CHAPTER 31

MARINE REFRIGERATION

MARINE refrigeration systems are used aboard seagoing vessels and offshore facilities and generally include cargo hold refrigeration, domestic refrigeration services, and refrigerated containers. These systems differ from stationary systems not only in physical aspects but also in the fact that marine systems must be designed to handle frequent starting and stopping. Process freezing or chilling plants on vessels might run continuously for weeks, but under certain conditions may be started and stopped daily. Cold storages are usually shut down after the cargo is discharged, and are restarted before new cargo is loaded.

Personnel changes of engineers and refrigeration crew members require that those unfamiliar with the installation be able, on short notice, to trace well-labeled systems and place the plant in operation or maintain it without undue hazards to the machinery, cargo, or personnel.

Plant layout aboard ships should be as simple as possible without sacrificing reliability. The machinery plant should be close to the main power plant to provide short piping and power connections and facilitate close supervision by operating personnel. Machinery space should be uncrowded, even at the expense of revenue space, to give ample room for operation, maintenance, and repair of both the apparatus and the ship's structure.

All machinery must have sturdy foundations, and all components should be secured against vibration from either themselves or other machinery. High-speed machinery should be mounted fore and aft, and all feeds, drains, and vessels must be installed with full consideration of the effects of pitch, roll, trim, and list.

Refrigeration equipment should not, in general, be kept in the same enclosed space as internal combustion engines, because engine damage can occur in the event of a refrigerant leak. Locating refrigeration equipment close to the main engine space usually improves economy of space and provides easy connection to power and cooling.

REFRIGERATION LOAD

A detailed discussion of load calculations has been omitted from this chapter, because the loads that might be encountered in a marine refrigeration plant are so widely varied. However, the methods used to calculate them can be found in Chapter 13, and load calculation considerations are discussed in this chapter in the section on Specific Vessels.

REFRIGERATION SYSTEM

Refrigerants

Refrigerants for shipboard use must meet the same environmental regulations that apply to land-based systems. The choices are similar, but special attention should be given to the availability of refrigerants and compressor lubricants at all ports of call.

The preparation of this chapter is assigned to TC 10.6, Transport Refrigeration.

Compressors

Generally, all of the same types of compressors used in stationary refrigeration plants can also be applied on ships. Chapter 34 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* describes compressors in detail and discusses their application and control.

Intermittent operation of compressors should be minimized to ease the starting load burden on the vessel's electrical generating plant. Automatic capacity control should be used to react to varying loads. Oversized compressors should be avoided.

The shafts of rotating equipment are usually oriented fore and aft to minimize the gyroscopic bearing loads that occur when a vessel rolls. Compressor lubrication systems must be able to function under all conditions of pitch, roll, trim, and list.

Reserve capacity and spare parts must be taken into account in the design. There must be redundancy built into the system, a complement of spare parts to ensure the ability to maintain temperature, or some combination of the two. ANSI/ASHRAE *Standard* 26 lists spare parts and tools to be provided on board. Table 1 suggests reserve capacities for various installations.

Condensers and Coolers

Shipboard condensers are most often of shell-and-tube design, using seawater as the condensing medium. Other types of condensers, such as plate-and-frame and double pipe, are sometimes used. Surfaces exposed to seawater must be resistant to corrosion. Cupronickel is the most common tube and tube sheet material for refrigerants other than ammonia. During selection of equipment, installation, and operation, special consideration must be given to preventing damage from galvanic corrosion, erosion, electrolysis, and anaerobic corrosion. Epoxy coatings and sacrificial anodes are often used as preventive measures.

Considerations for brine (including seawater) coolers and water-cooled oil coolers or subcoolers are similar to those for condensers. Materials of construction must be compatible with the medium being cooled or being used for cooling.

Shell-and-tube condensers are normally fitted with dual drains in order to drain freely under all conditions of pitch, roll, trim, or list. As an alternative, they may be installed on an angle great enough to compensate for the maximum angle of vessel trim or list that may be encountered.

Table 1 Operating and Reserve Capacities of Condensing Units

No. of Units, 100% Load	Additional or Reserve Unit, %	Total No. of Units
1	100	2
2	50	3
3	33 1/3	4
4	25	5
5 or more	20	6 or more

Receivers and Refrigerant Distribution

Receivers, either vertical or horizontal, must be installed so as to retain a liquid seal at their outlet under all conditions of pitch, roll, trim, or list. They should be fitted with an impact-resistant level glass, and may be additionally fitted with electronic level indication.

All of the same methods of refrigerant distribution that are used in stationary refrigeration plants are also used in shipboard refrigeration, including the use of secondary refrigerants. Generally, the same requirements must be met, in addition to those imposed by operating at sea.

Take care to ensure proper operation at any vessel angle that may be encountered. For direct-expansion systems, piping must ensure adequate oil return. Liquid level controls used for flooded and recirculating systems should be located in the middle of vessels rather than at either end. Provisions must be taken in vessel design to minimize liquid sloshing caused by sea conditions.

System piping must be able to withstand the stresses of operation at sea, including vibration, impact, and flexing of the ship's structure.

Controls

Recent technological developments have significantly changed how marine refrigeration plants are controlled. Electromechanical controls, which in earlier decades supplanted manual controls, are now increasingly being supplanted with solid-state controls in new and existing installations. The proliferation of electronics has influenced temperature and pressure controls, motor controls, level controls, data and trend logging, compressor sequencing, and leak detection. Microprocessors are becoming the common method of compressor control. As solid-state technology continues to advance, its advantages over prior methods of control are becoming increasingly pronounced. Automatic sequencing of multiple compressors has become as simple as entering parameters on a keypad. Electronic temperature controls are very precise, can easily be provided with multiple set points for varying duties, and can be located several hundred feet away from the space they are being used to control.

Pressures, temperatures, amperages, flow rates, liquid levels, events, and virtually any other information required can be delivered electronically to one or more central locations for monitoring and control. Computer technology allows logging these data for long- and short-term storage. The data can even be transmitted from a vessel at sea to a shore-based facility via satellite communication.

Electronic leak detection equipment can reduce the potential for accidental exposure to dangerous levels of refrigerant vapor in confined spaces.

The applications of solid-state technology are too numerous, and evolving too quickly, to list completely in this chapter. The changes in controls technology are probably the most significant in marine refrigeration over the last few years. It should be noted, though, that sophisticated controls are not a substitute for sound design and construction. Whatever control system is used, proper documentation must be provided; operating instructions must provide enough detail for users to operate the system with a minimum amount of training.

Thermometers and Thermostats

The thermometer (or thermostat display) is the principal indicator of how a refrigeration plant is functioning. Accurate control of space/room temperature depends on proper placement of the sensor(s) in that space. In spaces where the product is held just above freezing, placement is critical to avoid freezing the product. Sensors used with forced-air evaporators in this type of application should be placed in the delivery airstream, which is the point of critical temperature. Thus, if 32 to 33°F air is delivered, the product will be cooled as effectively as possible without risk of freezing. In spaces where a wider variance in temperature is tolerable, sensor placement is less critical. However, always attempt to place them in the most representative location.

Temperature recorders are essential to proper operation and control of cargo refrigeration systems. These can be paper charts, electronic media storage, or some combination of the two. The shipper or buyer of the product or cargo will often specify the type of recording device.

Electronic thermometers and thermostats have come into wide use in recent years. They allow for long distances between the sensor and the controller or display, are very precise, can often be tied in with microprocessor system controls and data logging systems, and many can be calibrated in the field. In a large refrigerated space, multiple sensors can be combined to give an average reading to the display or controller.

CARGO HOLDS

Arrangement

Arrangement and dimensions are determined by the ship's structure, compliance with compartmentalization of the hull as related to watertight integrity, vessel stability, and fire resistance. Cargo holds should not be designed exclusively for high-temperature service unless it is certain that the vessel will always remain in that limited trade.

Refrigeration controls must be located where they can be readily accessed by operating personnel regardless of whether holds are full of cargo. When controls, piping, or other equipment, such as evaporators, are located near hatches, adequate measures must be taken to prevent damage from impact by cargo, hatch covers, etc.

The greater the number of subdivisions in the refrigerated compartments, the greater the loss to the ship's revenue-generating spaces, because of the volumes occupied by insulated partitions, cooling apparatus, piping, and accesses. Thus, the all-refrigerated ship, with only the main structural boundaries insulated, makes the most efficient use of a ship's refrigerated enclosures. This efficiency comes with disadvantages, such as the difficulty in providing uniform temperatures throughout, and the inability to maintain different cargoes at different temperatures.

Space Cooling

Cargo is tightly packed in refrigerated holds of all types of vessels, with no aisles or clearances, presenting challenges to the designer. Cooling can be by extended-surface overhead-mounted coils, prime surface coils, or forced air.

For operation below freezing, the designer must consider whether defrosting will occur during operation, as with forced-air handlers, or after cargo is unloaded, as with prime surface coils. Draining defrost water from the space must be allowed for in the design of the hold, because it cannot usually be discharged to the outside of the space, as in stationary plants.

Insulation and Construction

Insulation. Moisture-, vapor-, and water-resistant insulation is of particular importance aboard ship because of frequent and extreme temperature cycles caused by intermittent refrigeration. On termination of refrigeration at discharging ports, insulation is at lower temperatures than the open room; often, the room surfaces are dripping wet with atmospheric moisture, which enters through the open door or hatch. Both warm and cold sides should be moisture-sealed equally; cold-side breather ports are not recommended. Other common sources of water in ships' cold storages are melting ice and defrosting cool surfaces.

Severe service conditions, which subject the insulation to injury or change by mechanical damage or vibration, and intermittent refrigeration place exacting requirements on insulation for ships' cold storages. The ideal shipboard composite insulation should have the following characteristics:

- High insulating value
- Imperviousness to moisture from any source

- Light in weight
- Flexibility and resilience to accommodate ships' stresses and loading
- Good structural strength
- Resistance to infiltrating air
- Resistance to disintegration or deterioration
- Fire resistance or fireproof self-extinguishing qualities
- Odorlessness
- Not conducive to harboring rodents or vermin
- Reasonable installation cost
- Workability in construction

In the United States, the properties of the insulation and the details of construction should meet approval by the U.S. Coast Guard and U.S. Public Health Service. For information on insulation materials and moisture barriers, see Chapters 23 to 26 of the 2005 *ASHRAE Handbook—Fundamentals*.

Construction. The three principal parts to the cold storage boundary are the envelope or basic structure, the insulating material, and the room lining.

The **envelope** is usually partly composed of the ship's hull, watertight decks, or watertight main bulkheads with members that resist entry of vapor from the warm side. Inboard boundaries outlining cold storages should have an equal ability to resist moisture. A continuous steel internal bulkhead with lap seams and welded stiffeners provides a boundary of adequate strength and tightness. Details of design may accommodate dimensioned insulators or facilitate means of fastening these materials. Doorway main bucks of steel channel provide good structure, but are usually a source of sweating on low-temperature rooms because of heat gain through the metal. Wooden door bucks minimize sweating but are a retreat from efforts to eliminate concealed wooden structure.

Partitioning bulkheads may be of similar detail, but airtight sealing is less important. Some installations are framed with angle-bar grids, between which the insulator is installed. In passenger vessels (over 12 passengers), Coast Guard regulations governing fire-resistant construction restrict wood assembly. Under no circumstances should wood be a part of the deck assembly, because it deteriorates rapidly under the prevailing conditions.

The assembled boundary of a ship's cold storage must withstand heavy deck loads and several bulkhead thrusts of cargo when the vessel rolls or pitches in a heavy sea; it must also be able to flex with the hull structure being stressed in any angle. The assembly must resist vibration caused by propelling machinery, the sea, and careless handling of cargo. The vapor seal of all surfaces must remain intact.

Only in extreme cases should voids in the **insulation** assembly be concealed. Filling such volumes with insulating material is cheaper and more effective than constructing internal framing. The exceptions to this rule are in the deep volumes formed by bilge brackets, deck brackets, and open box girders. Solid filling results in more insulation thickness than is needed for a heat barrier in the overhead and the ship's side, where beams and frames are deep.

The **room lining** must be sturdy enough to withstand the impact of frequent cargo loading and handling. On passenger vessels, U.S. Coast Guard regulations require that the lining be fire-resistant. Tongue-and-groove lumber is considered obsolete for any ship; on freight vessels where wood is permissible, exterior-grade plywood is sometimes applied. A few installations have been made either of laminated plastic sheets or wood fiber hardboard; both are satisfactory when properly supported. Steel linings are costly, impractical, and difficult to maintain and repair. The favored lining is the cement and fire-resistant fiber hardboard panel with aluminum sandwich lamination. When the insulator is secured with adhesives containing volatile solvents, the aluminum laminations should be of perforated metal or mesh.

The U.S. Public Health Service requires all linings to be ratproofed. Vulnerable linings should have an underlay of 1/4 in., 16 ga galvanized wire mesh for ratproofing.

Applying Insulation

When applying panels with adhesives over block insulators, butted joints should be separated sufficiently for the adhesive to extrude, provide a moisture-sealed joint, and accommodate movement of the panels by flexing of the ship's structure. Joints may be covered by cargo battens, which are also secured by adhesive and with brass screws. Bulkheads of all cold storages should be fitted with vertical cargo battens on 15 to 18 in. centers to hold cargo clear of the insulated bulkhead. This spacing allows circulation of air and prevents the contacting package from assuming the role of a room insulator.

Container vessels of cellular construction move containers along guiding columns; the boundaries of the hold, except for the hatch coamings, are not subject to mechanical damage. Here the insulation may be of the simplest, low-cost, ratproofed form without fitted hard panels or cargo battens.

Urethane foam deck insulation requires a restricting surface to confine and distribute the expanding material. In one method, plywood is secured over foam spacer blocks, and the material is injected into the space through properly spaced holes. The membrane and wearing surface covering are laid over the plywood. Wood in the deck is not good practice, however, and wood is not a suitable base for a heavy-duty wearing surface material. An alternative method calls for laying expanded board or blocks in an approved adhesive. Using the more resilient corkboard laid in adhesives may be good practice in some applications.

The greatest weakness in ship cold storage construction is the deck covering. Research and practice have not developed a totally satisfactory covering. Unlike a warehouse, a tightly packed cargo cold storage must have deck gratings both to ensure air circulation and to protect the bottom tier of products from heat leakage. Grating supports carry the cargo weight to concentrated load areas of the deck. The room may be filled with warm general cargo in alternative service, and a thermoplastic covering may be punctured by the supports.

The deck covering must be flexible enough to withstand the flexing of a ship or extreme temperature fluctuations, as well as maintain a moistureproof cover over the insulation. The most satisfactory material is a mastic composed of emulsified asphalt, sand, and cement. This material is applied cold; on setting, it has good load-bearing qualities, is impervious to water, has a small degree of ductility, and may be used in thinner layers than concrete. It should always be reinforced, and expansion joints should be included to accommodate shrinkage and adjustment to movements of the ship.

All rigid or semirigid deck coverings should have rubber-base composition expansion joints capable of bonding to the edges of the deck slabs or bulkhead and not subject to shrinking from age. The expansion joints should trace the periphery of the room, the line of all underdeck girder systems, bulkhead offsets to pillars, and similar lines of anticipated ship stress.

Water from ice-packed vegetables and from defrosting requires the deck covering to be impervious to moisture in the slab as well as the joints. If the deck insulation is wetted, it will deteriorate, lose its efficiency as an insulator, and give off odors. If wet deck insulation freezes, it will lift the deck covering and destroy it. If water penetrates to the steel, the ship's structure will corrode unnoticed.

All deck coverings will crack or become damaged during the ship's life. As a secondary security against water, a membrane should be laid between the insulator and the deck covering. The membrane need not be flashed to the bulkhead if suitable sealing expansion joints are fitted at the juncture of the bulkhead panel and the deck covering.

When an attempt is made to seal insulation with waterproof paper, it should be applied in double thickness, and the laps and perforations should be cement-sealed. Bulkhead and ceiling panels attached with suitable adhesives do not require waterproof paper inner linings.

Decks and Doors

The deck is the weakest point in the ship's refrigerated cargo hold. The weakest element in the deck is the deck drain, because of the difficulty in bonding the deck covering with the metal drain fitting. Water often finds its way between the covering and the insulation. The conventional deck drain is fitted with a perforated plate flush with the deck covering and hidden by the deck gratings. If the perforations become clogged by debris, water will accumulate at the drain. A drain fitting near a bulkhead or corner can create a weak section in the deck covering and develop cracks running to the bulkhead or across the corner. Figure 1 shows a satisfactory drain fitting. It is flush with the top of the gratings, has a lift-out cover for easy cleaning, and is bonded to the deck covering with expansion joint material. Drains between decks should be omitted wherever practical.

Refrigerated enclosure doors are generally a manufactured product. They should have generously designed steel hardware, and the door and frame should be metal-sheathed and have a flat sill and double gasket. Very large or double doors should have additional dogs to assure proper sealing when closed.

Sliding doors should be installed wherever possible to reduce interferences and conserve adjacent revenue space. When used, brackets should be installed to support portable horizontal spars inside the doors to prevent cargo from falling against the doors in a seaway. Molded glass fiber swinging doors insulated with urethane foams poured in place are available. They are strong and lightweight, are easily handled, and can be fitted with lightweight hardware.

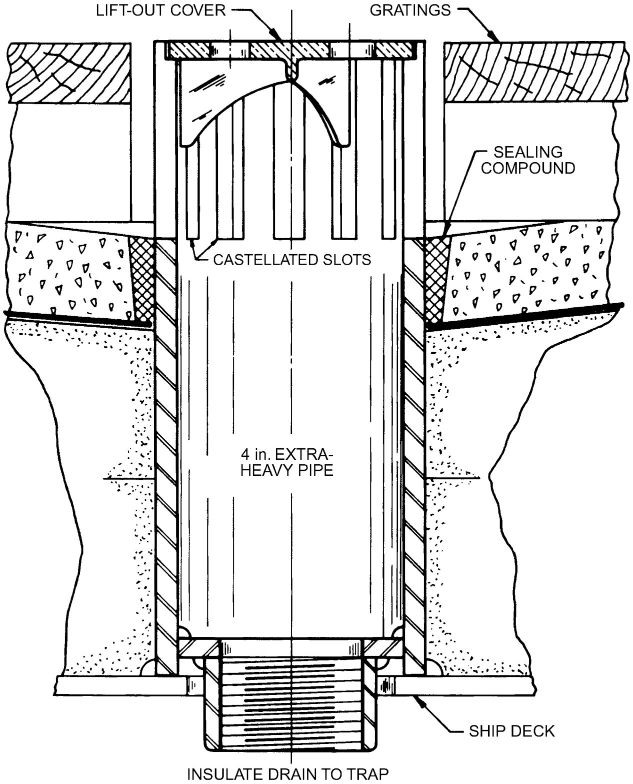

Fig. 1 Floor Drain Fitting

In finishing, wooden surfaces should be varnished rather than shellacked, because shellac has little protective penetration. Manufactured nonmetallic-surfaced materials may be painted or varnished, but if they are nonhygroscopic, their original surface will usually present a good appearance for longer than a painted coating.

Low-temperature apparatus or piping should be inspected carefully during installation. All joints and surfaces should be generously sealed to keep out atmospheric moisture. Special attention should be given to pipe covering ends, valves, and bulkhead penetrations. On below-freezing services, special composition adhesives should be used. The smallest omission or breach of a seal will allow progressive destruction of the covering.

On ships, where piping systems are relatively short, insulation functions more to prevent sweating or frosting of cold surfaces than to prevent heat gain.

SHIPS' REFRIGERATED STORES

Most vessels carry enough provisions for long voyages without replenishing en route. The refrigerating equipment must operate under extreme ambient conditions. Storage of frozen foods, packaging, humidity, air circulation, and space requirements are important factors.

Perishable foods can be fresh, dehydrated, canned, smoked, salted, and frozen. For most, refrigeration is necessary; for some, it may be omitted if the storage period is not too long. Space aboard ship is costly and limited; many rooms at different temperatures cannot be provided. Suitable product storage can be obtained by providing conditions outlined in Table 2 and described in the following sections.

Table 2 Classifications for Ships' Refrigeration Services

Service	Temp., °F	Passenger Vessels	Freight Vessels
Freezer rooms			
Meats/poultry	–20	X	X
Frozen foods	–20	X	X
Ice cream	–20	X	X
Fish	–20	X	X
Ice	28	X	
Bread	0	X	
Chill rooms			
Fresh fruit/vegetables	34	X	X
Dairy products/eggs	32	X	X
Thaw rooms	40 to 45	X	X
Wine rooms	48	X	
Bon voyage packages	40	X	
Service boxes in main galley			
Cooks' boxes	40	X	X
Butchers' boxes	40	X	
Bakers' boxes	40	X	
Salad pantry refrigerator	40	X	
Coffee pantry refrigerator	40	X	
Ice cream cabinet	10	X	
Mess rooms or pantries	40	X	X
Deck pantries	40	X	
Wine stewards' box	40	X	
Bars/fountains	Various	X	
Miscellaneous			
Ice cube freezers	See text	X	
Ice cream freezers	See text	X	
Biologicals	40	X	
Drinking water systems	See text	X	X
Ventilated stores			
Hardy root vegetables	See text	X	X
Flour/cereals	See text	X	X

COMMODITIES

Meats and Poultry

Substantial savings in space and preparation labor and better quality can be obtained with precut, boned, frozen meat and poultry packed in moisture- and vaporproof cartons and wrappers. For this reason, increased 0°F storage space should be anticipated. Fresh meats are less suitable because of their relatively short storage life. Also, the space required for fresh meats is two to four times more than that needed for prepackaged meats.

Fish, Ice Cream, and Bread

Good-quality fish, properly prepared and packaged, will remain odorless and palatable for a long time.

Commercially prepared ice cream is nearly always available and used to a great extent for both passenger and freight vessels. Ice cream for immediate use should be kept at a slightly higher temperature in an ice cream cabinet in the galley or pantry. If ice-cream-making equipment is used, provision must be made for hardening the ice cream, ices, and sherbets.

Excellent results can be obtained by purchasing freshly baked bread, sealing it in moistureproof wrappers, and storing it at 0°F. This supply may be supplemented by bread and other bakery items made on the ship. Frozen bread may be thawed in its wrapper in a few hours.

Fruits and Vegetables

Packaged frozen fruits, fruit juices or concentrates, and vegetables may be stored in any freezer room. All packaged frozen products may be held in a common 0°F storage space. However, improved accessibility, especially on large passenger vessels, may justify separate refrigerated spaces for some products.

In some cases, fresh-grown product is desired. These items may be stored in a common chill room, but some compromises with their optimum storage conditions must be expected.

Dairy Products, Ice, and Drinking Water

All dairy products may be stored in a single room, following customary shoreside practice. Strong cheeses with odors that might be adsorbed by other foods should be stored in a tightly enclosed chest or cabinet in the dairy refrigerator. Eggs may be processed by oil dipping or heat stabilization to make them less sensitive to unfavorable humidity conditions or odors. Large passenger vessels should be fitted with a separate egg storage room. Butter for reserve supply should come aboard frozen and be kept in a freezer. Frozen homogenized milk has been perfected to a degree that it can be carried for reasonably long periods. Aseptically canned whole milk may be stored without benefit of refrigeration, but this product has some limitations because of the detectable cooked flavor.

Flake ice machines and automatic ice cube makers are common on passenger and freight vessels. Chilled drinking water is piped to many parts of a ship. The water is cooled in closed-system scuttlebutts, and the necessary circulating lines serve living and machinery spaces where drinking fountains and carafe-filling taps are installed. Remote stations that would require unusually long insulated piping runs are better served by independent refrigerated drinking fountains.

STORAGE AREAS

Many borderline perishables, such as potatoes and onions, are satisfactorily stored with ventilation only. Hardy root vegetables carried on freight vessels not destined for winter zones are kept in slatted bins on a protected weather deck. Flour and cereals must be stored in cool, well-ventilated spaces to minimize conditions conducive to propagation of weevils and other insects.

Storage Space Requirements

Space requirements for refrigerated ships' stores can be approximated by formulas. However, catering officials and supervising stewards have specific ideas regarding the total volume and subdivisions, and these sometimes vary greatly. A freight ship in ordinary scheduled service seldom exceeds 45 days between replenishment of stores, and passenger vessels considerably less. In addition, deliveries en route are possible.

The space provided should allow suitable working floor areas for good storekeeping. When possible, stable piling 6 ft high is good practice; if the clear height of the room is less than 7 ft, allowances must be made for air circulation. A storage factor of 90 ft^3/ton of goods should suffice and allow floor working area. In the absence of a directing caterer or steward for consultation, Equation (1) may be used to estimate the total refrigerated storage space for merchant vessels. Ice storage is not included because of the various methods used in supplying it.

$$V = \left(\frac{NPD}{2000}\right)F \tag{1}$$

where

V = total volume of refrigerated storage (not including ice), ft^3
N = number of crew and passengers
D = number of days between re-storing
P = mass of refrigerated perishables per person per day, lb
= 10 lb for freighters
= 13.5 lb for passenger vessels
F = stowage factor (approximately 90 ft^3 per ton of goods)
2000 = lb/ton

For example, for a freighter on a 45-day voyage with a crew of 53 and 12 passengers,

$$V = \left(\frac{65 \times 10 \times 45}{2000}\right)90 = 1316 \text{ ft}^3$$

With 6 ft high stowage, the net floor area would be 219 ft^2. With 8 ft high ceilings, the gross volume would be 1752 ft^3.

Gross volume represents actual space available for storage of foods up to ceiling height and does not include the space occupied by cooling units, coils, gratings, or other equipment.

Stores' Arrangement and Location

Next to the arrangement of ships to meet their major purpose, the planning of ships' housekeeping facilities is most important. Efficient operation by culinary workers requires not only well-arranged working spaces, but also convenient supply stores. Storerooms are usually located in spaces least suitable for living quarters or revenue-earning volumes and in areas adjacent to the main galley and pantry. The arrangement should provide easy access, which generally places the reserve storage refrigerators on the deck below the galley.

Aboard freight vessels, refrigerators serve for daily issue as well as reserve storage. Aboard passenger vessels, reserve storerooms are less frequently entered, and greater use is made of the service or work boxes.

Passenger vessels carry a corps of steward's storekeepers, who should have an issue counter and office located within sight of the exits serving this area. The storerooms should extend to the ship's sides or have passageways reaching to sideport doors through which stores may be loaded directly into the ship. However, the arrangement of passenger ship stores will likely be compromised because of the interferences of structure, machinery or access hatches, and ventilation trunks.

In addition to the requirements for reserve storage of perishable foods, refrigerators (often referred to as working boxes) must be provided for the galley and pantry crew. On cargo vessels, a large domestic-type refrigerator will suffice. When more space is needed, a commercial walk-in box can be used. On passenger vessels, larger boxes are built-in like reserve refrigerators. Capacity of the passenger ship refrigerators is governed by the number of passengers carried, the variety of the menu, and the arrangement of the galley and pantries.

Ice cream stored in the reserve boxes is too hard for serving; hence, a dry or closed serving cabinet that will maintain temperatures from 5 to 10°F must be installed in the pantry. Passenger vessels may require ice-cream-making machines as well as bar and soda fountain equipment, the latter being fitted with commercial, independent refrigerating units.

SHIP REFRIGERATED ROOM DESIGN

Marine refrigeration equipment for offshore vessels should be designed, selected, and applied to function properly under extreme conditions with minimal dependence on expert servicing.

Refrigerated Room Construction

Free water that might enter the insulation through faulty floor or wall surfaces is the most harmful element to ships' refrigerated rooms. Room linings and floor coverings should be made of materials and have surface character that will give lifelong resistance to water absorption by the insulation and adherence of moisture on the room's interior surfaces. Construction of reserve and built-in refrigerated rooms should follow details similar to those of conventionally designed cargo holds.

Adequate floor drains of the type that may be cleaned without lifting floor gratings should be provided and located so that, with the probable stowage plan, the drains will be accessible for cleaning without moving shelving or excessive weights of stores.

All details should be in compliance with the regulations of the U.S. Public Health Service, which also emphasizes ratproofing. U.S. ships are also subject to strict fire-resistance regulations.

All doors and frames should be of sturdy construction to resist frequent slamming and should have metal sheathing or reinforced glass fiber doors. They should be large enough to facilitate loading of stores. The locking device must allow release of its fastenings from the inside by a person accidentally locked in.

All rooms should have galvanized or stainless steel racks or shelves to meet storekeeping needs, and they should be easily removable from their supports for rapid and thorough cleaning. The meat room and thaw room should have a single fore-and-aft meat rail for miscellaneous uses and thawing, respectively. Floor gratings or duckboards, fitted to each room, should be of a size and weight to facilitate removal and cleaning of gratings and the room.

The refrigerators should be fitted with waterproof electrical fixtures well guarded from damage by storing operations. Mount lighting switches inside each room at the door, with indicating lights in the outer passageway. Each room should have an audible alarm for use by any person inadvertently locked inside.

Remote reading thermometers, from which room temperatures can be read in the outside passageway, are essential to good operations. The sensor should be located in a representative location in the room, generally the geometric center at the ceiling. A large passenger installation justifies a duplicate electronic thermometer, with the instrument located in the refrigeration machinery room.

Service boxes in the galley and pantries should be constructed with a minimum amount of wood. The linings and shelving should be made of materials and have a surface character that facilitates thorough cleaning. Service refrigerators should not have raised door sills, and the floor should present a flush surface that is easily drained and cleaned. Cooling surfaces should be totally accessible for cleaning. Small units should be mounted without floor clearance on elevated bases, or be provided with at least an 8 in. clearance to facilitate scrubbing underneath.

SPECIFIC VESSELS

Cargo Vessels

Marine transport is an interim storage operation between preshipment storage of indeterminate duration, and distribution at destination ports. Good design requires the application of criteria that meet or even exceed those applied to shore-side cold storages.

The increased use of cargo containers has effected savings by providing faster loading and unloading of vessels. Containers also allow cargo to remain refrigerated during vessel loading and unloading. Even with these advantages, containers will never completely supplant built-in cargo refrigeration systems for many types of vessels, including passenger ships, logistical supply ships, refrigerated fruit carriers, refrigerated seafood carriers, and other types of special-service vessels.

Specifications

Refrigeration specifications should set forth the extreme operating conditions of loading, ambient and sea temperatures, and rates of pulldown. In the all-purpose installation, each compartment should be designed for refrigeration of warm, fresh products from the field or orchard; for the overall condition, a percentage division of chill and freezer cargo with simultaneous and total loading should be stated.

Typical conditions for a cargo vessel operating in all oceans with all cargoes include the following:

• Arrangement and net volume capacities of the refrigerated compartments	
• Thicknesses and kinds of insulation	
• Ambient temperatures	
Weather surfaces	100°F
Adjacent machinery spaces	100°F
Other adjacent spaces	85°F
Sea temperatures	85°F
• Overall stowage factor	70 ft^3/ton
• Percentage total loading as chill	75%
Percentage total loading as freezer	25%
• Receiving temperature, chilled cargo	80°F
Receiving temperature, frozen cargo	25°F
• Carrying temperature, chilled cargo	34°F
Carrying temperature, frozen cargo	0°F
• Initial period of cargo heat removal (equivalent)	72 h
• Replacement air at 85°F db, 75°F wb	3%

The specification writer should describe the kind of refrigeration system to be installed and specify the number of compressors and other auxiliary parts or apparatus together with sources of emergency pumping and water facilities. All equipment and installations should be specified as complying with the rules and regulations of the Classification Societies (ABS, Lloyd's Register, and others), the U.S. Coast Guard, the U.S. Public Health Service, ASHRAE *Standard* 15, and ASHRAE *Standard* 26.

The owner's representative should obtain from the vendors full descriptions, details, capacities, and specifications of the equipment proposed, to allow comparative analysis.

Completion tests should be required to determine workmanship and functional performance. Performance guarantees should cover operations under loaded service conditions.

Calculations

The following discussion of refrigeration load calculation considerations for a general-service plant carrying heterogeneous chilled cargo may appear simplified, but it is justified by the great range of conditions common to marine installations. Refrigeration loads for freezer cargo may be calculated in a similar manner using the same stowage factor, a specific heat of 0.40 Btu/lb·°F, and an equivalent pulldown period of 72 h. The loads for respiration heat, replacement air, or latent heat of fusion will not be present.

Specialized service in known ambient conditions may be calculated more precisely, but an arbitrary 10% margin should still be added to the results to compensate for aging and unforeseen heat gains.

With general calculations, the following operating conditions should be assumed:

- *Weather ambient conditions:* Up to 100°F.
- *Ambient sea conditions*: Up to 85°F.
- *Conductivity of insulation*: According to standards given for the material, urethane foam with an installed thermal conductivity k of about 0.15 Btu·in/h·ft^2·°F is suggested.
- *Resistivity of outer boundaries, inner linings, and surface films*: These factors should be ignored because boundaries and linings are usually dense and have high conductivity values.
- *Infiltration and open-door leakage*: For cargo refrigeration installations, such losses at sea are nil. Port exposures during loading and discharge reestablish pulldown conditions.
- *Ventilation or replacement air*: This factor is often omitted when carrying heterogeneous cargo for short to medium-length voyages. For specialized service, it may be as much as 300% of the gross room volume per hour.
- *Electrical energy conversion*: The energy load from fans and brine pumps will be on demand load rather than connected load. An arbitrary value of 3000 Btu/h per brake horsepower may be used.
- *Product load*: This factor ranges widely for heterogeneous cargo. Volume ranges from 40 to 120 ft^3/ton; an average volume is 70 ft^3/ton. Specific heat ranges from 0.22 to 0.95 Btu/lb·°F. The gross weight of the package and the specific heat of the product should be used.
- *Receiving temperature of cargo*: Chilled cargo ranges from carrying temperature to ambient. Frozen cargo ranges from –20 to 28°F.
- *Carrying temperature of cargo*: Ranges from 32 to 55°F for chilled cargo, and –20 to 0°F for frozen foods.
- *Respiratory heat of chilled cargo*: Meat products, eggs, and dairy products have no respiratory heat. Chapter 9 lists heat of respiration of many horticultural products at various storage temperatures.

FISHING VESSELS

Nearly all types of fishing vessels, from small, open gill-netters to large factory processing ships, use refrigeration in one form or another to preserve their catch. Methods range from ice taken aboard daily to sophisticated low-temperature production freezing systems and cold storages.

REFRIGERATION SYSTEM DESIGN

When designing a refrigeration system, the following issues should be considered:

- The vessel owner and design engineer must be aware of the monetary value of a fully loaded fish hold. Money saved by selecting and using substandard equipment may be a needless and expensive gamble.
- The vessel may be several hundred miles from a qualified service technician and have very limited resources on board for emergency repair. In the event of a system failure, effective initial design may maintain temperatures longer, thus preserving the product.
- Marine refrigeration systems are subjected to severe conditions, including high engine room temperatures, low ambient temperatures, electrolysis, corrosion, impacts, and vibrations. In some cases, these conditions are compounded by little or no maintenance, or worse, abusive maintenance.
- The system should be well laid out, and designed to allow new operators to adapt to the system quickly.
- All safety and operating controls should be used. In the event of a component failure, a back-up system should be available, or, ideally, built into the system. On vessels with production freezing systems, it is advisable to provide enough redundancy to enable the vessel to reach port with the already frozen product preserved in a frozen state, even if there is a failure of the production freezing plant.
- Upon completion, the vessel should be provided with all wiring and refrigerant flow diagrams, an operator's manual, and a supply of spare parts.

In the initial planning, the designer must know the following:

- For what fisheries the vessel is being equipped and in what area of the world the vessel will operate.
- In what future fisheries the vessel may be required to work. (At this point, such considerations will probably add little or no cost to the system.) Necessary alterations may be as small as increasing the spacing in the freezing racks.

Hold Preparation

On any vessel presently being refrigerated or being fitted for future refrigeration installations, 4 in. or more of insulating spray-on urethane is recommended. Special attention must be given to insulating areas of high heat, such as engine rooms, bulkheads, and the underside of the main decks. High-heat sources, such as the hatch coaming, shaft log, and fuel tanks with fuel returns from the engines, must also be insulated. The insulation must be protected to prevent moisture from destroying its insulating quality. Laid-up fiberglass is often used because of its strength, light weight, and versatility. Pen board guides, mounting brackets, and plate racks are at times fiberglassed into the liner, and thus become a very secure part of the vessel. Fiberglass has the advantage of being easily cleaned and sanitized.

REFRIGERATION WITH ICE

Ice is commonly used to preserve groundfish, shrimp, halibut, and most other commercial species. Bin or pen boards are installed to divide the hold as desired (Figure 2). Ice is usually stored in alternate bins so that it is handy for packing around the fish as the fish is loaded into the adjacent bin. The crushed ice varies in size up to 5 in. lumps. As the fish are stowed with crushed ice, each pen is generally divided horizontally by inserting boards so that the bottom fish will not be crushed. The compartmentalized sections should not be more than 30 in. high if undesirable crushing and bruising are to be avoided.

The approximate amount of ice required is 1 ton for each 2 tons of fish in summer, and 1 ton to each 3 tons of fish in winter, based

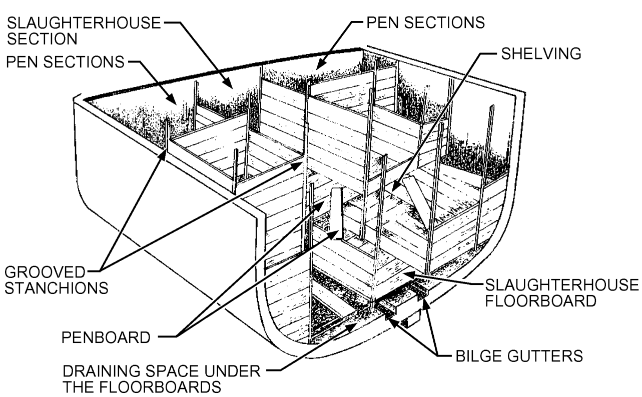

Fig. 2 Typical Layout of Pens in Hold

on a voyage of about 8 days. Less ice is needed if the ship has supplemental refrigeration.

The method of stowing the fish in ice is very important to the keeping quality. The depth of ice on the floor of the pen should be a minimum of 2 in. at the end of the voyage. This is obtained by having the initial bedding of ice 1 in. thick for each day of the voyage. In stowing, one or two layers of fish are laid on the bedding ice so that the ice is just completely covered. In no case should the layer of fish exceed 12 in. in thickness. The top covering layer of ice is about 9 in. thick, heaped up higher in the center than along the sides. This method of stowing permits the pile to adjust itself to melting and settling and results in good drainage of water and fish slime.

Many small fishing vessels are constructed of wood, with uninsulated holds. Larger vessels are usually of steel construction with insulated holds. Mechanical refrigeration is used on some vessels to keep ice from melting quickly and to maintain lower temperatures. The most common mechanical system uses direct-expansion cooling coils under the overhead in the hold and sometimes around the entire shell.

REFRIGERATION WITH SEAWATER

Refrigerated seawater is commonly used instead of ice for holding fish in satisfactory condition. The seawater is continuously pumped either around the fish and over cooling coils placed along the sides of the insulated tank, or through external chillers and then through, or over, the fish. Capacity requirements vary widely, and are primarily determined by how quickly the water needs to be chilled before taking on fish.

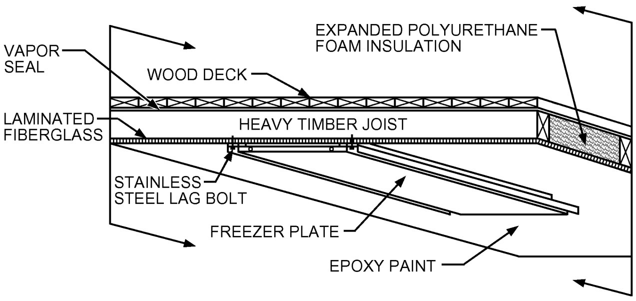

Fig. 3 Typical Underdeck Freezer Plate Installation

Design of refrigerated seawater systems is unusual, in that their primary function is to operate at full capacity during pulldown. Extra care must be taken by the designer to ensure that the compressor drive motors and condenser(s) are sized for the extremes, not just for the final temperature.

PROCESS FREEZING AND COLD STORAGE

Distant-water vessels are usually equipped for freezing and handling the catch at sea because they stay out for weeks or even months, making storage with ice or refrigerated seawater unfeasible. Although many different vessels and freezing systems are used, the general types can be classified as either those freezing large whole fish, such as tuna and halibut, and those freezing processed and semiprocessed fishery products, such as fish blocks or groundfish in bulk lots.

The method of freezing is determined by the physical and biochemical characteristics of the fish and the desired end product. For the most part, large fish such as tuna, which are eventually canned and somewhat resistant to salt intake, are conveniently frozen in brine wells where space savings and ease of handling offer convincing benefits. Cod, haddock, hake, pollack, and similar demersal or midwater species, which are more delicate than tuna, are usually frozen rapidly either in vertical or horizontal plate freezers (see Figures 3 and 4), or in air-blast freezers. Other products, such as crab, are frozen in flow-through sodium chloride brine tanks.

Virtually every type of equipment and method of freezing used in stationary installations is also used on vessels that freeze seafood at sea. Specialized products demand exacting methods of handling, freezing, and packaging. Additional design and application information can be found in other documents not specifically related to marine systems.

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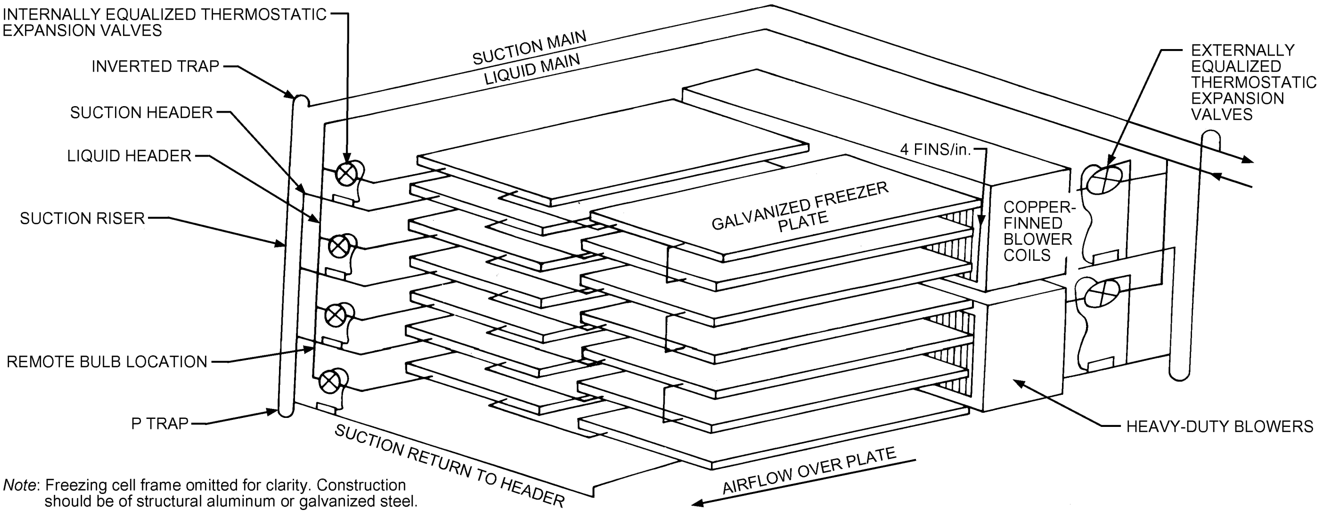

Fig. 4 Typical Marine Freezing Cell