

Table 2 Minimum Design Working Pressures for Evaporators

Refrigerant Number	Design Working Pressure—psig
11	30
12	140
22	150
114	50
717	150

pressures are specified and design working pressures are implied by this code.

Table 2 gives the minimum design working pressures generally used by manufacturers for evaporators considered to be pressure vessels.

The pressure relief device must be set to relieve the pressure at not more than the design working pressure. Unfired pressure vessels are usually tested hydraulically at 150 percent of the design pressure and subsequently by air or gas pressure at 125 percent of design pressure.

4. *ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels, Section VIII.* This is the basic code which covers the method of calculation for strength, allowable stresses for materials used, factory tests, inspection, and application of the ASME symbol to the approved vessel.

Most states have adopted the ASME code and, consequently, no pressure vessel may be installed in those states without the ASME stamp of approval. Insurance companies usually will not insure a refrigerant-containing vessel unless it has the ASME approved stamp, where applicable.

5. *Underwriters' Laboratories U.L.-597C Standard for Refrigerant Containing Components.* This standard applies more particularly to commercial size equipment and has been adopted by a majority of states and municipalities as a means of protecting the safety and health of the consumer. It involves specific design criteria, use of materials, testing and initial approval by Underwriters' Laboratories.

Chemical Requirements

Materials for Use with Refrigerant 717 (Ammonia). The most widely used materials in connection with ammonia are carbon steel and cast iron. Stainless steel, monel, cupro-nickel and similar alloys are satisfactory but more costly. Since copper and high-copper alloys are attacked by ammonia when moisture is present, their use is avoided. Aluminum and aluminum alloys may be used with caution with ammonia.

Materials for Use with Halocarbon Refrigerants. These refrigerants are used satisfactorily with all the common metals and alloys. Under certain conditions with moisture present they form acids which attack steel and even the non-ferrous metals. In properly cleaned and dehydrated systems this does not commonly occur.

Materials for Use with Water. Relatively pure water is satisfactory with both ferrous and non-ferrous metals. Brackish or sea water and some river waters are quite corrosive in contact with iron and steel and also with copper, aluminum, and many of the alloys of these metals. Proper analysis of the water will indicate the proper materials to be used.

Materials for Use with Brines. Sodium and calcium brines are almost universally used with ferrous metals and with a few non-ferrous alloys. They will attack copper and many of the copper-bearing alloys quite readily. Calcium brine is the more corrosive of the two. It is advisable, even with ferrous metals, to treat these brines periodically to hold the pH value near the neutral point.

Ethylene glycol and propylene glycol are stable compounds and are less corrosive than brine.

Performance Requirements

Continuous or Steady-state Cooling. Where water or brines are used to remove heat, as in product cooling or as in air

conditioning, the water or brine cooling temperature range (difference between entering and leaving liquid temperatures) can be established from practical considerations.

Except in tank-and-agitator systems, the cooling ranges used commonly vary from 5 to 15 F deg. The water or brine circulation rate through the cooler will be:

$$\text{gpm per tr} = \frac{24}{\Delta t(\text{sp gr})(c)} \quad (1)$$

where

gpm per tr = flow rate of fluid, gpm per ton of refrigeration.

Δt = cooling range, Fahrenheit degrees.

sp gr = specific gravity of fluid as compared to water.

c = specific heat of fluid as compared to water.

The water or brine pump size and the power requirements for its operation will depend upon both the circulation rate and the total pressure drop.

Specifications for selection or design of water or brine coolers should include:

1. Description of fluid cooled, if other than water.
2. Entering water or brine temperature.
3. Leaving water or brine temperature.
4. Circulation rate (gpm).
5. Permissible water or brine pressure drop.
6. Refrigerant used.
7. Saturated suction temperature of refrigerant corresponding to leaving refrigerant pressure.

Batch Type Cooling. When stored products, or cooling fluids, are cooled from some initial temperature to some final temperature over a period of time, the selection or design of a liquid cooler for that application is complicated by the varying load conditions imposed upon that cooler.

Since the time required to cool a batch over a certain temperature range is inversely proportioned to the cooling capacity of the refrigeration system used, system capacities at various temperatures of liquid on should not be averaged. Instead the time required will be proportional to the average of the reciprocals of the cooling capacities at the various liquid on temperatures.

For example, assume that water in a storage tank is to be cooled from 80 F to 50 F. The calculated load is 100 ton-hours (1,200,000 Btu) and the system capacities with various water on temperatures are to be:

Water On	System Capacity—Tons	Reciprocal
80 F	100	0.0100
70 F	80	0.0125
60 F	60	0.0167
50 F	40	0.0250

Sum of Reciprocals = 0.0642

$$\text{Average capacity} = \frac{4}{0.0642} = 62.2 \text{ tr}$$

$$\text{Approximate required cooling time} = \frac{100}{62.2} = 1.61 \text{ Hrs.}$$

A closer approximation would be to apply the trapezoidal rule to the reciprocals of the four tonnage values, or Simpson's Rule to three reciprocals.

FLUID FRICTION

The flow of fluids is discussed in Chapter 6. Equation 31 of Chapter 6 is the basic equation for calculating the pressure drop of fluids flowing inside conduits. The friction factor f and Reynolds number relationship are shown in Fig. 5 of Chapter 6.

Allowance should be made for pressure drop through water

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boxes, inlet and outlet fittings, and return bends. Friction losses in cast water heads commonly are estimated as equivalent to the loss in a tube length equivalent to 80 to 100 tube diameters for each inlet and outlet and each change in direction of flow plus inlet and outlet.

The method used in predicting fluid pressure drop through conduits of constant cross-sectional area can not be used in transverse baffled heat exchangers because the Reynolds number is constantly changing. Some success has been reported in solving this type of problem by the velocity head method but much work remains to be done before a procedure will be established that will successfully account for changes in tube outside diameter, tube pitch, tube layout, tube bundle bypass, baffle leakage, and the baffle window shape or area.¹⁻⁴

Refrigerant Pressure Drop

The pressure drop that can be tolerated in an evaporator depends upon the refrigerant used and its thermodynamic properties, the evaporator temperature, and what portion of the logarithmic mean temperature difference (LMTD) is adversely affected by the change in saturation temperature due to pressure drop within the evaporator.

Table 3 lists four of the commonly used refrigerants and their change in saturation temperature, per psi change in pressure at various ranges of evaporator temperature.

Table 3 shows that a Refrigerant 22 evaporator can operate at a higher refrigerant pressure drop than a Refrigerant 12 unit for the same F deg penalty in saturation temperature but a Refrigerant 22 evaporator operating at -30 F cannot tolerate the same pressure drop as it can at 40 F.

Refrigerant pressure drop for Refrigerant 12 and 22 evaporators, when cooling water, are usually held to a range of 2 to 6 psi and 3 to 9 psi respectively. Brine coolers employing Refrigerants 12 and 22 at typical conditions operate at 1½ to 4 psi and 2 to 6 psi respectively.

The mathematical prediction of refrigerant pressure drop in evaporators is difficult due to the change of state as in boiling. Experience has shown that if the refrigerant pressure drop is established on a given evaporator operating at a given weight rate of refrigerant and at given exit refrigerant conditions, then the pressure drop will vary almost directly as the specific volume of the exit gas for other evaporator temperatures on the same evaporator (providing the condensing temperature and temperature of the liquid refrigerant to the evaporator are held reasonably constant).

The volume of flash gas released by the expansion device in direct expansion evaporators has a decided effect on the refrigerant pressure drop. Liquid subcooling, for instance, will lower the refrigerant pressure drop by decreasing the amount of flash gas.

HEAT TRANSFER

Heat flows from one medium to another by virtue of temperature difference. The rate at which heat is transferred is a function of the temperature difference and the ability of the

Table 3 Variation in Saturation Temperature for 1 psi Change in Saturation Pressure

Evaporator Temp., F	Refrigerant			
	11	12	22	717
30 to 40 F	6.78	1.18	0.72	0.74
0 to 10 F	12.57	1.82	1.13	1.24
-30 to -40 F	—	3.71	2.27	2.88

fluids to give up or receive heat. Other parameters which must be considered are: (a) the effect of the refrigerant pressure drop upon the overall terminal temperature differences; (b) refrigerant distribution; (c) thickness of the tube wall and fins, if such are present, and the thermal conductivity of the material of which the tube and fins are made; (d) fouling deposits from the fluid being cooled; and (e) fouling deposits from the cooling medium. Except where wax deposits from oils develop, item e is negligible.

In general, the heat transfer rate is given by:

$$q = U_o A_o \Delta T_m \quad (2)$$

where

q = heat transfer rate, Btu per hour.

U_o = overall heat transfer coefficient based on outside surface, Btu per (hour) (square foot) (Fahrenheit degree).

A_o = outside surface area, square feet

ΔT_m = logarithmic mean temperature difference, Fahrenheit degrees.

The overall heat transfer coefficient is given by:

For water or brine inside of tubes

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{z}{k} + \left(\frac{1}{h_o}\right) S_z + \left(\frac{1}{h_{fw}}\right) S_z \quad (3)$$

For refrigerant inside of tubes

$$\frac{1}{U_i} = \left(\frac{1}{h_o}\right) S_z + \frac{z}{k} + \frac{1}{h_i} + \frac{1}{h_{fw}} \quad (3a)$$

where

h_i = heat transfer film coefficient for refrigerant, Btu per (hour) (square foot) (Fahrenheit degree).

z = thickness of tube wall, feet.

k = thermal conductivity of tube material, Btu per (hour) (square foot) (Fahrenheit degree per foot).

S_z = ratio of total outside surface to inside tube surface.

h_{fw} = heat transfer film coefficient for water or brine side.

$\frac{1}{h_{fw}}$ = fouling resistance on water or brine side.

The two film coefficients, h_i for the refrigerant, and h_{fw} for the water or brine, largely determine the overall heat transfer coefficient U_i . The resistance to heat flow through the tube wall (and fins, if any) z/k , and the water side fouling resistance $(1/h_{fw})S_z$ (referred to the refrigerant side) are usually small as compared to the film resistances, $1/h_i$ of the refrigerant, and $(1/h_{fw})S_z$ of the water or brine (referred to the refrigerant side).

Refrigerant Film Coefficient

Factors affecting boiling film coefficients include:

1. Physical properties of the refrigerant.
2. Nature of the surface including its roughness.
3. The rapidity with which the vaporized refrigerant is removed from the surfaces, i.e. how well can the surfaces be kept wetted?

Boiling film coefficients in evaporators where the refrigerant surrounds plain or finned tubes are influenced by:

1. Tube size (coefficient increases with a decrease in tube diameter).
2. Tube spacing, arrangement, height of tube bundle.
3. Tube roughness, fin arrangement.
4. Presence of oil.
5. Refrigerant distribution (distributing conduits, sprays, etc.).
6. Presence of noncondensables.
7. Evaporator temperature.
8. Method of expansion (valves, injectors, pumps, etc.).
9. Dryness of leaving vapor.