Space cooling. To one not familiar with marine practice, the logical question arises as to why there has been so little research on distribution of refrigeration within cargoes aboard ship after the manner of the conventional tests made in reefer cars or in the warehouse.

Rail cars have a degree of uniformity of proportion in regular dimensioned enclosure and are loaded with a single type of commodity in an established manner. These tests are representative of a great majority of repetitive loadings—and have significance. Unlike warehouses, ships' refrigerators are tightly stowed without aisles or clearances and the method of stowage is even more influential of results than is the design of the refrigeration equipment. Marine refrigerators are, of necessity, of countless variations in size, dimension, proportion or configuration.

For homogeneous cargoes, such as citrus fruits, bananas or apples, tests in a ship's individual refrigerator would have significance, but with the usual heterogeneous cargo offered, the possible variations in stowage methods and the lack of uniformity of refrigerator physical characteristics, research in such matters has limited value. Practical considerations and critical observations of outturn results are the principal rule and guide to procedure, all of which adds up to an accumulation of experience by the operator.

Circulating air is the conveyor system which lifts the heat from the cargo or other sources and carries it to the refrigerating or heat-absorbing surfaces. Air, with its low specific weight and low specific heat, is not an efficient transporter of heat, and in consequence, relatively large volumes of air must be circulated. Restricted streams of air in high velocity have their equivalent in broad streams of low velocity. For effective heat removal a long air path will require higher velocity than the short path in lower velocity, with equal air stream temperature rise. High velocity streams will wipe air films of high humidity from the product surfaces and replace them with air of lower humidity, thus accelerating dehydration of a vulnerable cargo.

The refrigeration of cargo by wall coils can now be considered obsolete practice and will therefore not be treated in this section.

Cold air systems. One of the better methods of refrigeration, particularly for chill cargo services, employs externally located coil bunkers and fan systems, which circulate chilled air through ducts and ported false bulkheads. The system is typical of the banana or fruit carrier. Traditionally, the brine cooled prime surface hair-pin coils of pipe are used, and the false bulkheads are at the ship's side, the air movement being transverse. This system furnishes supply air to one side of the compartment and the fans take suction from the opposite side of the room. Some installations are arranged to permit reversal of the direction of the air flow. Because of the uniformity of air distribution through the entire length and breadth of the compartment, refrigeration will effectively reach the entire volume if properly stowed and the ports are correctly adjusted. The usual distribution results in low air velocities and a relatively low moisture pick-up.

By calculating the refrigeration load and establishing the desired air temperature rise, the fan size can be calculated, and coil surfaces are determined after the manner of other air cooling devices.

European builders often employ vertical air streams between floor and ceiling plenums, but this system has not been adopted by American operators.

Cooling units—diffusers. These units are composed essentially of three sections, the bottom as an air inlet, the middle section encasing the cooling coils and the top section housing the motor-driven fans which are usually in multiple arrangement on a common shaft. Large units may be arranged horizontally in similar sequence. Diffusers are packaged units, easily and cheaply installed.

These units are fitted with distributing duct systems outlining the rooms, the outlets directing the air inward along the ceiling and downward along the bulkheads between the cargo battens.

The cooling coils are in some cases direct-expansion small tube evaporators with fins spaced fractions of an inch, each vertically arranged tube pass being fed liquid from the distributing head of a thermo-expansion valve. The evaporator outlet consists of a connecting manifold at the base of the coils. Other types employ prime surface tubes or coils cooled by direct-expansion or by brine.

The manufacturers of the units are usually willing to specify cooling surface areas based upon the calculated load of the individual installation. The ratios of cooling surface areas to refrigerator volumes are often referred to, but are not a scientific basis in design. The ratios, however, provide ready comparisons of competitive designs or proposals.

Most marine refrigerators operate at temperatures that require the cooling surfaces to be below 32 F and these surfaces rapidly accumulate frost. The relatively small cooling surface areas of a cold air unit become thickly coated and the restricted air flow becomes so impeded that defrosting is necessary. Prime surface coils require less frequent defrosting than extended surfaces of equivalent capacity rating.

Closely spaced fins may become completely blocked without frequent and thorough defrosting. The consequently reduced area of the air stream and the masking of the heat absorbing face by frost, reduces the refrigeration capacity of the unit. The effect may be avoided to a degree by a small temperature split between refrigerant and the air, and a compensatingly generous cooling surface ratio. The problem becomes most severe during initial cooling periods.

Small temperature split is the principal means by which a sea-going plant can provide desirable high relative humidities for fresh perishable cargo.

Cooling units or diffusers are installed behind guards or fenders against which the cargo may be piled and behind which necessary access is provided for the maintenance of motors, fans and control valves. The cargo space lost to these units and their associated ducts increase proportionately as the room becomes of smaller volume. Fans should have output adjustment in steps to half-rated speed and the motors should be of watertight design to prevent damage to windings or armature by internal motor sweating.

Defrosting systems. All cooling surfaces should have means for the melting of accumulated frost. Direct-expansion systems, if not too remote from the compressors, may be defrosted by hot gas, or alternatively with warm water spray. Hot gas defrosting is accomplished by reversing the flow of compressor discharge, the evaporator becoming a condenser where sensible and latent heats are absorbed by the frost. The liquid so produced must be accumulated and expanded in another evaporator, or with care in control it can be expanded in the condenser, gaining the heat for evaporation from the sea water. Hot gas defrosting is not without complications and most plants employ heated fresh or sea water for the purpose. When using heated water, its temperature should not exceed 90 degrees to avoid high refrigerant pressures in the evaporator.

Brine cooled surfaces may be defrosted by bypassing heated brine through the coils. The frost is first melted at the coil surface and rapidly displaces the frost as water and ice. A steam heated thermostatically controlled brine heater may be installed in central location for the purpose.

Replacement air. In some long voyage chill services, such as for bananas, citrus fruits, apples, etc., replacement air is necessary to remove excessive quantities of carbon dioxide and other gases. For uniformity of conditions within the room, the air should be of continuous addition rather than intermittent. The new air should first pass through the cooling unit before distribution, if constancy of temperature and humidity are to be effected.

Citrus fruits should have replacement air at the rate of from 2 to 3 percent per min based upon the gross volume of the refrigerator and bananas may require as much as 5 percent gross replacement.

When replacement ventilation is provided, accessible, efficient and well-insulated dampers should be fitted for cutting off this air supply when frozen food is carried.

Plant layout and piping. The first rule in plant layout aboard ship is that it should have an optimum of simplicity without the sacrifice of reliability. The second rule is that the machinery plant should be closely associated with the main power plant to provide short piping and power connections and to facilitate close supervision by engine watch officers. The not unusual exchange of engineers and the more frequent replacement of refrigeration crew members demands that strangers to the installation should be able on short notice to trace out the well-labeled systems and place the plant in operation or maintain it without undue hazards to the machinery or the cargo through error in manipulation or adjustment. A third rule in layout demands that even at the expense of valuable revenue space, an uncrowded machinery room be provided which will give ample space for operations, maintenance and repair of apparatus or ship's structure and that proper clearances be allowed for the insulation of low temperature parts.

All machinery should have sturdy foundations and all parts secured against vibrations set up by themselves or the main propulsion plant. High speed machinery should be mounted on fore-and-aft centerlines and all gravity feeds, drains or tanks should be designed or installed with full considerations of the effect of trim, roll or pitch of the vessel in a seaway.

With Refrigerant 12 condensing units each individual system must consist of compressor, condenser, receiver and evaporator and they must work independently from other systems in the primary refrigerant side. The number of units for a plant should be as indicated in Table 1, and the entire plant should be cross-connected in a manner that the standby units may take the load from any system normally assigned to a specific use.

It is apparent that multiple compartmented refrigerator arrangements operating with direct-expansion, can at best become a complicated central plant layout, particularly with hot gas defrosting. Remotely located evaporators result in decentralized control with apparatus scattered over the ship.

Halocarbon return piping may be designed on the basis of a 2 F deg total temperature drop between the evaporator and the compressor. The aforementioned oil trapping should be avoided and a heat exchanger for cooling the liquid should be fitted, preferably close to the evaporators. Minimum vapor velocities in horizontal lines of 700 to 800 fpm are recommended for oil return flow.

Liquid lines should be arranged to prevent line flashing from excessive pressure drop in the static head of risers or from high temperature and the heat exchanger location may be affected by this consideration. Liquid lines should be fitted with efficient driers and strainers. Other conventional fittings and apparatus are fully described in manufacturers' literature and require no further treatment in this section.

Plants using brine for distribution of refrigeration require a condensing unit for each evaporator (Fig. 8) after the manner of direct-expansion plants, but any arrangement of cross connection of brine systems may be effected with impunity.

Most marine plants operate over a wide range of refrigerator temperature from subzero to ambient, with any or all compartments interchangeable. This arrangement suggests a two-temperature brine plant in which the high temperature brine may refrigerate fresh products with minimum desiccation effect, and a low temperature brine for refrigerating frozen cargoes (Fig. 9).

A two-temperature brine plant suggests two circulating piping systems served by two pumps on the line and a standby pump available for either system. This layout is best provided

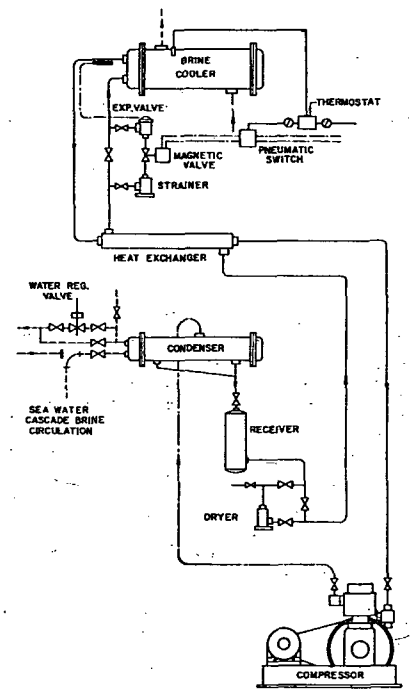

Fig. 8 .... Individual Refrigeration System (Refrigerant 12) for Brine Cooler