the ship's structure, in the compliance with floodability compartmentation of the hull, and in the extreme fire-resistant regulations to which American ships are singularly subject.

No vessel should be insulated or outfitted for an exclusively cold water route because almost certainly the vessel will in some future time or service move through warm waters. The resulting warm water reserve capacities in cold water services will prove of good return during the vessel's normal useful life.

The refrigerators should not be designed for high temperature cargo services only, unless there is a certainty that the vessel will always remain in that limited trade. Otherwise, all compartments should be readily convertible to any temperature service between subzero and 55 F, the resulting flexibility in the segregation of cargoes by temperature requirements or by ports of call being highly desirable.

In a vessel only a portion of which is refrigerated and designed to permit late loading and early discharge, the compartments will usually be located under the topmost deck to the hull. Further considerations will be given by the naval architect relative to the effect on trim of the vessel in normal loading conditions. Generally, the added weights of the insulation and the perishable cargo will not be as influential as would be the weight of dry cargoes which are usually of greater density. Often these compartments will be empty or light loaded during some legs of the voyage. Trim conditions will generally require that the refrigerators be placed forward of the mid length of the vessel, or grouped about the middle section where the moment arms for trim are of lesser consequence. Almost without exception the refrigerators are arranged symmetrically about the ship's longitudinal centerline.

The rooms or areas where the refrigerating control valves are installed should be so located and arranged that the apparatus or controls are accessible through trunks or passageways to the operating personnel at all times. When the boundary bulkheads parallel hatches, they should clear the openings by three feet as a safety measure, providing adequate room for handling hatch beams and covers.

The greater the number of subdivisions in the refrigerated compartments, the greater the loss to the ship's revenue spaces. This is due to the volumes occupied by the insulated partitions, the cooling apparatus, insulated piping and access areas. On this basis the all-refrigerated ship with main structural boundaries insulated only, would make for the most efficient use of a ship's costly enclosures. On the other hand, the conventional all-refrigerated ship with insulated hatch plugs at the weather deck, has several undesirable features. The difficulty of providing uniform compartment temperatures and of refrigerating the hatch areas remote from the refrigeration apparatus is recognized. With large volume rooms, the extended period in which the hatch is open to the outside atmosphere for loading and discharge is not conducive to providing good environment for frozen or fresh cargoes at this critical interval in their keeping lives. Seldom are frozen goods sufficiently subcooled to contribute adequate self-refrigeration during the extended interval of loading. Fresh products are not generally precooled before loading and the accumulation of respiratory heat in the compartment and its delayed extraction is obviously deterimental. During long discharge intervals in ports, much atmospheric moisture is given into the hold to cause *sweating* or frosting of products, some of which may suffer from this exposure. With partial delivery at a port of call, such an exposure may unfavorably affect the remaining cargo. The problem is otherwise without solution because of the harbor workers' refusal to work in the spaces with the refrigerating equipment in operation.

A more suitable arrangement of the all-refrigerated ship can be had by having the insulated compartments in the 'tween decks fitted with access doors in hatch-line bulkheads, and with the various combinations of insulated plug hatches at the lower hold and 'tween deck levels. Hatch areas may be used for general cargo or treated as separately refrigerated compartments. Many ships are fitted with side port doors at the 'tween deck level, through which cargo is handled by conveyors, independent of the ship's overall cargo gear. (Figs. 1 and 2.)

The central refrigeration machinery plant whenever possible should be located in, or immediately adjacent to, the main propulsion machinery room where the ship's responsible watch officers are in constant attendance. With the nomadic tendencies of unlicensed sea-going personnel who attend refrigerating equipment, close supervision by the engineer officers is essential. A central location of the refrigeration machinery usually results in economy of space and close connections for power and pumping facilities.



Fig. 1 .... Typical Arrangement of the All-Refrigerated Ship

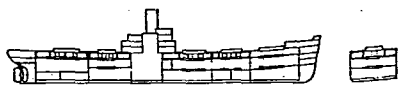

Fig. 2 .... Typical Arrangement of Combination Refrigerator and Dry Cargo Ship with Insulated Compartments in Upper Tween Decks

Insulation and Construction

Insulation. Composite insulation is often erroneously defined simply as a heat barrier. Describing an equally important function, the definition should include the property of the moisture-vapor barrier.

There is a wide variation in the moisture-vapor resistance of insulators and while the individual fiber or elements may be, and usually are, inherently non-hygroscopic, the interstices of an air-permeable insulator may hold in capillary suspension, water from condensation of airborne moisture, or free water from other sources. However, if permeable insulators can be sealed or shielded from all sources of moisture, it can borrow the property of moisture resistances from the seal. Assuming that moisture seals can be perfect, it allows a wide selection of insulating materials.

Moisture-vapor and water resistance is of particularly great importance on board ship because of frequent and extreme temperature cycles through intermittent refrigeration. Upon termination of refrigeration at discharging ports, there is always a period in which the body or concealed mass of insulation will be at lower temperature than the open room, and often the room surfaces stand dripping wet with atmospheric moisture which gains entrance through the open door or hatch. It is clear from this that in addition to the moisture seals on the warm side, the cold side should be equally well moisture-sealed and that the installation of cold side breather ports is fallacious. Other common sources of water in ships' refrigerators are from melting of ice packed with vegetables and from the defrosting of cooling surfaces.

The insulators for ship's refrigerators should have all the properties required by shoreside installations, but several of these properties are of magnified importance in the marine application. Severe service conditions which subject the insulation to injury or change by mechanical damage or vibration as well as intermittent refrigeration, place exacting requirements upon the composite design.

The ideal insulating material has not been found and the degree to which the various insulators approach the ideal must be measured by the user, designer or owner. It is a very controversial subject. The ideal shipboard composite insulation should have the following characteristics:

1. High insulating value.
2. Impervious to moisture from any source.
3. Light in weight.
4. Flexible and resilient to accommodate ship's stresses and loading.
5. Good structural strength.
6. Resistant to infiltrating air.
7. Resistant to disintegration or deterioration.
8. Fire-resistant or fire-proof self-extinguishing.
9. Odorless.
10. Not conducive to harboring rodents or vermin.
11. Reasonable installed cost.
12. Workable in construction.

Encumbering requirements have been placed upon American owned ships by government regulation and the properties of the insulator and the details of construction must meet exacting approval of the U. S. Coast Guard and the U. S. Public Health Service.

There are numerous block-type insulators, made of organic and inorganic materials. Some are very rigid and when used should be of small dimension blocks set in a cement that will remain pliant at all temperatures, the cement to provide the necessary flexibility. Some block insulators being fibrous are permeable and the blocks are coated with moisture resistant materials. The seal should be preserved after working or cutting by application of a suitable coating over the raw surfaces. There are block and blanket insulators made of fibre without benefit of seals and which depend upon the vapor seal of the assembled wall or surface to prevent the ingress of moisture.

Fibrous insulators are generally fire-resistant but in the majority of cases this quality has been voided by the use of wood structure intended to supply loading strength which the insulator does not have in itself.

Fibrous insulators are air-permeable but when installed behind continuous and perfect moisture-vapor seals they can give very creditable service. There are few insulators which inherently have both of the properties of heat and moisture barriers.

Corkboard will continue to be favored for many applications. It has many virtues as a ship insulator, including structural strength and fire-resistant properties. It has good moisture-resistant characteristics, is relatively impermeable and is durable.

Granulated or powdered insulators, while being capable of adjustment to flexing, are subject to packing, settling, or shifting, and some are flammable. This type of material is not suitable for shipboard use.

Where heavy concentrated loads may be imposed on refrigerator floors such as in lower holds or where containers may be handled with fork-lift trucks, the insulation may be of rigid block type material made from closed cell arrangement of glass beads. This material has a k value approximately 0.40 and requires added thicknesses for heat barrier properties equivalent to the traditional forms of insulators. It has a compressive strength of 100 lb per sq in. and a density of 9 lb per cu ft.

Plastic foam products have been well demonstrated in the insulation of ship's refrigerators and there is much to commend them. Their physical properties approach those listed as ideal for marine applications and being inherent in the material they require no supplementary materials to complement them. The cost of production for many of them has been reduced to now make them competitive to the more traditional forms of insulation. The manufacturers continue extensive research in the production and application of these materials, and they should be consulted to make certain that the latest technique is known.

Expanded polystyrene is available in block and plank form, and has an insulating value equal to or better than traditional types of insulators. It has a density of approximately 2 lb per cu ft and a compressive strength of approximately 30 lb per sq in. It can be obtained with special self-extinguishing fire-resistant properties. It is best secured with enveloping adhesives.

Under intense research on materials and methods of application the polyurethane family of foams are bidding fair to take a predominating position in the design of refrigeration facilities. These foams are now being expanded with Refrigerant 11 resulting in an insulating value that requires only half the thickness of that for the traditional insulators for equivalent effectiveness.

Polyurethane foams may be poured in the shop to produce blocks, planks, panels or shapes. Under suitable conditions it can be poured in place between restrictive forms. It may also be sprayed into position. Besides being of high insulating value and moisture-vapor resistance, its great virtue is its high surface bonding properties for all shipbuilding materials. Bonding values range from 19.5 psi with plywood to 45 psi to metals.

The principal problems in the application of polyurethane foams lie in the provision of suitable bonding surface temperatures, suitable atmospheric conditions, and the precautions necessary for preserving the component chemicals in reserve storage. When sprayed, the highly toxic catalyst volatilizes into the surrounding atmosphere, and therefore the operators must wear fresh-air masks. Usual shipyard operations are not conducive to isolating such an operation. Continued research will ultimately reduce or remove these hazards. One exceptional value of the poured foam comes from the ability to insulate irregular forms such as valves, manifolds, brine pumps, and apparatus, with absolute moisture-vapor barrier protection to the cold surface. Poured and sprayed foams require a higher degree of expertness in application than do other forms of insulators.

Construction. There are three principal parts to the refrigerator boundary: envelope or basic structure, the insulating material and the room lining. (Figs. 3, 4, and 5.)

The envelope is usually composed in part, of the ship's hull, the water-tight decks or the main water-tight bulkheads, which members obviously give effective resistance to the ingress of moisture-vapor from the warm side. The inboard boundaries outlining the refrigerators should have equal abil-