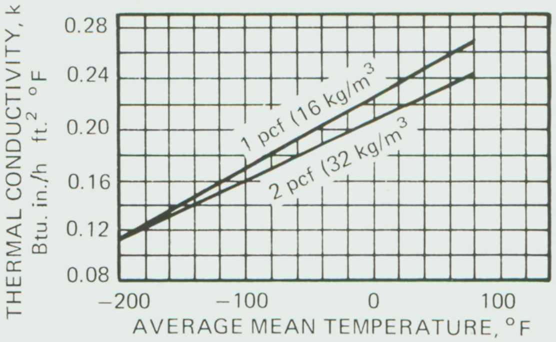


Figure 45

THERMAL CONDUCTIVITY, k OVER 300°F MEAN TEMPERATURE RANGE



These guidelines are specific to a particular package for fish. The "Dry Ice Loading Chart" (Figure 47) developed by Mr. Joseph Hanlon (Reference 13) is specific for an expanded polystyrene package with a two-inch wall and an interior volume just large enough to contain the dry ice. Mr. Hanlon's chart correlates well with studies made at ARCO Chemical's Development Laboratories (Figure 48).

Should one desire to insure that six pounds of meat remain frozen for five days, then one would have to use approximately 14 pounds of dry ice*, an estimate based on Figures 47 and 48. To verify this a box would have to be fabricated with two-inch walls and an interior volume large enough for the meat and dry ice. The meat has a volume of 54 cubic inches. Fifteen pounds of dry ice would have a volume of 267 cubic inches.

$$\frac{15 \text{ lb} \quad X \quad 1728 \text{ cu in / cu ft}}{97.2 \text{ lb / cu ft}} = 267 \text{ cu in.}$$

Volume of dry ice + volume of meat = total volume

267 cu in. + 54 cu in. = 321 cu in.

10" X 7" X 5" = 350 cu in.

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*The amount of heat that has to be absorbed to keep the meat below freezing is small by comparison, 100.8 Btu.

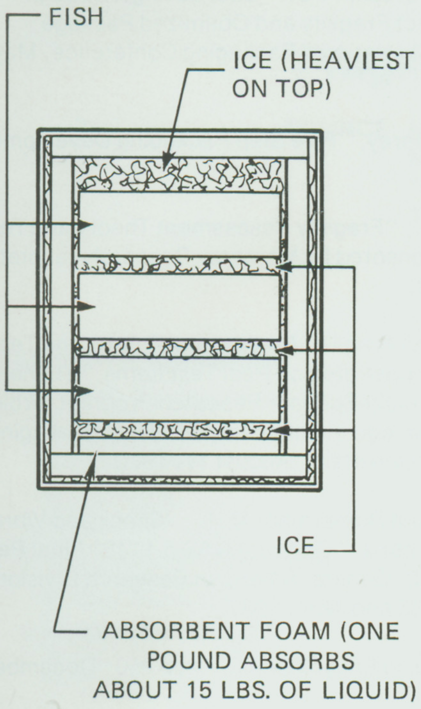
6 lb of meat X 0.40 Btu/lb (°F) X (—10 —32) = 100.8 Btu

0.40 Btu/lb (°F) — the specific heat of beef (fresh lean) below freezing.

—10°F = initial temperature of beef

$$\frac{100.8 \text{ Btu}}{241 \text{ Btu/lb}} = 0.42 \text{ lb of dry ice}$$

Figure 46
ICING GUIDELINES



ICING GUIDELINES (BASED ON 1 1/4 INCHES OF EXPANDED POLYSTYRENE INSULATION)

There must be sufficient ice to cool the fish to 32° F. and keep it at that temperature until it reaches its destination. To cool the fish to 32° F. from:

40° F., add 5 lbs. of ice per 100 lbs. of fish
50° F., add 10 lbs. of ice per 100 lbs. of fish
60° F., add 16 lbs. of ice per 100 lbs. of fish
70° F., add 21 lbs. of ice per 100 lbs. of fish

To keep the fish cool when the ambient temperature is:

40° F., add 2 lbs. of ice per 24 hrs.
60° F., add 6 lbs. of ice per 24 hrs.
80° F., add 10 lbs. of ice per 24 hrs.
100° F., add 14 lbs. of ice per 24 hrs.

Example: How much ice is needed for a 50-lb. box of fish when the initial product temperature is 60° F., and the estimated time in transit is 1 1/2 days, and the average ambient temperature in transit is estimated at 80° F.?

To cool: $\frac{16}{100} \times 50 = 8$ lbs.

To keep cool: $10 \times 1\ 1/2 = 15$ lbs.

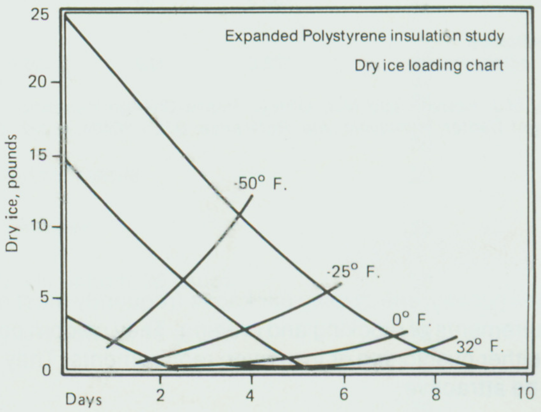
Total ice required $= 8 + 15 = 23$ lbs. minimum

A box with interior dimensions of 10'' X 7'' X 5'' would be large enough to accommodate six pounds of meat and 16 + pounds of dry ice. It should be fabricated from 2-inch board stock using lap joints and all means to insure a tight fit and minimize heat loss. Testing should be conducted at the anticipated ambient temperature.

Whether using dry ice to keep product frozen or ice to keep product cold, the principle is the same. As long as some of the moderating agent is present each pound will absorb heat equal to its heat of fusion and will remain at its melting temperature. Dry ice will absorb 241 BTU/lb. and will remain at —109°F. When all the dry ice has sublimed, then the package interior temperature will start to rise. It might take 120 hours for the dry ice to dissipate but might only take another five or six hours for the interior temperature to rise to above freezing. Ice will absorb 144 BTU/lb. and remain at 32°F until all ice is melted. This process, reversed, can also be used to keep product from going below a certain temperature.

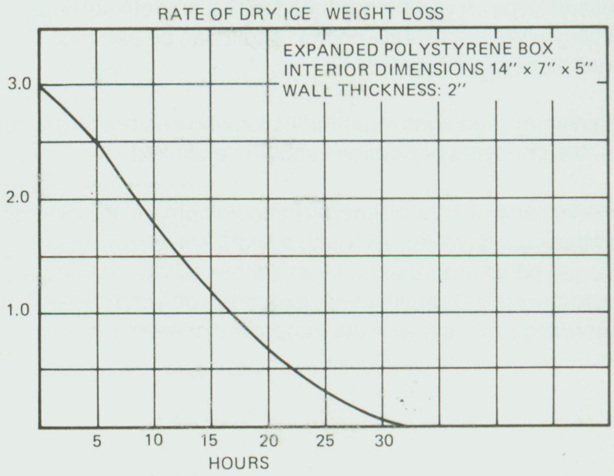
You can insure that the interior temperature of a package placed in a subfreezing environment will not go below 32°F by adding water, all the water will have to freeze before the temperature drops. If instead of 32° the lower temperature limit is 39°F, then a fused salt eutectic (Figure 49) should be used. All of the fused salt eutectic would have to solidify before the temperature would drop below 39°F. The temperature control materials of Figure 49 provide the package designer a wide range of temperature conditions from which to choose.

Figure 47



*Amount of dry ice necessary for different lengths of time in box insulated with two inches of expanded polystyrene, just large enough to contain dry ice. In two days, 4 pounds reach −25° F., 15 pounds take 4 days to reach −25°F.

Figure 48
EXPANDED POLYSTYRENE INSULATION STUDY



Whatever the temperature requirements, the procedure is the same. First, test a fabricated package at an estimated level to establish performance characteristics. With the accumulated data, test at the desired level. Finally, run a test with the product in the package. Monitored test shipments of the initial package production are always desirable before full production of any package.

Figure 49
TEMPERATURE CONTROL MATERIALS

Temperature control materials

	Melting point, °F.	*Heat of Fusion Btu per lb.*	*Density lb./ft.3*	*Cost $/lb.*
Dry Ice	*-109.0*	*241*	*97.3*	*0.04*
Water	*32.0*	*144*	*62.4*	*0.02*
Fused salt eutectic *31% Na2SO4* *13% NaCl* *16% KCL* *40% water*	*39.0*	*101*	*106.1*	*0.84*
n-Tetradecane	*41.9*	*98*	*48.1*	*6.00*
Acetic acid	*62.1*	*80*	*65.6*	*2.41*
Carbowax	*72.0*	*63*	*69.0*	*1.85*
Lithium nitrate trihydrate	*85.8*	*128*	*96.8*	*6.00*
Sodium hydrogen phosphate dodecahydrate	*97.0*	*114*	*94.9*	*4.33*
Stearic acid	*156.9*	*86*	*52.9*	*2.59*
Barium hydroxide octahydrate	*172.0*	*129*	*136.0*	*2.60*

D.V. Hale, M.J. Hoover, and M.J. O'Neill, Phase-Change Handbook, *Marshall Space Flight Center, Huntsville, Ala. Reference: B72 - 10464, p. 5-7, and other sources.*