humidity chambers in which operation ranges from high to low humidity conditions.

Altitude Chambers

Altitude chambers require the strength to resist an external pressure of 14.7 psi (2,120 psf) at all temperatures encountered when the stressed shell is the inner liner. It is especially important to take into consideration the embrittlement of ferrous materials at low temperatures. The inner liner mass should be held to a minimum when rapid temperature changes are required, due to its influence on conditioning equipment size.

If the exterior is stressed to withstand the vacuum load, the liner must have pressure relief to the insulation. If the chamber is equipped for high humidity, means must be provided to drain and dry the insulation. Another possibility is to use a structural material for the insulation and to maintain the inter-wall space at a fairly high vacuum by connecting it permanently to the main, or an auxiliary, vacuum pump. Considerable reduction of heat flow will result if a high vacuum is used. When the chamber is used at sea level pressure, the structural insulation holds the walls apart; when at altitude, approximately equal pressures exist on both sides of the relatively thin liner.

The welding of vacuum chamber seams and connections is particularly critical. The welds must be structurally strong enough to protect against the stresses imposed by expansion and contraction, and yet not produce *virtual leak* conditions. A *virtual leak* is a condition which traps air in such a way (as between two welds on a slip on flange) that it may leak into the vacuum chamber without detection from the outside. Good space chamber design calls for continuous polished welds on the inside and skip welding for reinforcing on the outside of the vacuum structure.

Leak checking must be performed on all parts of the structure. Dye checking and halogen leak detection with an electronic detector are considered rough checks for high vacuum system. A mass spectrometer using helium must be used for final checking of a system which is to operate in the 10^{-4} mm Hg or higher altitude range.

Gaskets

Gasketing of environmental chambers presents special problems. Inadequate gasket seals on a low temperature chamber can produce overloading of the refrigeration system. It may not be possible to maintain the required control tolerance in any system having a small door seal leak. Vacuum systems have particularly critical gasket problems. Gaskets on low temperature chambers can be protected by heaters against low temperature embrittlement.

Gasket sealing depends upon resilience to fill the surface irregularities and resistance to permanent deformation in order to maintain ability to reseal. Natural rubber has these characteristics in a limited temperature range but suffers from ozone cracking. Neoprene is the most commonly used synthetic gasket material because of its resistance to aging and ability to remain resilient from −65 to +400 F. The Viton elastomers offer higher temperature performance (up to 600 F) but, due to cost, are used principally for high vacuum systems. The silicons are suitable for −100 F to +250 F but tend to deform and take a set. Teflon and Kel-F are suitable for cryogenic temperature service, but not for elevated temperatures. They lack the resistance to deformation characteristic of rubber.

Vacuum systems require carefully designed O-ring type seals using butyl, neoprene, Viton, or other suitable elastomer. O-ring grooves and flange faces should be precision machined to produce best results. Permeability, outgassing, and temperature resistance of the O-ring material must be carefully evaluated.

Insulation

Many types of blanket or batt, loose fill, board or reflective insulations have been used singly or in combination. Factors influencing selection are thermal conductivity, specific heat, density, permeability, cost, moisture effects, vibration resistance, ease of handling, temperature suitability and strength. The factor *thermal diffusivity*, a function of conductivity, density, and specific heat, is quite important when rapid temperature changes are anticipated. Low values combined with low thermal mass will permit more rapid temperature changes for the same system capacity. Many insulations used for commercial or industrial applications are suitable for ultra-low temperatures if they are vapor sealed.

Glass fiber is in common use due to low cost, relatively low conductivity, and low thermal diffusivity. It must be provided with a vapor seal. Its useful range extends up to 1000 F when no binder is present. Mineral wool blankets are not so frequently used because of their high density and slightly higher conductivity. Silica aerogel is suitable from below −300 F up to 1200 F. It has a thermal conductivity below 0.15. It settles severely which may require later addition of material. It is permanently damaged by moisture, hence tight vapor sealing is required.

Foamed polyurethanes have thermal conductivity factors of about 0.14 and 0.22 depending upon the foaming agent and density. Refrigerant 11 gives the lower value and CO_2 the higher one. Densities from less than 1.0 to about 5 lb per cu ft are possible. Lowest conductivities occur in the 2 to 3 lb per cu ft density range. The material is frequently foamed in place.

Expanded polystyrene is a similar material with a conductivity factor of 0.23 to 0.27 and a density of 2 lb per cu ft. Its upper operating temperature is 160 to 170 F, whereas the urethanes are suitable up to 240 to 250 F. Expanded rubber has characteristics similar to the styrenes, except for higher density and greater compressive strength.

Reflective insulation, in the form of coated steel, aluminum, or sometimes stainless steel foil has been used, particularly in large chambers.

For temperatures above 500 to 600 F, the combination of several materials may be best. High density, fine fiber, batt type materials show (1) lower conductivity than low density materials in the higher ranges, (2) resistance temperature shock, and (3) have a lower thermal mass than block type. This type of material can be combined with more standard glass fiber batts (or equal) toward the exterior. Since the temperature differences are high, reflective foils in combination should also be considered.

The optimum insulation thickness will generally follow the economic and surface condensation practices followed for larger structures. However in enclosures smaller than a walk-in size, the thickness is frequently less. For instance, a 1 cu ft chamber for −100 F may have as little as 4 in. of glass fiber insulation.

The insulation thickness may be based somewhat upon the effect of the sleeves which must be provided for the refrigerant lines, wiring, temperature leads and test accessories. These sleeves are attached by some vapor tight means to the shell and liner. For non-altitude chambers, tubes of micarta or similar phenolic materials may be held in place

by vapor sealed bushings on each side of the wall. Thin stainless steel tubes, welded at the ends to the shell and liner are frequently used, and will stand more abuse. Sleeves for altitude chambers should be of stainless steel pipe or tube, welded to liner and shell, with capped ends. The effect of sleeves or other through-conductances is surprisingly large. Transfer should be carefully calculated, particularly when walls are thin.

Doors

Both overlap and plug-type doors are used, the latter most frequently on high-humidity chambers because of internal condensation, or on high temperature chambers to prevent or minimize warpage. They must be rugged and well fitted particularly for altitude chambers. Vapor sealing with multiple gaskets is important since defrosting means are infrequently provided, particularly on smaller chambers. Suitable gasket materials are natural or synthetic rubber or silicone materials. Plastics or light gage stainless steel are recommended for the thermal breaker strip; pressed wood hardboard type materials generally have insufficient resistance to physical damage, high temperatures or high humidities. Low wattage heater cables installed under the breaker strip prevent larger doors from freezing closed. Safety measures required for commercial walk-in freezers are a *must* for low temperature rooms, with doors easily opened from inside.

For altitude chambers, the door assembly must register against a gasket which will easily seal for the vacuum. Patented gaskets used have a thin lip for initiating the seal and a main rectangular section. Vacuum gaskets must be properly retained to prevent their being drawn into the chamber. Hardware for altitude chamber doors must allow for double articulation so the door and vacuum gasket will mate perfectly, and so the door may move as the vacuum pulls the door inward on the gasket.

Windows

For temperatures from −300 to +600 F, special hermetically sealed multilight window assemblies are manufactured. They are suitable for wide range humidity tests and, if provided with an inner pane of sufficient strength, for altitude tests as well. Tempered plate is required for the inner panes in order that temperature shocks will not cause failure. Due to the pressures that will build up, sealed assemblies for higher temperatures require careful design. For temperatures up to 1000 F, windows of vicor glass are required and hermetic sealing is difficult, but work along these lines indicates a possible range from −300 to +1000 F. The number of panes and design for a given duty are usually specified by the window manufacturer. A typical −100 F to +300 F window contains 6 lights of glass enclosing dry gas spaces.

Accessories

The following comments apply to miscellaneous accessories used with test chambers.

Interior lighting will nearly always be incandescent, in vapor tight and sometimes explosion-proof fixtures. Ample illumination will usually be given by 6 to 10 watts per sq ft of floor space. Lighting is sometimes placed outside a window to reduce internal heat load. Lamps are not recommended for use inside chambers above 600 F.

Power leads may handle normal alternating current or special aircraft voltages and frequencies.

Thermocouples in almost any number may be called for. Bare iron-constantan preferably should *not* be used in a high-humidity chamber. For the operator's convenience, thermocouples are frequently connected to plugs and outlets.

Tuning shafts, if small manually-operated, may be coupled to adjustable devices on the item being tested. These shafts should be stainless steel tubes. O-rings on the outside of the chamber may be used for pressure sealing.

Power shafts provided for driving rotating equipment, must have vacuum-tight shaft seals for vacuum chambers.

Sleeves and plugs are required for general purpose testing. Holes of various sizes may be specified. On altitude chambers, threaded or flanged caps must be provided.

Special lines for pneumatically or hydraulically operated equipment may require pressure pipes with special connections at the ends.

Protective panels are used to prevent the possibility of damage to the chamber if an internal explosion or sudden release of pressure occurs.

Reach-in ports, with or without gauntlets, may be used for minor work within a test space without opening of doors or disturbing internal conditions.

MECHANICAL REFRIGERATION SYSTEMS

Most test chambers are equipped to produce temperatures lower than −20 F, hence multistage cascade and compound-compression mechanical systems are employed. With proper refrigerant selection for each circuit, cascade systems require less horsepower and less displacement per ton at evaporating refrigerant temperatures below about −60 F. They are essentially two or more single-stage systems linked together by a cascade condenser or interstage heat exchanger. Compound systems were used for all test chambers up to about 1950. They now are primarily used for large field assembled systems or for requirements of −60 F evaporating refrigerant temperature and above.

Figs. 1 and 2 are schematic piping diagrams for cascade and compound systems. Fig. 3 shows approximate relative capacities for systems of the same horsepower. The cost of a cascade system for evaporating refrigerant temperatures below about −80 F is frequently more per horsepower, but less per ton in small and moderate sized systems. Cascade systems are generally smaller in size because of the lower compressor displacements required.

Reciprocating compressors are generally used for the high stage of both compound and cascade systems, and for the low stage of cascade and smaller compound systems. Rotary compressors find widespread use in the lower stages of large compound systems. Centrifugal compressors are most economically employed on quite large compound systems using Refrigerants 12 or 22, and have recently found use in large cascade systems.

Standard compressors are suitable for cascade systems and

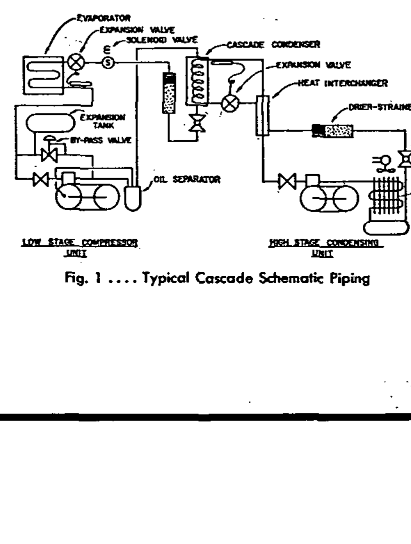

Fig. 1 .... Typical Cascade Schematic Piping