CHAPTER 16

MEAT PRODUCTS

AROUND the world about 4 to 5 million (0.4 million in the United States) four-legged animals such as hogs, cattle, calves, buffalo, water buffalo, lambs, sheep, goats, and deer are slaughtered each day to supply the demand for red meats and their products. The majority of these animals are slaughtered in commercial slaughterhouses (abattoirs) under supervision, while a small portion (0.08% in the United States) are still killed on the farm. The slaughter process from live animals to packaged meat products is illustrated in Figure 1.

SANITATION

Sound sanitary practices should be applied at all stages of food processing, not only to protect the public but to meet aesthetic requirements. In this respect, meat processing plants are no different from other food plants. The same principles apply regarding sanitation of buildings and equipment; provision of sanitary water supplies and wash facilities; disposal of waste materials; insect and pest control; and proper use of sanitizers, germicides, and fungicides. All U.S. meat plants operate under regulations set forth in inspection service orders. For detailed sanitation guidelines to be followed in all plants producing meat under federal inspection, refer to the U.S. Department of Agriculture's *Agriculture Handbook No. 570*, the Food Safety and Inspection Service (FSIS), and Marriott (1994).

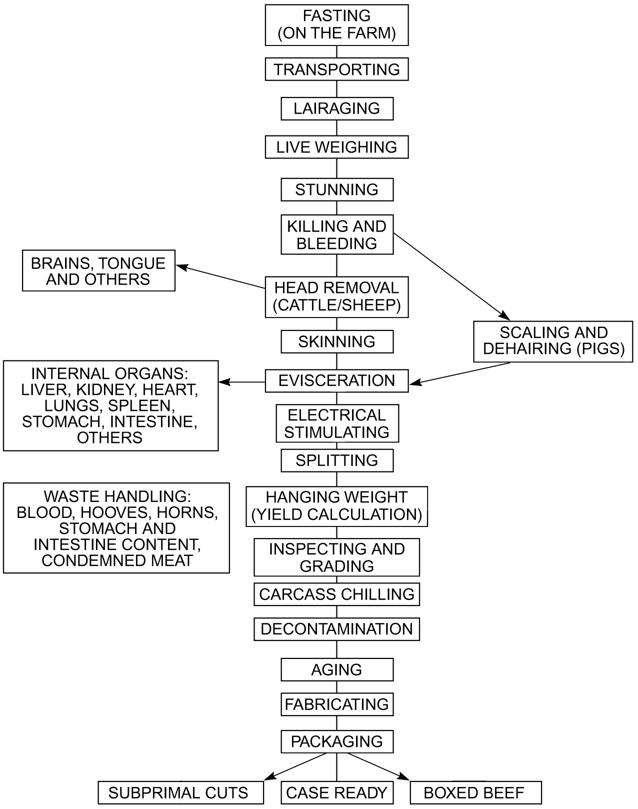

Fig. 1 Steps of Meat Processing

Proper safeguards and good manufacturing practices should minimize bacterial contamination and growth. This involves using clean raw materials, clean water and air, sanitary handling throughout, good temperature control (particularly in coolers and freezers), and scrupulous between-shift cleaning of all surfaces in contact with the product.

Precooked products present additional problems because favorable conditions for bacterial growth exist after the product has cooled to below 130°F. In addition, potential pathogens may experience enhanced growth because their competitor organisms were destroyed during cooking. Any delay in processing at this stage allows surviving microorganisms to multiply, especially when the cooked and cooled meat is handled and packed into containers prior to processing and freezing. Creamed products afford especially favorable conditions for bacterial growth. Filled packages should be removed immediately on filling and quickly chilled. Fast chilling not only reduces the time for growth, but can also reduce the number of bacteria.

It is even more important during processing to avoid any opportunity for the growth of pathogenic bacteria that may have entered the product. Although these organisms do not grow as quickly at temperatures below 40°F, they can survive freezing and prolonged frozen storage.

Storage at a temperature of about 25°F will permit the growth of psychrophilic spoilage bacteria, but at 14°F these, as well as all other bacteria, are dormant. Even though some cells of all bacteria types die during storage, activity of the survivors is quickly renewed with rising temperature. The processor should recommend safe preparation practices to the consumer. The best procedure is to provide instructions for cooking the food without preliminary thawing. In the freezer, sanitation is confined to keeping physical cleanliness and order, preventing access of foreign odors, and maintaining the desired temperatures.

Role of HACCP

Many of the procedures for the control of microorganisms are managed by the Hazard Analysis and Critical Control Point (HACCP) system of food safety, which is described in Chapter 11. It is a logical process of preventive measures that can control food safety problems. HACCP plans are required by the USDA in all plants. One aspect of the plan recommends that red meat carcasses and variety meats be chilled to 40°F within 24 h, and that this temperature be maintained during storage, shipping, and product display.

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

CARCASS CHILLING AND HOLDING

A hot-carcass cooler removes live animal heat as rapidly as possible. Side effects such as cold shortening, which can reduce tenderness, must be considered. Electrical stimulation can minimize cold shortening. Rapid temperature reduction is important in reducing the growth rate of microorganisms that may exist on carcass surfaces. Conditions of temperature, humidity, and air motion must be considered to attain desired meat temperatures within the time limit and to prevent excessive shrinkage, bone taint, sour rounds, surface slime, mold, or discoloration. The carcass must be delivered with a bright, fresh appearance.

Spray Chilling Beef

Spraying cold water intermittently on beef carcasses for 3 to 8 h during chilling is currently the normal procedure in commercial beef slaughter plants (Johnson et al. 1988). Basically, this practice reduces evaporative losses and speeds chilling. Regulations do not allow the chilled carcass to exceed the prewashed hot-carcass weight. The carcass is chilled to a large extent by evaporative cooling. As the carcass surface tissue dries, moisture migrates toward the surface, where it evaporates. Eventually, an equilibrium is reached when the temperature differential narrows and reduces the evaporative loss.

When carcasses were shrouded, once a frequently used method for reducing weight loss (shrink), typical evaporative losses ranged from 0.75 to 2.0% for an overnight chill (Kastner 1981). Allen et al. (1987) found that spray-chilled beef sides lost 0.3% compared with 1.5% for non-spray-chilled sides. Those authors stated that although variation in carcass shrink of spray-chilled sides was influenced by carcass spacing, other factors, especially those affecting the dynamics of surface tissue moisture, may be involved. Carcass washing, length of spray cycle, and carcass fatness also influence the variation in shrink. With sufficient care, however, carcass cooler shrink can be nearly eliminated.

Loin eye muscle color and shear force are not affected by spray chilling, but fat color can be lighter in spray-chilled compared to non-spray-chilled sides. Over a 4 day period, color changes and drip losses in retail packs for rib steaks and round roasts were not related to spray chilling (Jones and Robertson 1989). Those authors also concluded that spray-chilling could provide a moderate reduction in carcass shrinkage during cooling without having a detrimental influence on muscle quality.

Vacuum-packaged inside rounds from spray-chilled sides had significantly more purge (i.e., air removed) (0.9 lb or 0.26%) than those from conventionally chilled sides. Spacing treatments where foreshanks were aligned in opposite directions and where they were aligned in the same direction but with 6 in. between sides both result in less shrink during a 24 h spray-chill period than the treatment where foreshanks were aligned in the same direction but with all sides tightly crowded together (Allen et al. 1987). Some studies with both beef (Hamby et al. 1987) and pork (Greer and Dilts 1988) indicated that bacterial populations of conventionally and spray-chilled carcasses were not affected by chilling method (Dickson 1991). However, Acuff (1991) and others showed that use of a sanitizer (chlorine, 200 ppm, or organic acid, 1 to 3%) significantly reduces carcass bacterial counts.

Chilling Time

Although certain basic principles are identical, beef and hog carcass chilling differs substantially. The massive beef carcass is only partially chilled (although shippable) at the end of the standard overnight period; the average hog carcass may be fully chilled (but not ready for cutting) in 8 to 12 h, while the balance of the period accomplishes only temperature equalization.

The beef carcass surface retains a large amount of wash water, which provides much evaporative cooling in addition to that derived from actual shrinkage; but evaporative cooling of the hog carcass, which retains little wash water, occurs only through actual shrinkage. A beef carcass, without skin and destined largely for sale as fresh cuts, must be chilled in air temperatures sufficiently high to avoid freezing and damage to appearance. Although it must subsequently be well tempered for cutting and scheduled for in-plant processing, a hog carcass, including the skin, can tolerate a certain amount of surface freezing. Beef carcasses can be chilled with an overnight shrinkage of 0.5%, whereas equally good practice on hog carcasses will result in 1.25 to 2% shrinkage.

The bulk (16 to 20 h) of beef chilling is done overnight in high-humidity chilling rooms with a large refrigeration and air circulation capacity. The balance of the chilling and temperature equalization occurs during a subsequent holding or storage period that averages 1 day, but can extend to 2 or 3 days, usually in a separate holding room with a low refrigeration and air circulation capacity.

Some packers load for shipment the day after slaughter, since some refrigerated transport vehicles have ample capacity to remove the balance of the internal heat in round or chuck beef during the first two days in transit. This practice is most important in rapid delivery of fresh meat to the marketplace. Carcass beef that is not shipped the day after slaughter should be kept in a beef-holding cooler at temperatures of 34 to 36°F with minimum air circulation to avoid excessive color change and weight loss.

Refrigeration Systems for Coolers

Refrigeration systems commonly used in carcass chilling and holding rooms are operated with ammonia as the primary refrigerant and are of three general types: dry coils, chilled brine spray, and sprayed coil.

Dry-Coil Refrigeration. Dry-coil systems comprise most chilling and holding room installations. Dry-coil systems usually include unit coolers equipped with coils, defrosting equipment, and fans for air-vapor circulation. Because the coils are operated without continuous brine spray, eliminators are not required. Coils are usually finned, with fins limited to 3 or 4 per inch or with variable fin spacing to avoid icing difficulties. The units may be mounted on the floor, overhead on the rail beams, or overhead on converted brine spray decks.

Dry-coil systems operated at surface temperatures below 32°F build up a coating of frost or ice, which ultimately reduces the airflow and cooling capacity. Coils must therefore be defrosted periodically, normally every 4 to 24 h for coils with 3 or 4 fins per inch, to maintain capacity. The rate of buildup, and hence the defrosting frequency, decreases with large coil capacity and high evaporating pressure.

Defrosting may be done either manually or automatically by the following methods:

- **Hot-gas defrost** is accomplished, with the fans off, by introducing hot gas directly from the system compressors into the evaporator coils. The evaporator suction is throttled to maintain a coil pressure of about 60 to 75 psig (at approximately 40 to 50°F). The coils then act as condensers and supply the heat for melting the ice coating. Other evaporators in the system must supply the load for the compressors during this period. Hot-gas defrost is rapid, normally requiring 10 to 30 min for completion. See Chapter 3 for further information about hot-gas defrost piping and control.
- **Coil spray defrost** is accomplished (with the fans turned off) by spraying the coil surfaces with water, which supplies the heat required to melt the ice coating. Suction and feed lines are closed off, with pressure relief from the coil to the suction line to minimize the refrigeration effect. Enough water at 50 to 75°F must be used to avoid freezing on the coils, and care must be taken to ensure that drain lines do not freeze. The sprayed water tends

to produce some fog in the refrigerated space. Coil spray defrost may be more rapid than hot-gas defrost.

- **Room air defrost** (for rooms 35°F or higher) is accomplished with the fans running while suction and feed lines are closed off (with pressure relief from coil to suction line), to permit buildup of coil pressure and melting of the ice coating by transfer of heat out of the air flowing across the coils. Refrigeration therefore continues during the defrosting period, but at a drastically reduced rate. Room air defrost is slow; the time required may vary from 30 min to several hours if the coils are undersized for dry-coil operation.
- **Electric defrost** is accomplished with electric heaters with fans either on or off. During defrost, refrigerant flow is interrupted.

Unit coolers may be defrosted by any one or combinations of the first three methods. All methods involve a reduction in chilling capacity, which varies with time loss and heat input. Hot-gas and coil spray defrost interrupt the chilling only for short periods, but they introduce some heat into the space. Room air defrost severely reduces the chilling rate for long periods, but the heat required to vaporize the ice is obtained entirely from the room air.

Evaporator controls customarily employed in carcass chilling and holding rooms include refrigerant feed controls, evaporator pressure controls, and air circulation control.

Refrigerant feed controls are designed to maintain, under varying loads, as high a liquid level in the coil as can be carried without excessive liquid spillover into the suction line. This is accomplished by using an expansion valve that throttles the liquid from supply pressure (typically 150 psig) to evaporating pressure (usually 20 psig or higher). The throttling of the liquid flashes some of it to gas, which chills the remaining liquid to saturation temperature at the lower pressure. If it does not bypass the coil, the flashed gas tends to reduce flooding of the interior coil surface, thus lowering coil efficiency.

The valve used may be a hand-controlled expansion valve supervised by operator judgment alone, a thermal expansion valve governed by the degree of superheat of the suction gas, or a float valve (or solenoid valve operated by a float switch) governed by the level of feed liquid in a surge drum placed in the coil suction line. This surge drum suction trap permits the ammonia flashed to gas in the throttling process to flow directly to the suction line, bypassing the coil. The trap may be small and placed just high enough so that its level governs that in the coils by gravity transfer. Or, as in the ammonia recirculation system, it may be placed below coil level so that the liquid is pumped mechanically through the coils in much greater quantity than is required for evaporation. In the latter case, the trap is sized large enough to carry its normal operating level plus all the liquid flowing through the coils, thus effectively preventing liquid spillover to the compressors. Nevertheless, it is necessary in all cases to provide further protection at the compressors' liquid return.

Present practice strongly favors liquid ammonia recirculation systems, mainly because of the greater coil heat transfer rates with the resultant greater refrigerating capacity over other systems (see Chapter 3). Some have coils mounted above the rail beams with 4 to 6 ft of ceiling head space. Air is forced through the coils, sometimes using two-speed fans.

Manual and thermal expansion valves do not provide good coil flooding under varying loads and do not bypass the flashed feed gas around the coils. As a result, evaporators so controlled are usually rated 15 to 25% less in capacity than those controlled by float valve or ammonia recirculation.

Evaporator pressure controls regulate coil temperature, and thereby the rate of refrigeration, by varying evaporating pressure within the coil. This is accomplished by using a throttling valve in the evaporator suction line downstream from the surge drum suction trap. All such valves impose a definite loss on the refrigeration system, and the amount of the loss varies directly with the pressure drop through the valve. This increases the work of compression for a given refrigeration effect.

The valve used to control evaporating pressure may be a manual suction valve set solely by operator judgment, a back pressure valve actuated by coil pressure or temperature, or a back pressure valve actuated by a temperature-sensing element somewhere in the room. Manual suction valves require excessive attention when loads fluctuate. The coil-controlled back pressure valve seeks to hold a constant coil temperature but does not control room temperature unless the load is constant. Only the room-controlled compensated back pressure valve responds to room temperature.

Air circulation control is frequently used when an evaporator must handle separate load conditions differing greatly in magnitude, such as the load in chilling rooms that are also used as holding rooms or for the negligible load on weekends. The use of two-speed fan motors (operated at reduced speed during the periods of light load) or turning the fans off and on can control air circulation to a degree.

Chilled Brine Spray Systems. These systems are generally being abandoned in favor of other systems due to such a system's large required building space, inherent low capacity, brine carryover tendencies, and difficulty of control.

Sprayed Coil Systems. These consist of unit coolers equipped with coils, brine spray banks, eliminators to prevent brine carryover, and fans for air-vapor circulation. The units are usually mounted (without ductwork) either on the floor or overhead on converted brine spray decks. Refrigeration is supplied by the primary refrigerant in the coils. Chilled or nonchilled recirculated brine is continually sprayed over the coils, eliminating ice formation and the need for periodic defrosting.

The brine predominantly used is sodium chloride, with caustic soda or another additive for controlling pH. Because sodium chloride brine is corrosive, bare-pipe coils (without fins) generally see service. The brine is also highly corrosive to the rail system and other cooler equipment.

Propylene glycol with added inhibitor complexes is another coil spray solution used in place of sodium chloride. As with sodium chloride brine, propylene glycol is constantly diluted by moisture condensed out of the spaces being refrigerated and must be concentrated by evaporating water from it. The reconcentration process requires special equipment designed to minimize glycol losses. Sludge that accumulates in the concentrator may become an operating problem; to avoid it, additives must be selected and pH closely controlled. Finned coils are usually used with propylene glycol.

Because of its noncorrosive nature in comparison to sodium chloride, propylene glycol greatly reduces the cost of unit cooler construction as well as maintenance of space equipment.

Other Systems. Considerable attention is being directed to system designs that will reduce the amount of evaporative cooling at the time of entrance into the cooler and eliminate ceiling rail and beam condensation and drip. Good results have been achieved by using low-temperature blast chill tunnels before entrance into the chill room. The volume of ceiling condensate is reduced because the rate of evaporative cooling is reduced in proportion to the degree of surface cooling. Room condensation has been reduced by the addition of heat above carcasses (out of the main air stream), fans, minimized hot water usage during cleanup, better dry cleanup, timing of cleanup, and using wood rail supports.

Grade and yield sorting, with its simultaneous filling of several rooms, has shortened the chilling time available if refrigeration is kept off during the filling cycle. Its effect has to be offset by more chill rooms and more installed refrigeration capacity. If full refrigeration is kept at the start of filling, the peak load is reduced to the rooms being filled. Hot-carcass cutting has been started with only a short chilling time. Cryogenic chilling has also been tested for hot-carcass chilling.

Beef Cooler Layout and Capacity

Carcass halves or sides are supported by hooks suspended from one-wheel trolleys running on overhead rails. The trolleys are generally pushed from the dressing floor to the chilling room by powered conveyor chains equipped with fingers that engage the trolleys, which are then distributed manually over the chilling and holding room rail system. Chilling and holding room rails are commonly placed on 3 to 4 ft centers in the holding rooms, with pullout or sorting rails between them. The rails must be placed a minimum of 2 ft from the nearest obstruction, such as a wall or building column, and the tops of the rails must be at least 11 ft above the floor. The supporting beams should be placed a minimum of 6 ft below the ceiling for optimum air distribution. Applicable to new construction in plants engaged in interstate commerce, regulations for some of these dimensions are issued by the Meat Inspection Division of the FSIS.

To ensure effective air circulation, carcass sides should be placed on the rails in both chilling and holding coolers so that they do not touch each other. Required spacing varies with the size of the carcass and averages 2.5 ft per two sides of beef. In practice, however, sides are often more crowded.

A chilling room should be of such size that the last carcass loaded into it does not materially retard the chilling of the first carcass. While size is not as critical as in the case of the hog carcass chill room (because of the slower chill), to better control shrinkage and condensation, it is desirable to limit chill cooler size to hold not more than 4 h of the daily kill. Holding coolers may be as large as desired because of their ability to maintain more uniform temperature and humidity.

While overall plant chilling and holding room capacities vary widely, chilling coolers generally require a capacity equal to the daily kill; holding coolers require 1 to 2 times the daily kill.

Beef Carcasses. Dressed beef carcasses, each split into two sides, range in weight from approximately 300 to 1000 lb, averaging about 700 lb per head. Specific heats of carcass components range from 0.50 Btu/lb·°F for fat to 0.8 Btu/lb·°F or more for lean muscle, averaging about 0.75 Btu/lb·°F for the carcass as a whole.

The body temperature of an animal at slaughter is about 102°F. After slaughter, physiological changes occur that generate heat and tend to increase carcass temperature, while heat loss from the surface tends to lower it.

The largest part of the carcass is the round, and at any given stage of the chilling cycle its center has the highest temperature of all carcass parts. This *deep round* temperature (about 105°F when the carcass enters the chilling cooler) is therefore universally used as a measure of chilling progress. If it is to be significant, the temperature must be taken accurately. Incorrect techniques will show temperatures as much as 10°F lower than actual deep round temperature. An accurate technique that yields consistent results is shown in Figure 2. The technique applies a fast-reacting, easily read stem dial thermometer, calibrated before and after tests, inserted upward to the full depth through the hole in the aitch bone.

At the time of slaughter, the water content of beef muscle is approximately 75% of the total weight. Thereafter, a gradual drying of the surface takes place, resulting in weight loss or shrinkage. Shrinkage and its measurement are greatly affected by the final operations of the dressing process: weighing and washing. Weighing must be done prior to washing if the weights are to reflect actual product shrinkage.

A beef carcass retains large amounts of wash water on its surface, which it carries into the cooler. The loss of this water, occurring in the form of vapor, does not constitute actual product loss. However, it must be considered when estimating the system capacity since the vapor must be condensed on the coils, thus constituting an important part of the refrigeration load.

The amount of wash water retained by the carcass depends on its condition and on washing techniques. A carcass typically retains 8 lb, part of which is lost by drip and part by evaporation. Water pressures used in washing vary from 50 to 300 psig, and temperatures from 60 to 115°F.

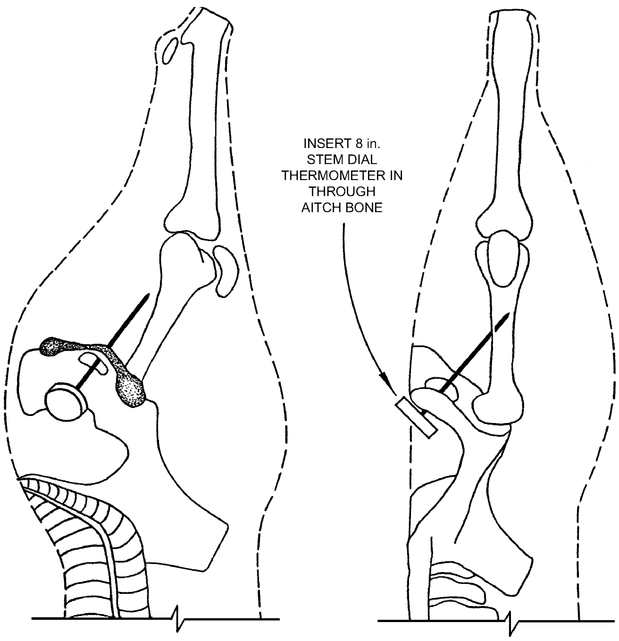

Fig. 2 Deep Round Temperature Measurement in Beef Carcass

To minimize spoilage, a carcass should be reduced to a uniform temperature of about 35°F as rapidly as possible. In practice, deep round temperatures of 60°F (measured as in Figure 2, with surface temperatures of 35 to 45°F, are common at the end of the first day's chill period.

To prevent formation of surface slime, most carcasses are cut, vacuum packaged, and boxed within 24 to 72 h. Otherwise, a carcass surface requires a certain dryness during storage. Exposed beef muscle chilled to an actual temperature of 36°F will not slime readily if dried at the surface to a water content of 90% of dry weight (47.4% of total weight). Such a surface is in vapor pressure equilibrium with a surrounding atmosphere at the same temperature (36°F) and 96% rh. In practice, a room atmosphere at 32 to 34°F and approximately 90% rh will maintain a well-chilled carcass in good condition without slime (Thatcher and Clark 1968).

Chilling-Drying Process. Curves of carcass temperature during a chilling-holding cycle are shown in Figure 3. Note that some heat loss occurs before a carcass enters the chilling cooler. The evaporative cooling of surface water dominates in the initial stages of hot-carcass chilling. As chilling progresses, the rate of losses by evaporative surface cooling diminishes and the sensible transfer of heat from the carcass surface increases. Note that the time-temperature rates of change are subject to variations between summer and winter ambient conditions, which influence system capacity.

The rate of transfer is increased both by more rapid circulation of air and lower air temperature, but these are limited by the necessity of avoiding surface freezing.

Estimated differences in vapor pressure between surface water (at average surface temperature) and atmospheric vapor during a typical chilling-holding cycle, and the corresponding shrinkage curve for an average carcass, are shown in Figure 4. Note the tremendous vapor pressure differences during the early part of the chill cycle when the carcass is warm. The evaporative loss could be reduced by beginning the chill with room temperature high, then lowering it slowly to minimize the pressure difference between carcass surface water and room vapor at all times. However, this slows

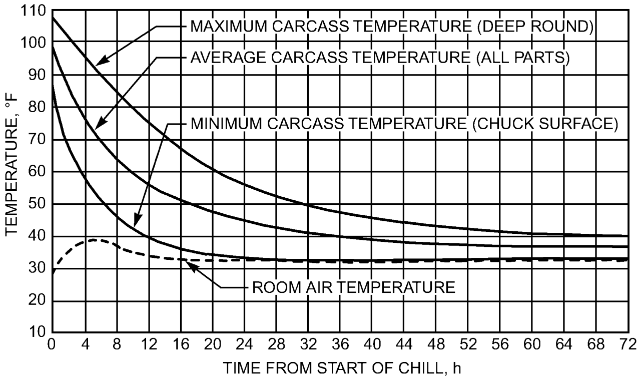

Fig. 3 Beef Carcass Chill Curves

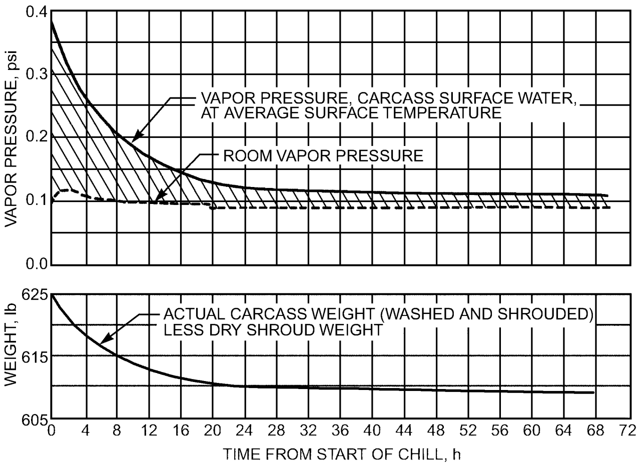

Fig. 4 Beef Carcass Shrinkage Rate Curves

the chill and prolongs the period of rapid evaporation. The quick chill practice is favored; but the cold shortening effect and bacterial growth must be considered in carcass quality and keeping time.

Evaporation from the warm carcass in cool air is nearly independent of room relative humidity because the warm carcass surface generates a much higher vapor pressure than the cooler vapor surrounding the carcass. If the space surrounding a warm carcass is saturated, evaporation forms fog, which can be observed at the beginning of any chill.

Evaporation from the well-chilled carcass with surface temperature at or near room temperature is different. The spread between surface and room vapor pressures approaches zero when room air is near saturation. Evaporation proceeds slowly, without forming fog. Evaporation does not cease when a room is saturated; it ceases only if the carcass is chilled through to room temperature, and no heat transfer is taking place.

The ultimate disposition of water condensed on the coils depends on the temperature of the coil surface and the method of coil operation. In continuous defrost (sprayed coil) operation, condensed and trapped water dilute the solution sprayed over the coil. In nonfrosting dry-coil operation, condensed water falls to the evaporator pan and drains to the sewer. Water frozen on the coil is lost to the sewer if removed by hot-gas or coil spray defrost. Periodic room air defrost, however, vaporizes part of the ice and returns it to room atmosphere, while losing the remainder to drain. This method of defrost is not normally used in beef chill or holding coolers because temperatures are not suitable, and thus the defrost period is excessive, resulting in abnormal room temperature variations. Most chill and holding evaporators are automatically defrosted with water or hot gas on selected time cycles. The weight changes that take place in an average beef carcass are given in Table 1.

Table 1 Weight Changes in Beef Carcass

Chilling Cooler	Weight, lb
Initial dry weight	615
Wash water pickup	8
Initial wet weight	623
Spray chill water use	16
Drip (not evaporated)	10
Weight at maximum (8 h postmortem)	633
Weight loss 8 to 24 h postmortem	18
Net weight loss (ideal)	0
Holding Cooler	
Weight loss/day	3
Final weight (48 h postmortem)	602

Chilling of the beef carcass is not completed in the chill cooler but continues at a reduced rate in the holding cooler. A carcass well chilled when it enters the holding cooler shows minimum holding shrinkage; a poorly chilled one shows high holding shrinkage.

If shrinkage values are to have any significance, they must be carefully derived. Actual product loss must be determined by first weighing the dry carcass prior to washing and then weighing it out of the cooler. In-motion weights are not sufficiently precise; carcasses must be weighed at rest. Scales must be accurate, and, if possible, the same scale should be used for both weighings. If shrinkage is to have any comparison value, it must be measured on carcasses chilled to the same temperature, since chilling occurs largely by evaporative weight loss.

Design Conditions and Refrigeration Load. Equipment selection should be based on conditions at peak load, when product loss is greatest. Room losses, equipment heat, and carcass heat add up to a total load that varies greatly—not only in magnitude but in proportion of sensible to total heat (sensible heat ratio)—throughout the chill. As the chill progresses, the vapor load decreases and the sensible load becomes more predominant.

Under peak chilling load, excess moisture condenses into fog—enough to warm the air-vapor-fog mixture to the sensible heat ratio of the heat removal process. The heat removal process of the coil therefore underestimates the actual rate of water removal by the amount of vapor condensed to fog (Table 2).

Fog does not generally form under later chilling-room loads and all holding-room loads, although it may form locally and then vaporize. Sensible heat ratios of air vapor heat gain and air vapor heat removal are then equal (Table 3).

Beef chilling rooms generally have evaporator capacity sufficient to hold room temperature under load approximately as shown in Figure 3. This results in an increase in room temperature to 35 to 40°F, with gradual reduction to 32 to 34°F. However, many installations provide greater capacity, particularly dry-coil systems, which thereby avoid excessive coil frosting. In batch-loaded coolers, room temperature may be as low as 25°F under peak load, provided it is raised to 30°F as the chill progresses, without surface freezing of the beef. The shrinkage improvement affected by these lower temperatures, however, tends to be less than expected (in beef chilling) because of the relatively small part played by sensible transfer of heat.

Standard practice in the holding room calls for providing enough evaporator capacity to keep the room temperature at 32 to 34°F at all times. Holding room coils sized at peak load, low air vapor circulation rate, and a coil temperature 10°F below room temperature tend to maintain the approximately 90% rh that avoids excessive shrinkage and prevents surface sliming.

Table 2 Load Calculations for Beef Chilling

Cooler size, ft:	62 × 74 × 18.5
Cooler capacity:	476 carcasses
Average carcass weight:	625 lb
Assumed chill rate:	50°F in 20 h
Assumed air circulation:	167,400 cfm
Loading time:	3.3 h maximum
Assumed air to coil:	33°F, 100% rh
Assumed fan motive power:	36 hp
Specific heat of beef:	0.75 Btu/(lb·°F)
Air density:	0.08 lb/ft^3

	Loads, Btu/h		
Heat Gain—Room Load	**Sensible**	**Latent**	**Total**
1. Transmission, infiltration, personnel, fan motor, lights, and equipment heat	162,000	4100	166,100
2. Product heat (average, first 4 h):			
a. 476 × 625 × 0.75 × 50 × 0.1	1,115,700		
b. 476 × 14.3 × 0.13 × 1070[a]	–947,000	947,000	1,115,700
3. Total heat gain (room load), kW (Items 1 + 2a + 2b)	332,700	951,100	1,283,800
Heat Removal—Coil Load			
4. Air circulation, lb/h dry air 167,400 × 0.08 × 60 = 803,500	—	—	—
5. Heat removed per lb of dry air, total heat (Item 3)/(Item 4) = 1.6 Btu/lb	—	—	—
6. Air-vapor enthalpy, Btu/lb dry air:			
a. Air to coil, 33°F, 100% rh	7.927	4.242	12.17
b. Btu removed, temperature drop 3.7°F	–0.927	–0.672	–1.60
c. Air from coil, 29.3°F, 100% rh	7.000	3.570	10.57
7. Cool air-vapor heat removal, Btu (Item 4) (Item 6b)	744,000	539,800	1,283,800
8. Room vapor condensed to fog (Item 7) - (Item 3)	411,300	–411,300	
9. Water (ice) removed by coil 476 × 14.3 × 0.13 × 144[b]		128,000	128,000
10. Total heat removal (coil load), Btu/h (Items 3 + 8 + 9)	744,000	667,800	1,411,800

[a] Heat of vaporization [b] Heat of fusion

Table 3 Load Calculations for Beef Holding

Cooler size, ft:	100 × 136 × 18.5
Cooler capacity, one day's kill:	1120 carcasses
Average carcass weight:	610 lb
Assumed chill rate:	7.5°F in 24 h
Assumed air circulation:	91,200 cfm
Assumed air to coil:	34°F, 96% rh
Assumed fan motive power:	24 hp
Specific heat of beef:	0.75 Btu/(lb·°F)
Air density:	0.08 lb/ft^3

	Loads, Btu/h		
Heat Gain—Room Load	**Sensible**	**Latent**	**Total**
1. Transmission, infiltration, personnel, fan motor, lights, and equipment heat	245,000	10,000	255,000
2. Product heat (average, first 4 h):			
a. 1120 × 610 × 0.75 × 7.5 × 0.5	192,000		
b. 1120 × 1.8 × 0.06 × 1070[a]	–131,000	131,000	192,000
3. Total heat gain (room load), Btu/h (Items 1 + 2a + 2b)	306,000	141,000	447,000
Heat Removal—Coil Load			
4. Air circulation, lb/h dry air 91,200 × 0.08 × 60 = 437,800	—	—	—
5. Heat removed per lb of dry air, Btu (Item 3)/(Item 4) = 1.023	—	—	—
6. Air-vapor enthalpy, Btu/lb dry air:			
a. Air to coil, 34°F, 96% rh	8.167	4.227	12.394
b. Btu removed, temperature drop 2.9°F	–0.700	–0.323	–1.027
c. Air from coil, 31.1°F, 100% rh	7.467	3.904	11.367
7. Coil air-vapor heat removal, Btu/h	306,000	141,000	447,000
8. Room vapor condensed to fog	—	—	—
9. Water (ice) removed by coil 1120 × 1.8 × 0.06 × 144[b]	—	17,400	17,400
10. Total heat removal (coil load), Btu/h (Items 3 + 8 + 9)	306,000	158,400	464,400

[a] Heat of vaporization [b] Heat of fusion

From the average temperature curve shown in Figure 3 and the shrinkage curve in Figure 4, certain generalizations useful in calculating carcass chilling load may be made. In the chilling cooler, the average carcass temperature is reduced approximately 55°F, from about 102°F to about 47°F, in 20 h. Simultaneously, about 14.3 lb of water is vaporized for each 625 lb carcass entering the chill; only 4.3 lb of this is actual shrinkage. The losses of sensible heat and water occur at about the same rate. In the sample load calculations, this is calculated at an average of 10% for the first 4 h of chill for sensible heat and 13% for the evaporation of moisture, which roughly agrees with the curves of Figures 3 and 4. This is the maximum rate of chill and is used for sizing the refrigeration equipment and piping.

In the holding cooler, the average carcass temperature is reduced from 47 to 39.5°F in 24 h. Simultaneously, about 1.8 lb of water is vaporized per carcass. Where spray chilling is employed, this shrinkage approaches zero. Here also, the losses of sensible heat and water occur at about the same rate. The sample load calculations are figured at a 5% average for the first 4 h for sensible heat and 6% for latent heat.

Under peak chilling and holding room conditions, water trapped and condensed out by the coils imposes a further latent load on the evaporators. This occurs in the form of heat extracted to freeze condensed water into ice or of heat removed to chill the returning warmed and strengthened spray solution. In the absence of a more complex evaluation, this load may be considered equal to the latent heat of fusion (144 Btu/lb) of the water removed.

Based on the data just mentioned, cooler loads may be calculated as illustrated in Tables 2 and 3. Transmission, infiltration, personnel, and equipment loads are estimated by standard methods such as those discussed in Chapter 12.

The complete calculation is made to illustrate the heat removal process associated with the chilling-drying of the carcass. In particular, it illustrates that the sensible heat ratio of the heat transfer in the coil cannot be used to measure the amount of water removed from the space when fog is involved.

Evaporator Selection. Evaporator selection is a procedure of approximation only, because of the inaccuracies of load determination on the one hand and of predicting sustained field performance of coils on the other. Furthermore, there is rarely complete freedom of specification; for example, the air vapor circulation rate for a given coil may be limited to avoid spray solution carryover or excessive fan power.

Sprayed and dry-coil systems perform equally well with respect to shrinkage, provided compressor capacity is adequate and the evaporators are correct for the system selected. Evaporator require-

Table 4 Sample Evaporator Installations for Beef Chilling[a]

Cooler size, ft:	62 × 74 × 18.5
Cooler capacity:	476 carcasses
Deep-round chill:	to 50°F in 20 h
Design load:	1,412,000 Btu/h
Coil operation:	liquid recirculation
Loading time:	3.3 h
Average carcass weight:	625 lb
Assumed air to coil:	33°F, 100% rh
Sensible heat ratio:	53%

	Dry Coil
Coil Description:	
Type of coil	Finned
Fin spacing, fins/in.	4
Coil depth, number of pipe rows	8
Coil face area	20.4 ft^2
Coil surface area, total	2238 ft^2
Fan Description, Airflow:	
Type of fan	Centrifugal
Flow through coil	9300 cfm
Flow, coil face area	455 cfm/ft^3
Fan motive power	2 hp
Unit Rating[b] (*Total Heat*):	
TD for capacity rating, °F[c]	10
Chilling capacity, Btu/h	81,000
Temperature drop, air through coil, °F	3.7
Equipment for 520 Carcasses:	
Number units required	18
Total motive power, fans and pumps, hp	36
Coil surface per carcass, ft^2	88
Airflow per carcass, cfm	350

[a] Data describe actual successful installations, but other successful installations may be different.

[b] Ratings shown are estimated from performance of actual systems. Dry-coil ratings are at average frost conditions, with airflow reduced by frost obstruction. This example describes actual installations; it is not to be interpreted as an accepted standard. Other installations, employing both more and less equipment, are also successful.

[c] TD is temperature difference between refrigerant and air.

ments vary widely with the type of system. Comparative evaporator data on a typical, successful flooded coil installation in the chilling cooler are presented in Table 4.

The coil overall heat transfer coefficient and airflows shown describe sustained field performance under actual chilling conditions and loads; they should not be confused with clean coil test ratings. The heat transfer coefficient varies greatly with the character of the coil and its operation and is influenced by such variables as (1) the ratio of extended-to-prime surface, which may range from 7-to-1 to 21-to-1 in standard dry coils; (2) coil depth, which typically ranges from 8 to 12 rows in sprayed coils and from 4 to 10 rows in dry coils; (3) fin spacing, which may be 3 or 4 per inch in typical dry coils; (4) condition of the surface, either continuously defrosted or generally coated with frost; and (5) airflow, which may vary from 250 to 750 cfm per square foot of coil face area.

Greater temperature differences (TDs) than those shown are sometimes used, but a higher TD is valid only at high room temperatures. The lower TD (10°F) shown for dry coils is desirable to limit frosting. Many dry-coil evaporators have higher ratios of extended-to-prime surface and higher airflows per unit face area than shown.

The difficulties involved in obtaining accurate shrinkage figures on carcasses chilled to a specified degree cause wide differences of opinion as to the coil capacity required for good chilling. Although data describe actual successful installations, other successful installations may differ.

Boxed Beef

The majority of the output of beef slaughterhouses is in the form of prefabricated sections of the carcass, vacuum packed in plastic bags and shipped in corrugated boxes. Standard cuts can be sold at cost savings to the market. The shipping density is much greater, with easier material handling, and the bones and fat are removed where their value as a byproduct is greatest. Customers purchase only the sections they need, and the trim loss at final processing to primal cuts is minimized.

Vacuum-packaging with added carbon dioxide, nitrogen, or a combination of gases has the following advantages:

- Creates anaerobic conditions, preventing the growth of mold (which is aerobic and requires the presence of oxygen for growth)
- Provides more sanitary conditions for carcass breaking
- Retains moisture, retards shrinkage
- Excludes bacteria entry, extends shelf life
- Retards bloom until opened

After normal chilling, a carcass is broken into primal cuts, vacuum packed, and boxed for shipment. Temperatures are usually held at 28°F to prevent the development of pathogenic organisms. Aging of the beef continues after vacuum-packaging and during shipment, because the exclusion of oxygen or the addition of gases does not slow enzymatic action in the muscle.

Freezing Times of Boneless Meat. The cooling of boneless meat from 50 to 10°F requires the removal of about 133 Btu/lb of lean meat (74% water), most of which is latent heat liberated when the liquid water in the meat changes to ice. Most of the time needed to freeze meat is spent in cooling from 30 to 25°F.

For boneless meat in cartons, the rate of freezing depends on the temperature and velocity of the surrounding air and on the thickness and thermal properties of the carton and the meat itself.

Figure 5 shows the effects of the first three factors on cooling times for lean meat in two carton types. For example, the chart shows a total cooling time of about 24 h for solid cardboard cartons 5 in. thick at an air temperature of –26°F and a velocity of 400 fpm. The corresponding air temperatures and cooling times may be found for any specified thickness of carton and air velocity. Conversely, the chart can be used to find combinations of air velocity and temperature needed to freeze cartons of a particular thickness in a specified time (Figure 6).

Accuracy of the estimated freezing times is about 3% for air velocities greater than 400 fpm. Calculations are based on Plank's Equation as modified by Earle. A latent heat of 107 Btu/lb and an average freezing point of 28°F are assumed for lean meat.

Increasing the fat content of meat reduces the water content and hence the latent heat load. Thermal conductivity of the meat is reduced at the same time, but the overall effect is for freezing times to drop as the percentage of fat rises. Actual cooling times for mixtures of lean and fatty tissue should therefore be somewhat less than the times obtained from the chart. For meat with 15% fat, the reduction is about 17%.

Hog Chilling and Tempering

The internal temperature of hog carcasses entering the chill coolers from the killing floor varies from 100 to 106°F. The specific heat shown in Chapter 8 is 0.62 Btu/lb·°F, but in practice 0.7 to 0.75 Btu/lb·°F is used because changed feeding techniques have created leaner hogs. The dressed weight varies from 90 to 450 lb approximately, the average being near 180 lb. Present practice requires dressed hogs to be chilled and tempered to an internal ham

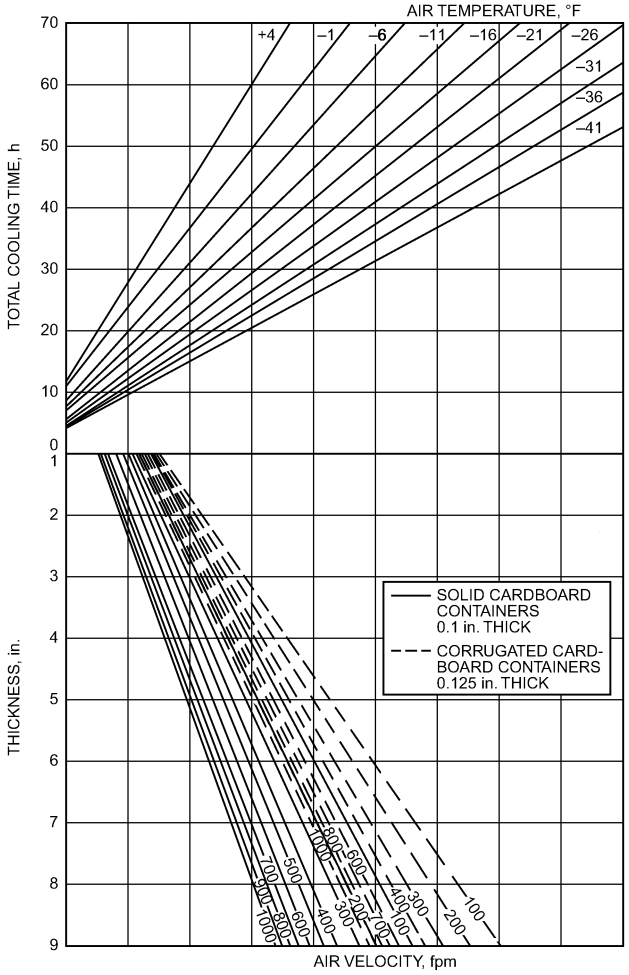

Fig. 5 Freezing Times of Boneless Meat

temperature of 37 to 39°F overnight. This limits the chilling and tempering time to 12 to 18 h.

Cooler and refrigeration equipment must be designed to chill the hogs thoroughly with no frozen parts at the time the carcasses are moved to the cutting floor. Carcass crowding, reducing exposure to circulated chilled air, and excessively high peak temperatures are all detrimental to proper chilling.

The following hog cooler design details will provide

- Sufficiently quick chilling to retard bacterial development and prevent deterioration
- A cooler shrinkage from 0.1 to 0.2%
- Firm carcasses that are dry and bright without frozen surface or internal frost, suitable for efficient cutting

Hog Cooler Design. The capacity of hog coolers is set by the dressing rate of hogs and the planned hours of operation. However, on a one-shift basis, it is economically sound to provide cooler hanging capacity for 10 h dressing in order to properly handle the chilling of large sows that require more than 24 h exposure in the chill room; handle increased dressing volumes when market conditions warrant overtime operation; and have some flexibility in unloading and loading the cooler during normal operations. On a two-shift basis, extra cooler capacity for overtime operation is not necessary.

The rail height should be 9 ft to provide both good air circulation and adequate clearance between the floor and the largest dressed hog. (In the United States, this is a requirement of the FSIS and most state regulations.) Rails should be spaced at a minimum of 30 in. on centers to provide sufficient clearance for the hanging hogs and to prevent contact between carcasses.

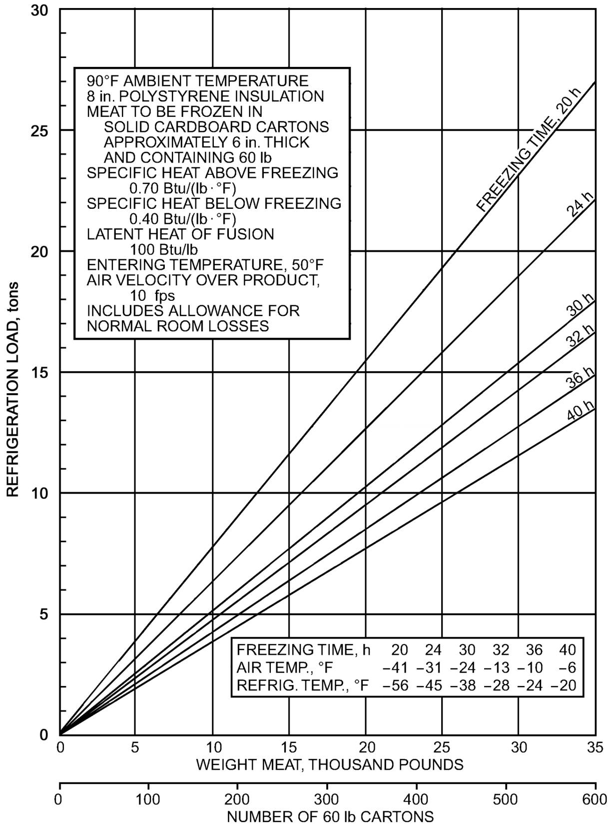

Fig. 6 Blast Freezer Loads

The spacing of hogs on the rail varies according to the size of the hog. Hogs should be spaced so that there is at least 1.5 to 2 in. between the flank of one carcass and the back of the carcass immediately in front of it. The rail spacing of 13 in. on centers is normal for 180 lb dressed hogs.

Many meat-packing refrigeration engineers maintain that several hog chill coolers with a capacity of 2 h loading for 300 to 600 kill/h or 4 h loading for lower killing capacities is more economical than one large chill cooler.

The hog cooler should be designed on the following basis:

- Total amount of hanging rail should be equal to
  - (One-shift operation) (10 h × Rate of kill × 12 ft/13 hogs).
  - (Two-shift operation) (16 h × Rate of kill × 12 ft/13 hogs).
  - For combination carcass loading, hogs and cattle, calves, or sheep, the figures should be modified accordingly.
- The rail height should be 9 ft. It may be 11 ft for combination beef and hog coolers.
- The rail spacing should be a minimum of 30 in.
- The inside building height will vary depending on the type of refrigeration equipment installed. A clear height of 6 ft above the rail support is adequate for space to install units, piping, and controls; it provides sufficient plenum over the rails to ensure even air distribution over the hog carcasses.

Preliminary, intensive batch, inline chilling is practiced in some plants, resulting in smaller shrinkages with the variations in chilling systems.

Selecting Refrigeration Equipment. Both floor units and units installed above the rail supports are used. Floor units, with a top discharge outlet equipped with a short section of duct to discharge air in a space over the rail supports, are used by a few pork processors. A few brine spray units equipped with ammonia coils, and water or hot-gas defrost units are being used.

Two types of units are available for installation above the rail supports. One uses a blower fan to force air below and through a horizontally placed coil with the air discharging horizontally from the front or top of the unit. The other consists of a vertical coil with axial fans or blowers to force the air through the unit. Both units are designed for various types of liquid feed control.

The horizontal units are equipped for both hot-gas and water defrosting. All have finned surfaces designed for hog chill cooler operation. Evaporator controls should be provided as described in the previous section on beef carcass coolers.

Careful selection of units and use of automatic controls, including liquid recirculation, provides an air circulation, temperature, and humidity balance that chills hogs with minimum shrinkage in the quickest time.

The temperature control should be set to provide an opening room temperature of 26 to 28°F. As the cooler is loaded, the suction temperature decreases to provide the additional refrigeration effect required to handle increased refrigeration load and maintain room temperature at 30 to 32°F. Ample compressor and unit capacity is required to achieve these results.

Dry coils selected to maintain a 10 to 12°F temperature difference (refrigerant to air) at peak operation provides adequate coil surface and a TD of 1 to 5°F prior to opening and about 10 h after closing the cooler. This low temperature difference results in economical high-humidity conditions during the entire chilling cycle. Cutting practices typically use a high initial chilling TD and a lower TD at the end of the chilling cycle.

Sample Calculation. The hog chilling time-temperature curves (Figure 7) are composite curves developed from several operation tests. The relation of the room temperature and ammonia suction gas temperature curves show that the refrigeration load decreased about 9 h after closing the cooler. After about 9 h, the room temperature is increased and the hog is tempered to an internal ham temperature of 37 to 39°F.

Table 5 was prepared using empirical calculations to coordinate product and unit refrigeration loads. A shortcut method for determining hog chill cooler refrigeration loads is presented in Table 6. The latent heat of the product has been neglected, since the latent heat of evaporation is equal to the reduction of sensible heat load of the product. Total sensible heat was used in all calculations.

Example 1: Select cooling units for 600 hogs/h at 180 lb average dressed weight using 2 h loading time cooler.

Four coolers minimum requirement (five desirable)
Each cooler
Capacity 1200 hogs = 11.3 tons (Table 6)
Product peak load = 6 × 14 = 84.0 tons (Table 5)
Total = 95.3 tons

Select 18 units of 5.3 tons at 10.3°F temperature difference per cooler
Approximately 198,000 cfm
Air changes per minute = 198,000/68,000 = 2.9

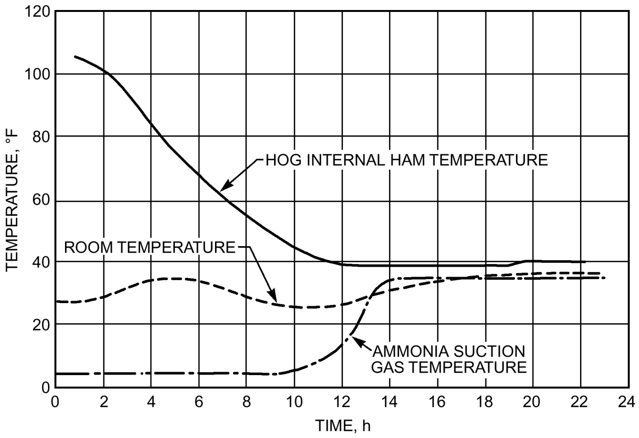

Fig. 7 Composite Hog Chilling Time-Temperature Curves

The refrigeration of the hog cutting room, where the carcass is cut up into its primal parts, is an important factor in maintaining the quality of the product. A maximum dry-bulb temperature of 50°F should be maintained. This level is low enough to prevent excessive rise in temperature of the product during its relatively short stay in the cutting room and also complies with USDA-FSIS requirements.

Chilled carcasses entering the room may have surface temperatures as low as 30°F. Unless the dew point of the air in the cutting room is maintained at a temperature below 30°F, moisture will condense on the surface of the product, providing an excellent medium for bacterial growth.

Floor, walls, and all machinery on the cutting floor must be thoroughly cleaned at the end of each day's operation. Cleaning releases a large amount of vapor in the room that, unless quickly removed, will condense on the walls, ceiling, floor, and machinery surfaces. When the outside dew-point temperature is less than the room temperature, vapor removal can be accomplished by installing fans to continuously exhaust the room during cleanup.

These fans should operate only during the cleanup period and as long as required to remove the vapor produced by cleaning. An

Table 5 Product Refrigeration Load, Tons

	Cooler Loading Time, h			
Hours	1	2	4	8
1	7.20*	7.20	7.20	7.20
2	6.80	14.00*	14.00	14.00
3	6.49	13.29	20.49	20.49
4	6.19	12.68	26.88*	26.68
5	5.94	12.13	25.42	32.62
6	5.71	11.65	24.33	38.33
7	5.56	11.27	23.40	43.89
8	5.44	11.00	22.65	49.33*
9	5.38	10.82	22.09	47.51
10	—	5.38	16.38	39.71
11	—	—	10.82	34.22
12	—	—	5.38	28.03
13	—	—	—	22.09
14	—	—	—	16.38
15	—	—	—	10.82
16	—	—	—	5.38

*Values are for peak load:
100 hogs/h at 180 lb dressed weight average
Chilled from 102 to 38°F in 16 h
Based on operating test, not laboratory standards

Table 6 Average Chill Cooler Loads Exclusive of Product

Cooler Capacity	Room Dimensions, ft	Floor Area, ft^2	Room Volume, ft^3	Refrigeration tons*
1200 Hogs	40 × 100 × 17	4000	68,000	11.3
2400 Hogs	80 × 100 × 17	8000	136,000	22.6
3600 Hogs	120 × 100 × 17	12,000	204,000	33.9
4800 Hogs	100 × 160 × 17	16,000	272,000	45.2
6000 Hogs	100 × 200 × 17	20,000	340,000	56.5

*Based on 6000 ft^3 room volume/ton (or use detailed calculations for building heat gains, infiltration, people, lights, and average unit cooler motors from Chapter 29 of the *ASHRAE Handbook—Fundamentals*).

exhaust capability of five air changes per hour should be satisfactory. When the room temperature is lower than the outside dew-point temperature, this method cannot be used. The water vapor must then be condensed out on the evaporator surfaces.

Many people work in the hog cutting room. Attention should be given to the heat given off by personnel, normally 1000 Btu/h per person. Heat given off by electric motors must also be included in the refrigeration load.

Special consideration should also be given to the latent heat load caused by knife boxes, wash water, workers, and infiltration. If the sensible heat load is not sufficient, this high latent heat load must be offset by reheat at the refrigeration units in order to maintain the desired low relative humidity.

The quantity of air circulated is influenced by the amount of sensible heat to be picked up and the relative humidity to be maintained, usually between 7 and 12 complete air changes each hour. The air distribution pattern requires careful attention to prevent drafts on the workers.

Forced-air units are satisfactory for refrigerating cutting floors. Ceiling height must be sufficient to accommodate the units. A wide selection of forced-air units may be applied to these rooms. They can be floor or ceiling mounted, with either dry-coil or wetted-surface units arranged for flooded, recirculated, or direct-expansion refrigerant systems.

Suction pressure regulators should be provided with both the flooded and the direct-expansion units. Automatic dry- and wet-bulb controls are essential for best operation.

Pork Trimmings

Pork trimmings come from the chilled hog carcass, principally from the primal cuts: belly, plate, back fat, shoulder, and ham.

Trimmings per hog average 4 to 8 lb. Only trimmings used in sausage or canning operations are discussed here.

In the cutting or trimming room, trimmings are usually at a temperature between 38 and 45°F; an engineer must design for the higher temperature. The product requires only moderate chilling to be in proper condition for grinding, if it is to be used locally in sausage or canning operations. If it is to be stored or shipped elsewhere, hard chilling is required. Satisfactory final temperature for local processing is 28°F. This is the average temperature after tempering and should not be confused with surface temperature immediately after chilling. It is possible for the trimmings to have a much lower surface temperature than internal temperature immediately after chilling, especially if they have been quick-chilled.

Good operating practice requires rapid chilling of pork trimmings as soon as possible after removal from the primal cuts. This retards enzymatic action and microbial growth, which are responsible for poor flavor, rancidity, loss of color, and excessive shrinkage.

The choice of chilling method depends largely on local conditions and consists of a variation of air temperature, air velocity, and method of achieving contact between air and meat. Continuous belt equipment using low-temperature air fluids or one of the cryogenic fluids to obtain lower shrinkage is available.

Truck Chilling. Economic conditions may require existing chilling or freezer rooms to be used. Some may require an overnight chill, others less than an hour. The following methods make use of existing facilities:

- Trimmings are often chilled with CO_2 snow prior to grinding to prevent excessive temperature rise during grinding and blending. Additionally, finished products, such as sausage or hamburger in chubs, may be crusted or frozen in a glycol/brine liquid contact chiller.
- Trimmings are put on truck pans to a depth of 2 to 4 in. and held in a suitable cooler kept at 30°F. This method requires a short chill time and results in a near uniform temperature (30°F) of the trimmings.
- Trimmings are spread 4 or 5 in. deep on truck pans in a 0°F freezer and held for 5 to 6 h, or until the meat is well stiffened with frost. Use of temperatures lower than 0°F (with or without fans) will expedite chilling if time is limited. After trimmings are hard-chilled, they are removed from the metal pans and tightly packed into suitable containers. They are held in a 26 to 28°F room until shipped or used. Average shrinkage using this system is 0.5% up to the time they are put in the containers.
- Trimmings from the cutting or trimming room are put in a meat truck and held in a cooler with a temperature from 28 to 30°F. This method usually requires an overnight chill and is not likely to reach a temperature of 32°F in the center of the load.
- If trimmings are not to be used within one week, they should be frozen immediately and held at –10°F or lower.

Fresh Pork Holding

Fresh pork cuts are usually packed on the cutting floor. If they are not shipped the same day that they are cut and packed, they should be held in a cooler with a temperature of 20 to 28°F.

Forced-air cooling units are frequently used for holding room service because they provide better air circulation and more uniform temperatures throughout the room, minimize ceiling condensation caused by air entering doorways from adjacent warmer areas (because of traffic), and eliminate the necessity of coil scraping or drip troughs if hot-gas defrost is used.

Cooling units may be the dry type with hot-gas defrost, or wetted surface with brine spray. Units should have air diffusers to prevent direct air blast on the products. Unless the room shape is unusually odd, discharge ductwork should not be necessary.

Since the product is boxed and wrapped and the holding period is short, humidity control is not too important. Various methods of automatic control may be used. CO_2 has been applied within boxes of pork cuts. Care must be taken to maintain the ratio of pounds of CO_2 to pounds of meat for the retention period. The enclosures must be relieved and ventilated in the interest of life safety.

Calf and Lamb Chilling

Dry coils are typically used for calf and lamb chilling. These can be either the between-the-rail type, the suspended type above the rail, or floor units. The same type of refrigerating units used for pork may be used for lamb, with some modifications. For example, in the chilling of lambs and calves, it is desirable to use reduced air changes over the carcass. This is accomplished by two-speed motors, using the higher speed for the initial chill and reducing the rate of air circulation when the carcass temperatures are reduced, approximately 4 to 6 h after the cooler is loaded.

Lambs usually weigh 40 to 80 lb, with an approximate average dressed carcass weight of 50 lb. Sheep weigh up to an average of approximately 125 lb and readily take refrigeration. Adequate coil surface should be installed to maintain a room temperature below 30°F and a relative humidity of 90 to 95% in the loading period. The evaporating capacity should be based on an average 10°F temperature differential between refrigerant and room air temperature, with an opening room temperature of 32°F.

Compensating back pressure regulating valves, which vary the evaporator pressure as the room temperature changes, should be used. As the room and carcass temperatures drop, the temperature differential is reduced, thus holding a high relative humidity (40 to 45%). At the end of a 4 to 6 h chill period, the air over the carcass may be reduced to help keep the bloom and color of the product.

Carcasses should not touch each other. They enter the cooler at 98 to 102°F, with the carcass temperature taken at the center of the heavy section of the rear leg. The specific heat of a carcass is 0.7 Btu/lb·°F. Air circulation for the first 4 to 6 h should be approximately 50 to 60 changes per hour, reduced to 10 to 12 changes per hour. The carcass should reach 34 to 36°F internally in about 12 to

14 h and should be held at that point with 85 to 90% rh room air until shipped or otherwise processed. This gives the least possible shrinkage and prevents excess surface moisture.

In calf-chilling coolers, approximately the same procedure is acceptable, with carcasses hung on 12 to 15 in. centers. The dressed weight varies at different locations, with an approximate 85 to 90 lb average in dairy country and a 200 to 350 lb (sometimes heavier) average in beef-producing localities. The same time and temperature relationship and air velocities previously given for chilling lambs are used for chilling calves, except when calves are chilled with the hide on. Also, the time may be extended for air circulation. Air circulation need not be curtailed in hide-on chilling in this application because rapid cooling gives better color to these carcasses after they are skinned.

The refrigerating capacity for lamb- and calf-chill coolers is calculated the same as for other coolers, but additional capacity should be added to permit reduced air circulation and maintain close temperature differential between room air and refrigerant.

Chilling and Freezing Variety Meats

The temperature of variety meats must be lowered rapidly to 28 to 30°F to reduce spoilage. Large boxes are particularly difficult to cool. For example, a 5 in. deep box containing 70 lb of hot variety meat can still have a core temperature as high as 60°F 24 h after it enters a –20°F freezer. Variety meats in boxes or packages more than 3 in. thick may be chilled very effectively during freezing by adding dry ice to the center of the box.

For design calculations, variety meat has an initial temperature of about 100°F. Specific heats of variety meats vary with the percentage of fat and moisture in each. For design purposes, a specific heat of 0.75 Btu/lb·°F should be used.

Quick Chilling. A better and more widely used method consists of quick chilling at lower temperatures and higher air velocities, using the same type of truck equipment as in the overnight chilling method. This method is also used for chilling trimmings. Care must be exercised in the design of the quick-chilling cabinet or room to provide for the refrigeration load imposed by the hot product. One industry survey shows that approximately 50% of large establishments are using quick-chill in their variety meat operations.

The quick-chilling cabinet or room should be designed to operate at an air temperature of approximately –20 to –40°F with air velocities over the product of 500 to 1000 fpm. During initial loading, the air temperature may rise to 0°F. In the design of quick-chilling units, refrigeration coils are used with axial flow fans for air circulation.

The recommended defrosting method is with water and/or hot gas, except where units with continuous defrost are used. The product is chilled to the point where the outside is frosted or frozen and a temperature of 28 to 30°F is obtained when the product later reaches an even temperature throughout in the packing or tempering room. The time required to chill the product by this method depends on the depth of product in the pans, the size of individual pieces, air temperature, and velocity. Normally, 0.5 to 4 h is a satisfactory chill period to attain the required 28 to 30°F temperature. In addition to the obvious savings in time and space, an important advantage of this method is the low total shrinkage, averaging only 0.5 to 1%. These values were obtained in the same survey as those in Table 7.

Packaging Before Chilling. Another method of handling variety meats involves packaging the product before chilling as near as possible to the killing floor. The packed containers are placed on platforms and frozen in a freezer. Separators should permit air circulation between packages.

This method is used in preparing products for frozen shipment or freezer storage. The internal temperature of the product should reach 25°F for prompt transfer to a storage freezer. For immediate shipment, the internal temperature of the product must be reduced to 0°F; this may be done by longer retention in the quick freezer. Here package material and size, particularly package thickness, largely determine the rate of freezing. For example, a 5 in. thick box will take from 16 h upward to freeze, depending on the type of product, package material, size, and loading method.

Table 7 Storage Life of Meat Products

	Months			
	Temperature, °F			
Product	**10**	**0**	**–10**	**–20**
Beef	4 to 12	6 to 18	12 to 24	12+
Lamb	3 to 8	6 to 16	12 to 18	12+
Veal	3 to 4	4 to 14	8	12
Pork	2 to 6	4 to 12	8 to 15	10
Chopped beef	3 to 4	4 to 6	8	10
Pork sausage	1 to 2	2 to 6	3	4
Smoked ham and bacon	1 to 3	2 to 4	3	4
Uncured ham and bacon	2	4	6	6
Beef liver	2 to 3	2 to 4		
Cooked foods	2 to 3	2 to 4		

The dry-bulb air temperature in these freezers is maintained at –40 to –20°F, with air velocities over the product at 500 to 1000 fpm. The time required to reach the desired internal temperature is a combination of refrigeration capacity, size of largest package, insulating properties of package material, and so forth. A generous safety factor should be used in sizing evaporator coils for this type of service. These freezers are best incorporated within refrigerated rooms. Defrosting is by the water or hot-gas method, except where units with continuous defrost are used. Shrinkage varies in the range of only 0.5 to 1%.

The initial freezing equipment cost and design load can be reduced if carbon dioxide is included in the packaging phase as part of the operational plan. Another efficient cooling method uses plate freezers to form blocks of product that can be loaded on pallets with minimal packaging.

Packaging and Storage

Packages for variety meats do not yet have any standard sizes or dimensions. Present requirements are a package that will stand shipping, with sizes to suit individual establishments. The importance of the package becomes more apparent in the case of the hot pack freezing method. Standardization of sizes and package materials promotes faster chilling and more economical handling.

Storage of variety meats depends on its end use. For short storage (under one week) and local use, 28 to 30°F is considered a good internal product temperature. If stored for shipping, the internal temperature of the product should be kept at 0°F or below. Recommended length of storage is controversial; type of package, freezer temperature and relative humidity, amount of moisture removed in original chill, and the variations of the products themselves all affect storage life.

Packers' recommendations regarding storage time vary from 2 to 6 months and longer, since variety meats pick up rancidity on the surface and soft muscle tissue dehydrates while freezing. More rapid freezing and vapor-proof packaging are important in increasing storage life.

Packaged Fresh Cuts

Packaging fresh cuts of meat intended for direct placement into retail display cases presents an increased focus on the sanitation of the processing room. The same environmental concerns also apply to some processors of precooked, ready-to-eat products.

The uncooked fresh cuts are packaged in sealed packages with an atmosphere of sterile nitrogen/oxygen/carbon dioxide mixture to control pathogens and organic activity. Shelf life is extended from days to weeks.

It is important to prepare and package this product in an environment free of harmful bacteria and other pathogens, and to transport these products at a continuously controlled temperature to the market display case. Techniques to accomplish this include

- Processing room temperature of 36 to 38°F
- A semi-clean-room environment with positive air pressure created by highly filtered, refrigerated outdoor air
- Keeping only packaging film and pouches in the room (e.g., no boxes or cardboard)
- A program of follow-through with temperature-monitoring devices shipped with the product, and returned

The clean-room techniques include an isolated workcrew entering through a sanitation anteroom, changing outer garments, wearing hair nets, using footbath sanitation, and handwashing with disinfection.

Facilities to accommodate frequent microbiological testing should be provided.

Refrigeration Load Computations

The average evaporator refrigerating load for a typical chilling process above freezing may be computed as follows:

$$q_r = m_m c_m (t_1 - t_2) + m_t c_t (t_1 - t_2) + q_w + q_i + q_m \qquad (1)$$

where

q_r = refrigeration load, Btu/h
m_m = weight of meat, lb/h
m_t = weight of trucks, lb/h
c_m = specific heat of meat, Btu/lb·°F
c_t = specific heat of truck, containers, or platforms (0.12 for steel), Btu/lb·°F
t_1 = average initial temperature, °F
t_2 = average final temperature, °F
q_w = heat gain through room surfaces, Btu/h
q_i = heat gain from infiltration, Btu/h
q_m = heat gain from equipment and lighting, Btu/h

The following example illustrates the method of computing the refrigeration load for a quick-chill operation.

Example 2. Find the refrigeration load for chilling six trucks of offal from a maximum temperature of 100 to 34°F in 2 h. Each truck weighs 400 lb empty and holds 720 lb of offal. The specific heat is 0.12 Btu/lb·°F for the truck and 0.75 Btu/lb·°F for the offal. The room temperature is to be held at 0°F, with an outdoor temperature of 40°F and a rh of 70%. The walls, ceiling, and floor gain 72 Btu/ft^2 and have an area of 947 ft^2. The volume of the room is 1881 ft^3 and 12 air changes in 24 h are assumed.

Solution: Values for substitution in Equation (1) are as follows:

m_m = 6 × 720/2 = 2160 lb/h
c_m = 0.75 Btu/lb·°F
$t_1 - t_2$ = 100 – 34 = 66°F
m_t = 6 × 400/2 = 1200 lb/h
c_t = 0.12 Btu/lb·°F
q_w = 72 × 947/24 = 2841 Btu/h
q_i = (1.12 × 1881 × 12)/24 = 1053 Btu/h where
1.12 = heat removed per ft^3 of air entering, Btu
q_m = (10 × 2545) + (200 × 3.4) = 26,140 Btu/h
10 = assumed horsepower
2545 = Btu per horsepower hour
200 = lights, W
3.4 = Btu/W·h

Substituting in Equation (1),

$$q_r = (2160 \times 0.75 \times 66) + (1200 \times 0.12 \times 66) + 2841$$
$$+ 1053 + 26,140 = 146{,}534 \text{ Btu/h} = 12.2 \text{ tons}$$

Good practice is to add 10 to 25% to the computed refrigeration load.

Table 8 Room Temperatures and Relative Humidities for Smoking Meats

	Room Conditions			
	°F Dry-Bulb	% Relative Humidity	Final Product Temp., °F	Time, h
Prechill method				
Hams, picnics, etc.				
High temperature	38 to 40	80	60	8 to 10
Low temperature	26 to 28	80	60	2 to 3
Derind bacon				
Normal	26 to 28	80	28	8 to 10
Blast	0 to 10	80	26	2 to 3
Hanging or tempering				
Ham, picnics, etc.	45 to 50	70	50 to 55	
Derind bacon	26 to 28	70	26 to 28	
Wrapping or packaging				
Hams, picnics, etc.	45 to 50	70		
Storage	28 to 45	70		

PROCESSED MEATS

Prompt chilling, handling, and storage under controlled temperatures help in the production of mild and rapidly cured and smoked meats. The product is usually transferred directly from the smokehouse to a refrigerated room, but sometimes a drop in temperature of 10 to 30°F can occur if the transfer time is appreciable.

Since the day's production is not usually removed from the smokehouses at one time, the refrigeration load is spread over nearly 24 h. Table 8 outlines temperatures, relative humidities, and time required in refrigerated rooms used in handling smoked meats.

Prechilling of smoked meat reduces drips of moisture and fat, thus increasing yield. Meats can be chilled at higher temperatures, with air velocities of up to 500 fpm (Table 8). At lower temperatures, air velocities of 1000 fpm and higher are used. Chilling in the hanging room or in the wrapping and packaging rooms results in slow chilling and high temperatures when packing. Slow chilling is not desirable for a product that is to be stored or shipped a considerable distance.

Meats handled through smoke and into refrigerated rooms are hung or racked on cages that are moved on an overhead track or mounted on wheels. Sometimes the product is transferred from suspended cages to wheel-mounted cages between smoking and subsequent handling.

Smoked hams and picnic meats must be chilled as rapidly as possible through the incubation temperature range of 105 to 50°F. A product requiring cooking before eating is brought to a minimum internal temperature of 140°F to destroy possible live trichinae, while a product not requiring cooking before eating is brought to a minimum internal temperature of 155°F.

A maximum storage room temperature of 40°F dry bulb should be used when delivery from the plant to retail outlets is made within a short time. A room dry-bulb temperature of 28 to 32°F is desirable when delivery is to points considerably removed from the plant and transfer is made through controlled low-humidity rooms, docks, cars, or trucks, keeping the dew point below that of the product.

Bacon usually reaches a maximum temperature of 125°F in the smokehouse. Since most smoked bacon in a sliced form is packaged, it may be transferred directly to the chill room if it has been skinned before smoking. If the bacon is to be skinned after smoking, it is usually allowed to hang in the smokehouse vestibule for 2 to 4 h, until it drops to a temperature of 90°F before skinning.

Bacon is usually molded and sliced at temperatures just below 28°F. Chill rooms are usually designed to reduce the internal temperature of the bacon to 26°F in 24 h or less, requiring a room dry-bulb temperature of 18 to 20°F. A tempering room (which also serves as storage for stock reserve), held at the exact temperature at which bacon is sliced, is often used.

Bacon molding can be done either after tempering, in which case it is moved directly to the slicing machines, or after the initial hardening, and then be transferred to the tempering room. In the latter case, care should be taken that none of the slabs is below 24°F so that the product will not crack during molding. Bacon cured by the pickle injection process generally shows fewer pickle pockets if it is molded after hardening, placed no more than eight slabs high on pallets, and held in the tempering room.

In any of the rooms mentioned, air distribution must be uniform. To minimize shrinkage, the air supply from floor-mounted unit coolers should be delivered through slotted ducts or by means of closed ducts supplying properly spaced diffusers directed so that no high-velocity airstreams impinge on the product itself. The exception would be in blast chill rooms where high air velocities are needed, but in reality the product is subjected to the condition for only a short time.

Refrigeration may be supplied by floor or ceiling-mounted dry- or wet-coil units. If the latter are selected, water, hot-gas, or electric defrost must also be used.

Many processors use three methods of chilling smoked meats: rapid blast chilling, brine chilling by direct-contact spraying, and cryogenic chilling. Direct-contact spraying is especially emphasized, because it minimizes shrinkage, increases shelf life, and provides more uniform chilling. This method is usually carried out in special enclosures designed to combat the detrimental effects of salt brine. Color and salt taste may need close monitoring in contact spraying.

The product should enter the slicing room chilled to a uniform internal temperature not to exceed 50°F for beef rounds and 40 to 45°F for other fresh carcass parts, depending on the individual packer's temperature standard. Internal temperatures below 26°F tend to cause shattering of products such as bacon during slicing and slow fabrication. For that type of product, temperatures above 32°F cause improper shingling from the slicing machine.

The slicing and packaging room temperature and air movement are usually the result of a compromise between the physical comfort demands of the operating personnel and the requirements of the product. The design room dry-bulb temperature should be below 50°F, according to USDA-FSIS regulations.

An objectionable amount of condensation on the product may occur. To guard against this, the coil temperature should be maintained below the temperature of the bacon entering the room, thus keeping the dew point of the room air below the product temperature. The product should be exposed to the room air for the shortest possible time.

Bacon Slicing and Packaging Room

Exhaust ventilation should remove smoke and fumes from the sealing and packaging equipment and comply with OSHA occupancy regulations. Again, heat exchangers should be considered for reducing the resulting increased refrigeration load.

Refrigeration for this room may be supplied by forced-air units—floor or ceiling mounted, dry or wet coil—or finned-tube ceiling coils. Dry coils should have defrost facilities if coil temperatures are to be kept at more than several degrees below freezing. Air discharge and return should be evenly distributed, using ductwork if necessary. To avoid drafts on personnel, air velocities in the occupied zone should be in the range of 25 to 35 fpm. The temperature differential between primary air and room air should not exceed 10°F to assure personnel comfort. To provide optimum comfort and dew-point control, reheat coils are necessary.

Where ceiling heights are adequate, multiple ceiling units can be used to minimize the amount of ductwork. Automatic temperature and humidity controls are desirable in cooling units.

To provide draft-free conditions, drip troughs with suitable drainage should be added to finned-tube ceiling coils. However, it is difficult, if not impossible, to maintain a room air dew point low enough to approach the product temperature. Some installations operating with relative humidities of 60 to 70% do not have product condensation problems.

One control method consists of individual coil banks connected to common liquid and suction headers. Each bank is equipped with a thermal expansion valve. The suction header has an automatically operated back-pressure valve. The thermostatically controlled dual back-pressure regulator and liquid-header solenoid are both controlled by a single thermostat. This arrangement provides a simple automatic defrosting cycle.

Another system uses fin coils with glycol sprays. Humidity is controlled by varying the concentration strength of the glycol and the refrigerant temperature.

Sausage Dry Rooms

Refrigeration or air conditioning is an integral part of year-round sausage dry rooms. The purpose of these systems is to produce and control the air conditions for proper removal of moisture from the sausage.

Various dry sausages are manufactured, for the most part uncooked. This sausage is generally of two distinct types—smoked and unsmoked. Keeping qualities depend on curing ingredients, spices, and removal of moisture from the product by drying.

FSIS regulates the minimum temperature and amount of time that the product must be held after stuffing and prior to release, depending on the method of production. The dry room temperature shall not be lower than 45°F, and the length of time the product should be held in the dry room prior to release depends on the diameter of the sausage after stuffing and the method of preparation used.

After stuffing, the sausages are held at a temperature of 60 to 75°F and 75 to 95% rh in the sausage greenroom to develop the cure. The sausages are suspended from sticks at the time of stuffing and may be held on the trucks or railed cages or be transferred to racks in the greenroom. Sausages in 3.5 to 4 in. diameter casings are generally spaced about 6 in. on centers on the sausage sticks. The length of time the sausages are held in the greenroom depends on the method of preparation, the type and dimensions of the sausage, the operator, and the judgment of the sausage maker regarding proper flavor, pH, and other characteristics.

Those sausage varieties that are not smoked are then transferred to the sausage dry room; those that are to be smoked are transferred from the greenroom to the smokehouse and then to the dry room.

In the dry room, approximately 30% of the moisture is removed from the sausage, to a point at which the sausage will keep for a long time, virtually without refrigeration. The drying period required depends on the amount of moisture to be removed to suit trade demand, type of sausage, and type of casing. The moisture transmission characteristics of synthetic casings vary widely and greatly influence the rate of drying. The diameter of the sausage is probably the most important factor influencing the drying rate.

Small-diameter sausages, such as pepperoni, have more surface in proportion to the weight of material than do large-diameter sausages. Furthermore, the moisture from the sausage interior has to travel a much shorter distance to reach the surface, where it can evaporate. Thus, the drying time for small-diameter sausages is much shorter than that for large-diameter sausages.

Typical conditions in the dry room are approximately 45 to 55°F and 60 to 75% rh. Some sausage makers favor the lower range of temperatures for unsmoked varieties of dry sausage and the higher range for smoked varieties.

In processing dry sausage, moisture can only be removed from the product at the rate at which the moisture comes to the surface of the casing. Any attempt to speed the drying rate results in overdrying the surface of the sausage, a condition known as case hardening. This condition is identified by a dark ring inside the casing, close to the surface of the sausage, which precludes any further attempt to remove moisture from the interior of the sausage. On the other hand, if sausage is dried at too slow a rate, excessive mold occurs on the surface of the casing, sometimes leading to an unsatisfactory appearance. An exception is the Hungarian salami, which requires a high humidity so that a prolific mold growth can occur and flourish.

As with any other cool or refrigerated space, sausage dry rooms should be properly insulated to prevent temperatures in adjoining spaces from influencing the temperature in the dry room. Ample insulation is especially important in the case of dry rooms located adjacent to rooms of much lower temperature or rooms on the top floor, where the ceiling may be exposed to relatively high temperatures in summer and low temperatures in winter.

Insulation should be adequate to prevent the inner surface of the walls, floor, and ceiling of the dry room from differing more than a degree or two from the average temperature in the room. Otherwise, there is the possibility of condensation due to the high relative humidity in these rooms, which leads to mold growth on the surfaces themselves and, in some cases, on the sausages as well.

The sticks of sausage are generally supported on permanent racks built into the dry room. In the past, these were frequently made of wood; however, sanitary requirements have virtually outlawed the use of wood for this purpose in new construction. The uprights and rails for the racks are now made of either galvanized pipe, hot-dip galvanized steel, or stainless steel. The rails for supporting the sausage sticks should be spaced vertically at a distance that leaves ample room for air circulation below the bottom row and between the top row and the ceiling. Generally, a spacing of not less than 1 or 2 ft between rails depends on the length of sausage stick used by the individual manufacturer.

The horizontal spacing between sausages should be such that they do not touch at any point, to prevent mold formation or improper development of color. Generally, with the large 4 in. diameter sausages, a spacing of 6 in. on centers is adequate.

Dry-Room Equipment. In general, two types of refrigeration equipment are currently used for attaining the required conditions in a dry room. The most common is a refrigeration-reheat system, in which the room air is circulated either through a brine spray or over a refrigerated coil and sufficiently cooled to reduce the dew point to the temperature required in the room. The other type involves the use of a hygroscopic liquid sprayed over a refrigerating coil in the dehumidifier, thus condensing the moisture from the air without the severe overcooling usually required by the refrigeration-reheat type of system. The chief advantage of this arrangement is that refrigeration and heating loads are greatly reduced.

The use of any type of liquid, brine or hygroscopic, requires periodic tests and adjusting the pH to minimize corrosion of the equipment. Although most systems depend on a type of liquid spray to prevent frost buildup on the refrigerating coils, some successful rooms use dry coils with hot-gas or water defrost.

The air for conditioning the dry room is normally drawn through the refrigerating and dehumidifying systems by a suitable blower fan (or fans) and discharged into the distribution ductwork.

Rooms used exclusively for small-diameter products with a rapid drying rate may actually have air leaving the room to return to the conditioning unit at a lower dry-bulb temperature and greater density than the point at which it is introduced. A dry-room designer needs to know what the room will be used for to determine the natural circulation of the room air. Supply and return ducts can then be arranged to take advantage of and accelerate this natural circulation to provide thorough mixing of incoming dry air with the air in the room.

Regardless of the location of the supply and return ducts, care should be taken to prevent strong drafts or high-velocity airstreams from impinging on the product; this will result in local overdrying and unsatisfactory products.

A study of air circulation within the product racks will show that as air passes over the sausages and moisture evaporates from them, this air becomes cooler and heavier, and thus has a tendency to drop toward the bottom of the room, creating a vertical downward air movement within the sausage racks. This natural tendency must be considered in designing the duct installation if uniform conditions are to be achieved.

An example of the calculation involved in designing a sausage dry room follows. These calculations apply to a room used for an assortment of sausages, with an average drying time of approximately 30 days. They would not be directly applicable to a room used primarily for very large salami (which has a much longer drying period) or a room used primarily for small-diameter sausage.

In the latter case, use of the air-circulating rate shown in this example will allow the air to absorb so much moisture in passing through the room that it will be difficult to obtain uniform conditions throughout the space. Furthermore, the amount of refrigeration required to lower the air temperature enough to produce the required low inlet-air dew point would be excessive. An air circulation rate of 12 air changes per hour should therefore be considered average for use in average rooms. The actual circulating rate should be adjusted to obtain the best compromise of refrigeration load and air uniformity for the particular type of product handled.

Example 3. Air conditioning for sausage drying room

Room Dimensions:
40 ft, 2 in. by 33 ft, 6 in. by 11 ft, 6 in.
Floor space: 1350 ft^2
Volume: 15,600 ft^3
Outdoor wall area: 980 ft^2
Partition wall area: 770 ft^2

Hanging Capacity:
Number of racks: 12
Length of racks: 27 ft
Number of rails high: 5
Spacing of sticks: 2 per foot of rail
Number of pieces of sausage per stick: 7
Average weight per sausage: 4 lb
Total weight: 12 × 27 × 5 × 2 × 7 × 4 = 90,720 lb of product
Assume 90,000 lb green weight hanging capacity
Loading per day: 1500 lb

Assumed Outdoor Conditions (*Summer*):
95°F db; 74.5°F wb; 39% rh; h = 37.8 Btu/lb; 66°F dp; 96 gr/lb

Dry-Room Conditions Desired:
55°F db; 50°F wb; 70% rh; h = 20.2 Btu/lb; 46°F dp; 46 gr/lb

Sensible Heat Calculations:
Walls (2 in. insulation):
980(95 – 55) × 0.10 = 3920 Btu/h
Partition (4 in. insulation):
770(95 – 55) × 0.067 = 2060 Btu/h
Floor and ceiling:
2700(55 – 55) × 0.10 = none
Infiltration: 0.5 × 15,600(95 – 55)
× 0.243 × 0.075 = 5700 Btu/h
Lights: 600 W × 3.415 = 2050 Btu/h
Motors: 5 × 1 hp × 2546 = 12,730 Btu/h
Product: 1500 × 0.8(95 – 55)/24 = 2000 Btu/h
Total sensible heat = 28,460 Btu/h

Latent Heat Calculations:
Product
90,000 × 0.30 × 1000/(60 × 24) = 18,750 Btu/h
(18,750 × 7000)/(60 × 1000) = 2188 gr/min
Infiltration
0.5 × 15,600 × 0.075(37.8 – 20.2) = 10,300 Btu/h
(10,300 – 5700) 7000/(60 × 1000) = 537 gr/min
Total grains of moisture = 2188 + 537 = 2725 gr/min

Assume 12 air changes per hour with an empty room volume of 15,600 ft^3 = (15,600)(12/60)(0.075) = 234 lb of air per minute. Then each pound of air must absorb 2725/234 = 11.6 gr of moisture. Because air at the desired room condition carries 46 gr/lb, the air must enter the room with only 46 – 11.6 = 34.4 gr/lb, corresponding to 41.8°F db and 40°F wb (h = 15.3 Btu/lb).

Temperature rise due to sensible heat gain (air specific heat = 0.243 Btu/lb·°F):

28,460/(234 × 0.243 × 60) = 8.3°F db

Temperature drop due to evaporative cooling from latent heat of product only:

$18{,}750/(234 \times 0.243 \times 60) = 5.5°\text{F}$

Net temperature rise in the room = 8.3 – 5.5 = 2.8°F, or the air entering the room must be 55 – 2.8 = 52.2°F db at 38.5°F dp (34.5 gr/lb).

Refrigerating load = 234(20.2 – 15.3) × 60 = 68,800 Btu/h

Reheat load = 234(17.8 – 15.3) × 60 = 35,100 Btu/h

Room load = 234(20.2 – 17.8) × 60 = 33,700 Btu/h

Lard Chilling

In federally inspected plants, the USDA-FSIS designates the types of pork fats that, when rendered, are classified as lard. Other pork fats, when rendered, are designated as rendered pork fats. The rendering process requires considerable heat, and the subsequent temperature of the lard at which refrigeration is to be applied may be as high as 120°F. The following data for refrigeration requirements may be used for either product type.

The fundamental requirement of the FSIS is good sanitation through all phases of handling. The use of copper or copper-bearing alloys that come in contact with lard should be avoided, because minute traces of copper lower the stability of the product.

Lard has the following properties:

Specific gravity at	0°F	= 0.99
	70°F	= 0.93
	160°F	= 0.88
Heat of solidification		= 48 Btu/lb
Melting begins at –32 to –40°F.		
Melting ends at 110 to 115°F.		
Point of half fusion is around 40°F.		
Specific heat in solid state	–110°F	= 0.28 Btu/lb·°F
	–40°F	= 0.34 Btu/lb·°F
Specific heat in liquid state	110°F	= 0.50 Btu/lb·°F
	212°F	= 0.52 Btu/lb·°F

In the production of lard, refrigeration is applied so that the final product will have enough texture and a firm consistency. The finest possible crystal structure is desired.

Calculations for chilling 1000 lb of lard per hour are

Initial temperature: 120°F
Final temperature: 80°F
Heat of solidification: 48 Btu/lb
Specific heat: 0.50 Btu/lb·°F

$$S_f = 100\frac{t_e - t_f}{t_e - t_b} = 100\frac{115 - 80}{115 - (-40)} = 22.6\%$$

where

S_f = percent solidification at final temperature
t_e = temperature at which melting ends
t_f = final temperature
t_b = temperature at which melting begins

Latent heat of solidification:

$$48(22.6/100) = 10.8 \text{ Btu/lb}$$

Sensible heat removed:

$$0.50(120 - 80) = 20 \text{ Btu/lb}$$

Total heat removed:

$$1000(10.8 + 20) = 30{,}800 \text{ Btu/h} = 2.57 \text{ tons refrigeration}$$

Assuming a 15% loss because of radiation, for example, in the process, the required refrigeration for application to chill 1000 lb of lard per hour would be 1.15 × 2.57 = 2.96 tons.

Filtered lard at 120°F can be chilled and plasticized in compact internal swept surface chilling units, which use either ammonia or halogenated hydrocarbons. A refrigerating capacity of about 36,000 Btu/h per 1000 lb of lard handled per hour for the product only should be provided. Additional refrigeration for the requirements of heat equivalent to the work done by the internal swept surface chilling equipment will also be needed.

When operating this type of equipment, it is essential to keep the refrigerant free of oil and other impurities so that the heat transfer surface will not have a film of oil on it to act as insulation and cut down the unit's capacity. Some installations have oil traps connected to the liquid refrigerant leg on the floor below to provide an oil accumulation drainage space.

The safety requirements for this type of chilling equipment are described in ASHRAE *Standard* 15. Note that such units are pressure vessels and, as such, require properly installed and maintained safety valves.

The recommended storage temperature for packaged refined lard is 31 to 33°F. The storage temperature required for prime steam lard in metal containers is 40°F or below for up to a 6 month storage period. Lard stored for a year or more should be kept at 0°F.

Blast and Storage Freezers

The standard method of sharp-freezing a product destined for storage freezers comprises freezing the product directly from the cutting floor in a blast freezer until its internal temperature reaches the holding room temperature. The product is then transferred to holding or storage freezers.

The product to be sharp-frozen may be bagged, wrapped, or boxed in cartons. Individual loads are usually placed on pallets, dead skids, or in wire basket containers. In general, the larger the ratio of surface exposed to blast air to the volume of either the individual piece or the product's container, the greater the rate of freezing. Product loads should be placed in a blast freezer to ensure that each load is well exposed to the blast air and to minimize possible short-circuiting of the airflow. Each layer on a load should be separated by 2 in. spacers to give the individual pieces as much exposure to the blast air as possible.

The most popular types of blast equipment are the self-contained air-handling or cooling units that consist of a fan, evaporator, and other elements in one package. These units are usually used in multiples and placed in the blast freezer to provide the optimum blast air coverage. The unit fans should be capable of high air velocity and volumetric flow; two air changes per minute is the accepted minimum.

The coils of the evaporator may have either a wet or a dry surface. See Chapter 42 for information on defrosting.

Blast chill design temperatures vary throughout the industry. Most designs are within a –20 to –40°F range. For low temperatures, booster compressors that discharge through a desuperheater into the general plant suction system are used.

Blast freezers require sufficient insulation and good vapor barriers. If possible, a blast freezer should be located so that temperature differentials between it and adjacent areas are minimized in order to decrease insulation costs and refrigeration losses.

Blast freezer entrance doors should be power operated. Suitable vestibules should also be provided as air locks to decrease infiltration of outside air.

Besides normal losses, heat calculations for a blast freezer should include the loads imposed by such material handling equipment as electric trucks, skids, and spacers, together with the packaging materials for the product. Some portion of any heat added under the floor to prevent frost heaving must also be added to the room load.

Storage freezers are usually maintained at 0 to –15°F. If the plant operates with several high and low suction pressures, the evaporators can be tied to a suitable plant suction system. The evaporators can also be tied to a booster compressor system; if the booster system is operated intermittently, provisions must be made to switch to a suitable plant suction system when the booster system is down. Storage freezer coils can be defrosted by hot gas, electricity, or water. Emphasis should be placed on not defrosting too fast with hot gas (because of pipe expansion) and on providing well-insulated, sloped, heat-traced drains and drain pans to prevent freeze-ups.

Direct Contact Meat Chilling

Continuous processes for smoked and cooked wieners use direct sodium chloride brine tanks or deluge tunnels to chill the meat as soon as it comes out of the cooker. Every day, the brine is prepared fresh in 2 to 13% solutions depending on the chilling temperature and the salt content of the meat.

Cooling is usually done on sanitary stainless steel surface coolers, which are either refrigerated coils or plates in cabinets. Using this type of unit allows coolant temperatures near the freezing point without damaging the cooler; damage may occur when brine is confined in a tubular cooler. The brine is circulated in quantities necessary to fully wet the surface cooler and fill the distribution troughs of the deluge.

Another type of continuous process uses a brine tank into which the wieners drop out of a conveyor that has carried them through the smoking and cooking process. The pumped brine moves the product to the end of the tank, where it is removed by hand and inserted into peeling and packaging lines.

FROZEN MEAT PRODUCTS

The handling and selling of consumer portions of frozen meats has many potential advantages compared with merchandising fresh meat. The preparation and packaging can be done at the packinghouse, allowing economies of mass production, byproduct savings, lower transportation costs, and flexibility in meeting market demands. At the retail level, frozen meat products reduce space and investment requirements and labor costs.

Freezing Quality of Meat

After an animal is slaughtered, physiological and biochemical reactions continue in the muscle until the complex system supplying energy for work has run down and the muscle goes into rigor. These changes continue for up to 32 h postmortem in major beef muscles. Hot boning with electrical stimulation renders meat tender on a continuous basis without conventional chilling. Freezing meat or cutting carcasses for freezing before the completion of these changes cause cold-shortening and thaw-shortening, which render meat tough. The best time to freeze meat is either after rigor has passed or later, when natural tenderization is more or less complete. Natural tenderization is completed during 7 days of aging in most major beef muscles. Where flavor is concerned, freezing as soon as tenderization is complete is desirable.

For frozen pork, the age of the meat before freezing is even more critical than it is for beef. Pork loins aged 7 days before freezing deteriorate more rapidly in frozen storage than loins aged 1 to 3 days. In tests, a difference could be detected between 1 and 3 day old loins, favoring those only 1 day old. With frozen pork loin roasts from carcasses chilled for 1 to 7 days, the flavor of lean and fat in the roasts was progressively poorer with longer holding time after slaughter.

Effect of Freezing on Quality

Freezing affects the quality—including color, tenderness, and amount of drip—of meat.

Color. The color of frozen meat depends on the rate of freezing. Tests in which prepackaged, steak-size cuts of beef were frozen by immersion in liquid or exposure to an air blast at between –20 and –40°F revealed that airblast freezing at –20°F– produced a color most similar to that of the unfrozen product. An initial meat temperature of 32°F was necessary for best results (Lentz 1971).

Flavor and Tenderness. Flavor does not appear to be affected by freezing per se, but tenderness may be affected depending on the condition of the meat and the rate and end-temperature of freezing. Faster freezing to lower temperatures was found to increase tenderness; however, consensus on this effect has not been reached.

Drip. The rate of freezing generally affects the amount of drip, and meat nutrients, such as vitamins, that are lost from cut surfaces after thawing. Faster freezing tends to reduce the amount of drip, although many other factors, such as the pH of meat, also have an effect on drip.

Changes in Fat. Pork fat changes significantly in 112 days at –5°F, whereas beef fat shows no change within 260 days at this temperature. At –20 and –30°F, no measurable change occurs in either meat in one year.

The relationship of fat rancidity and oxidation flavor has not been clearly established for frozen meat, and the usefulness of antioxidants in reducing flavor changes during frozen storage is doubtful.

Storage and Handling

Pork remains acceptable for a shorter storage period than beef, lamb, and veal due to the differences in fatty acid chain length and saturation in the different species. Storage life is also related to storage temperature. Because animals within a species vary greatly in nutritional and physiological backgrounds, their tissues differ in susceptibility to change when stored. As a result of the differences between meat animals, packaging methods, and acceptability criteria, a wide range of storage periods is reported for each type of meat (see Table 7).

Lentz (1971) found that appreciable changes in the color and flavor of frozen beef occur at storage temperatures down to –40°F in 1 to 90 days (depending on temperature) for samples held in the dark. Changes were much more rapid (1 to 7 days) for samples exposed to light. Color changes were less pronounced after thawing than when frozen.

Reports on the effect of different storage temperatures on fat oxidation and palatability of frozen meats indicate that a temperature of 0°F or lower is desirable. Cuts of pork back fat held at 20, 10, 0, and –10°F show increases in peroxide value; free fatty acid is most pronounced at the two higher temperatures. For a storage period of 48 weeks, 0°F or lower is essential to avoid fat changes. Pork rib roasts of 0°F showed little or no flavor change up to 8 months, whereas at 10°F, fat was in the early stages of rancidity in 4 months. Ground beef and ground pork patties stored at 10, 0, and –10°F indicate that meats must be stored at 0°F or lower to retain good quality for 5 to 8 months. For longer storage, –20°F is desirable.

The desirable flavor in pork loin roasts stored at –6 to –8°F, with maximum fluctuations of 5 to 8°F, decreased slightly, apparently without significant difference between treatments. Fluctuations from 0 to 10°F did not harm quality.

Storage temperature is perhaps more critical with meat in frozen meals because of the differing stability of the various individual dishes included. Frozen meals show marked deterioration of most of the foods after 3 months at 13 to 15°F.

Storage and Handling Practices. Surveys of practices in the industry indicate why some product reaches the consumer in poor condition. One unpublished survey indicated that 10% of frozen foods may be at 6°F or higher in warehouses, 16°F or higher in assembly rooms, 21°F or higher during delivery, and 17°F or higher in display cases. All these temperatures should be maintained at 0°F for complete protection of the product.

Packaging

At the time of freezing, a package or packaging material serves to hold the product and prevent it from losing moisture. Other functions of the wrapper or box become important as soon as the storage period begins. Ideal packaging material in direct contact with meat should have low moisture vapor transmission rate; low gas transmission rate; high wet strength; resistance to grease; flexibility over a temperature range including subfreezing; freedom from odor, flavor, and any toxic substance; easy handling and application characteristics adaptable to hand or machine use; and reasonable price. Individually or collectively, these properties are desired for good appearance of the package, protection against handling, preventing dehydration, which is unsightly and damages the product, and keeping oxygen out of the package.

Desiccation through use of unsuitable packaging material is one of the major problems with frozen foods. Another problem is that of distorted or damaged containers due either to lack of expansion space for the product in freezing or to selection of low-strength box material.

Whenever free space is present in a container of frozen food, ice sublimes and condenses on the film or package. Temperature fluctuation increases the severity of frost deposition.

SHIPPING DOCKS

A refrigerated shipping dock can eliminate the need for assembling orders on the nonrefrigerated dock or other area, or using a more valuable storage space for this purpose. This is especially true in the case of freezer operations. Some businesses do not really need a refrigerated order assembly area. One example is a packing plant that ships out whole carcasses or sides in bulk quantities and does not need a large area in which to assemble orders. Many such plants are constructed without any dock at all, simply having the load-out doors lead directly into the carcass-holding cooler, requiring that increased refrigerating capacity be installed in the vicinity of the shipping doors to prevent undue temperature rise in the coolers during shipping.

A refrigerated shipping dock can perform a second function of reducing the refrigeration load, which is most important in the case of freezers but serves almost as valuable a function with coolers. Even with cooler operations, the installation of a refrigerated dock greatly reduces the load on the cooler's refrigerating units and ensures a more stable temperature within the cooler. At the same time, it is possible to only provide refrigeration to maintain dock temperatures on the order of 40 to 45°F, so that the refrigerating units can be designed to operate with a wet coil. In this way, frost buildup on the units is avoided and the capacity of the units themselves substantially increased, making it unnecessary to install as many or as large units in this area.

In the case of freezers, the units should be designed and selected to maintain a dock temperature slightly above freezing, usually about 35°F. With this dock temperature, orders may be assembled and held prior to shipment without the risk of defrosting the frozen product, and the workers can assemble orders in a much more comfortable space than the freezer. The design temperature should be low enough that the dew point of the dock atmosphere is below the product temperature. Condensation on the surface of the products is one step in developing off-condition product.

With a dock temperature of 35°F, the temperature difference between the freezer itself and the outdoor summer condition is split roughly in half. Because the airflow through the loading doors or other openings is proportional to the square root of the temperature difference, this results in an approximate 30% reduction in airflow through the doors—both the doors into the dock itself and the doors from the dock into the freezer. At the same time, by cooling the outdoor air to approximately 35°F, in most cases about 50% of the total heat in the outdoor air is removed by the refrigerating units on the dock.

Because using a refrigerated dock reduces the airflow through the door into the freezer by approximately 30%, and 50% of the heat in the air that does pass through this door is removed, the net effect is to reduce the infiltration load on the units within the freezer itself by about 65%. This is not a net gain; because an equal number of these units operate at a much higher temperature, the power required to remove the heat on the dock is substantially lower than it would be if the heat were allowed to enter the freezer.

The infiltration load from the shipping door, whether it opens directly into a cooler or freezer or into a refrigerated dock, is extremely high. Even with well-maintained foam or inflatable door seals, a great deal of warm air leaks through the doors whenever they are open. Such air infiltration may be calculated approximately by

$$V = CHW\theta(H)^{0.5}(t_1 - t_2)^{0.5} \qquad (2)$$

where

V = air volume, ft^3/h at the higher temperature condition
C = 1.4 = empirical constant selected to convert airflow into ft^3/h and to account for the contraction of the airstream as it passes through the door and for the obstruction created by a truck parked at the door with only nominal sealing
H = height of the door, ft
W = width of the door, ft
θ = time the door is open, min/h
t_1 = outdoor air temperature or the air at the higher temperature, °F
t_2 = temperature of air in the dock or cooler, °F

Time θ is estimated, based on the time the door is assumed to be obstructed or partially obstructed. If the doors are equipped with good seals and these are well-maintained so that the average truck will be tightly sealed to the building, this time would be assumed as only the time necessary to spot the truck at the door and complete the air seal.

The unit cooler providing refrigeration for the dock area should be ceiling-suspended with a horizontal air discharge. Each unit should be aimed toward the outer wall and above each of the truck loading doors, if possible, so that cold air strikes the wall and is deflected downward across the door. This downward airflow just inside the door tends to oppose the natural airflow of the entering warm air, thus helping reduce the total amount of infiltration.

In general, a between-the-rails unit cooler has proved most successful for this purpose, since it distributes the air over a fairly wide area and at low outlet velocity. Such an airflow pattern does not create severe drafts in the working area and is more acceptable to employees working in the refrigerated space. The preceding comments and equation for determining air infiltration also apply to shipping doors, which open directly into storage or shipping coolers.

ENERGY CONSERVATION

Water, a utility previously considered free, frequently has the most rapid rate increases. Coupled with high sewer rates, it is the largest single-cost item in some plants. If fuel charges are added to the hot-water portion of water usage, water is definitely the most costly utility. Costs can be reduced by better dry cleanup, use of heat exchangers, use of filters and/or settling basins to collect solids and greases, use of towers and/or evaporative condensers, elimination of water as a means of product transport, and an active conservation program.

Air is needed for combustion in steam generators, sewage aeration, air coolers or evaporative condensers, and blowing product through lines. Used properly in conjunction with heat exchangers, air can reduce other utility costs—fuel, sewage, water, and electricity. Nearly all plants need close monitoring of valves either leaking through or left open in product conveying. Low-pressure blowers are frequently used in place of high-pressure air, reducing initial investment and operating costs of driving equipment.

Steam generation is a source of large savings through efficient boiler operation (fuel and water sides). Reduced use of hot water and sterilizer boxes, and proper use of equipment in plants with electric and steam drives, should be promoted. Sizable reductions can be realized by scavenging heat from process-side steam and hot water and by systematically checking steam traps. In some plants, excess hot water and low-energy heat can be recovered using heat exchangers and better heat balances.

Electrical energy needs can be reduced by

- Properly sizing, spacing, and selecting light fixtures and an energy program of keeping lights off (lights comprise 25 to 33% of an electric bill)
- Monitoring and controlling the demand portion of electric usage
- Checking and sizing motors to their actual loads for operation within the more efficient ranges of their curves
- Adjusting the power factor to reduce initial costs in transformers, switchgear, and wiring
- Lubricating properly to cut power demands

Although refrigeration is not a direct utility, it involves all or some of the factors just mentioned. Energy use in refrigeration systems can be reduced by

- Operating with lower condenser and higher compressor suction pressures
- Properly removing oil from the system
- Purging noncondensable gases from the system
- Adequately insulating floors, ceilings, walls, and hot and cold lines
- Using energy exchangers on exhaust and air makeup
- Keeping doors closed to cut humidity or prevent an infusion of warmer air
- Installing high-efficiency motors
- Maintaining compressors at peak efficiency
- Keeping condensers free of scale and dirt
- Using proper water treatment in the condensing system
- Operating with a microprocessor-based management system

Utility savings are also possible when usage is considered with product line flows and storage space. A strong energy conservation program not only saves total energy but frequently results in greater product yields and product quality improvements, and therefore increased profits. Prerigor or hot processing of pork and beef products is being used to greatly reduce the energy required for postmortem chilling. Removal of waste fat and bone prior to chilling reduces the amount of chilling space by 30 to 35% per beef carcass.

REFERENCES

Acuff, G.R. 1991. Acid decontamination of beef carcasses for increased shelf life and microbiological safety. *Proceedings of the Meat Industry Resources Conference*, Chicago.

Allen, D.M., M.C. Hunt, A.L. Filho, R.J. Danler, and S.J. Goll. 1987. Effects of spray chilling and carcass spacing on beef carcass cooler shrink and grade factors. *Journal of Animal Science* 64:165.

Dickson, J.S. 1991. Control of *Salmonella typhimurium, Listeria monocytogenes*, and *Escherichia coli* O157:H7 on beef in a model spray chilling system. *Journal of Food Science* 56:191.

Earle, R.L. Physical aspects of the freezing of cartoned meat. *Bulletin* 2, Meat Industry Research Institute of New Zealand.

Greer, G.G. and B.D. Dilts. 1988. Bacteriology and retail case life of spray-chilled pork. *Canadian Institute of Food Science Technology Journal* 21:295.

Hamby, P.L., J.W. Savell, G.R. Acuff, C. Vanderzant, and H.R. Cross. 1987. Spray-chilling and carcass decontamination systems using lactic and acetic acid. *Meat Science* 21:1.

Johnson, R.D., M.C. Hunt, D.M. Allen, C.L. Kastner, R.J. Danler, and C.C. Schrock. 1988. Moisture uptake during washing and spray chilling of Holstein and beef-type carcasses. *Journal of Animal Science* 66:2180.

Jones, S.M. and W.M. Robertson. 1989. The effects of spray-chilling carcasses on the shrinkage and quality of beef. *Meat Science* 24:177-188.

Kastner, C.L. 1981. Livestock and meat: Carcasses, primal and subprimals. In CRC *Handbook of Transportation and Marketing in Agriculture*, pp. 239-258. E.E. Finney, Jr., ed. CRC Press, Boca Raton, FL.

Lentz, C.P. 1971. Effect of light and temperature on color and flavor of prepackaged frozen beef. *Canadian Institute of Food Technology Journal* 4:166.

Marriott, N.G. 1994. *Principles of food sanitation*, 3rd ed. Chapman and Hall, New York.

USDA-FSIS. U.S. inspected meats and poultry packing plants—A guide to construction and layout. *Agriculture Handbook No. 570*. U.S. Department of Agriculture.

BIBLIOGRAPHY

ASHRAE. 1994. Safety code for mechanical refrigeration. ANSI/ASHRAE *Standard* 15-1994.

Heitter, E.F. 1975. Chlor-chill. *Proceedings of the Meat Industry Resources Conference AMIF*, pp. 31-32. Arlington, VA.