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Practical Guide
Low Temperature Refrigeration

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To start, let's define what we mean by low temperature refrigeration. The term low temperature refers to the cooler side of a general temperature range. In air conditioning, chilled water or glycol at 32°F (0°C) would be considered low. In industrial refrigeration, blast freezing at -50°F to -60°F (-45°C to -50°C) is considered low. In the realm of cryogenics, temperatures approaching -460°F or 0°R (-273°C or 0 k) are suitably designated low. But none of these belong in the category discussed in this article.

Low temperature refrigeration is the range of temperatures falling below what is normally considered industrial refrigeration and above the temperatures associated with field of cryogenics. The temperature range of this classification is from -58°F to -148°F (-50°C to -100°C). This range of temperatures includes applications for food, pharmaceutical, and chemical processing. It is generally used in the petroleum and chemical industries as laboratory environmental chambers and thermal storage equipment.

The size and type of equipment used varies from small pre-packed low temperature environmental chambers of only a few horsepower (kW) to large custom-designed and often field-erected systems ranging to several hundred horsepower (kW). These larger units are by nature one-of-a-kind, designed and built for a specific purpose, for a specific duty at a precisely controlled low temperature condition. The large units use a combination of one, two or more refrigerants in open cascade arrangements to obtain the desired low temperature.

Manufacturers of the small packaged environmental chambers typically use an autocascade cycle. They maintain proprietary control over the processes and the specific refrigerants used in their systems. The compressors are generally stock hermetic compressors available from the commercial refrigeration trade. The refrigerant mixtures, however, are proprietary as are the combinations and balancing of the heat exchangers required to obtain the final low temperature in an efficient manner.

Custom-designed equipment, both environmental chambers and field-erected systems, begins where the auto cascade systems tend to reach their maximum - around 10 hp (7.5 kW). Autocascade systems are not suitable for liquid cooling, so when there is need for a low temperature secondary cooling fluid (brine), the equipment must be custom-designed.

The engineering, design and field erection of the custom-designed equipment is generally done by people from the industrial refrigeration marked area. However, the need for custom-designed equipment in the low temperature range is infrequent, so experience and expertise within organizations that accept work in this area tends to accumulate slowly.

This article brings together current information and experience available on the systems, designs, refrigerants, secondary coolants, practical recommendations, and cautions pertaining to low temperature systems. This information will be useful to suppliers, purchasers, designers and end-users of low temperature refrigeration systems.

System Types

Several types of systems are used to achieve low temperatures, depending on the actual temperature desired and the specific compressors used. And the specific compressors used. The large loft or pressure difference from the evaporating temperature is one the condensing temperature is one of the biggest engineering problems for these low temperature systems.

Single-stage economized screw compressor system.

This is the simplest low temperature system. It is useful down to about - 60°F (-50°C). A single-stage system using a reciprocating compressor would have excessive discharge temperatures. A screw compressor can attain low temperatures in single-stage compression because the discharge temperature is controlled by the amount and temperature of the oil flooding the compressor. The screw compressor also has a relatively flat volumetric efficiency curve, permitting a volumetric efficiency of 80% or more at a 20:1 compression ratio.

Figure 1 Shows the relationship of volumetric efficiency (VE) and compression ratio for both screw and reciprocating compressors. The chart shows that reciprocating compressors perform poorly beyond a ratio of 10:1. They would also operate at excessive discharge and oil temperatures.

A screw compressor with an economizer subcools the liquid refrigerant. This subcooling significantly increases compressor capacity. It also improves the overall operating efficiency and comes close to that of a two-stage system.

Two-stage single refrigerant system.

The two-stage single refrigerant system can use either screw or reciprocating compressors. To determine the overall compression ratio of a two-stage system, multiply the compression ratios of each stage. The compression ratio of each stages will be in a range suitable for reciprocating compressors, and their discharge temperatures will be moderate. The minimum horsepower requirement for a two-stage system operating at a given set of conditions occurs when the compression ratios of each stage are about the same.

Two-stage systems include interstage cooling that desuperheats the discharge gas leaving the low-stage (booster) compressor. Inter-stage cooling also cools the liquid refrigerant to a temperature near the interstage temperature. Cooling the liquid refrigerant increases system capacity.

The temperature limits for a two-stage system depend on the specific refrigerants chosen. Some of those limits include:

Refrigerant	Minimum low temperature
HCFC-22	-90°F/-70°C
R-507	-90°F/-70°C
R-717	-60°F/-50°C

Two-circuit cascade system.

The two-circuit cascade system is the most common and is suitable for the entire low temperature refrigeration range. It has two separate refrigerant circuits - a high temperature circuit and a low temperature circuit. They are coupled thermally at the condenser of the low temperature circuit. The evaporator of the high temperature circuit is the condenser for the low temperature circuit. The high temperature circuit uses a standard refrigerant like that found in a single-stage system.

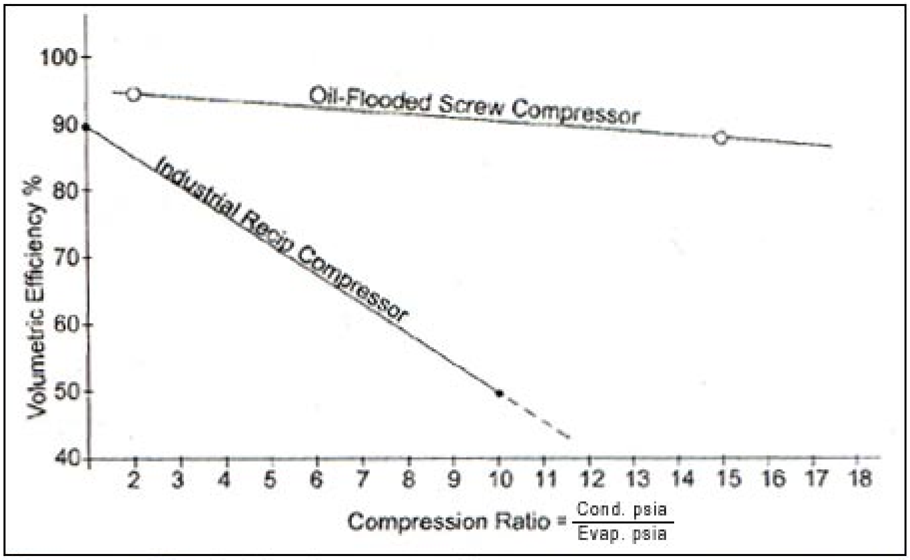

Figure 1: Typical volumetric efficiency vs. compression ratio for industrial opendrive refrigeration compressors.

The low temperature circuit contains a refrigerant suitable to obtain the desired low temperature.

Standard refrigerants cannot operate at very low temperatures because their saturation pressure at the low temperature is too low. If the saturation pressure is less than about 21 in. Hg vac/4 psia (28 kPa), very little refrigerant vapor is drawn into the compressor. Vapor density is also extremely low at these pressures, so the mass low of refrigerant through the system is very low.

Refrigerant used for the low temperature circuit of cascade systems generally have a saturation pressure at the low temperature condition above atmospheric pressure to help keep air from being drawn into the system. The higher pressure cascade refrigerant, because of its density, will require a much smaller compressor to provide the needed system capacity then if a standard refrigerant were used.

Three-circuit cascade system:

To obtain temperatures around - 150°F (-100°C), the standard high temperature circuit plus two cascade circuits may be required. The evaporator for the higher temperature cascade refrigerant would be the condenser for the lower temperature cascade refrigerant. The system then has an additional step of temperature reduction to obtain the final desired low temperature. Very few of these systems exist.

Autocascade systems.

Low temperature conditions similar to those obtained with large custom-designed and field-erected cascade systems may be achieved by an autocascade system. Autocascade systems are complete, self-contained systems in which multiple stages of cascade cooling occur simultaneously. This is accomplished by means of several steps of vapor/liquid separation and adiabatic expansion of the different refrigerants contained in the refrigerant change. The low temperature may be achieved with a single-stage compressor in conjunction with the appropriate mixture of two or more refrigerants and a series of counter-flow heat exchangers.

Autocascade systems are typically much smaller than custom-designed equipment, and they use standard hermetic compressors ranging up to above 10 hp (7.5 kW). These systems have a surprisingly low compression ratio and a high volumetric efficiency. Heat exchanger design and system chemistry are complex. The compressor displacement is large for the unit's low temperature capacity. The refrigerant compositions and the sensitive component arrangements are proprietary.

The components of an autocascade refrigeration system basically include a compressor, a condenser (water-or air cooled), a mixture of refrigerants with varying boiling points, and a series of heat exchangers. **Figure 2** shows a schematic diagram of a simple single-stage autocascade system using a two-refrigerant mixture.

In this case, the high boiling point refrigerant is liquefied in the condenser (3) but the lower boiling point refrigerant remains as a vapor. These are separated in vessel (5). The lower boiling point refrigerant vapor proceeds to the cascade condenser (7). In the cascade condenser, the high boiling point refrigerant passes through the expansion device (9) and flashes to a vapor. The heat to vaporize the high temperature refrigerant liquid condenses the low boiling point refrigerant vapor. The low boiling point liquid refrigerant proceeds through a second expansion device (10) and into the low temperature evaporator (11) where it costs the air blown across the coil to obtain the desired low temperature. Both refrigerants return to the compressor via the suction lines.(12)

This simple system leads one to he idea that lower temperatures can be achieved efficiently if there were more refrigerants in the mixture and the cascade process repeated several times prior to reaching the low temperature evaporator. Figure 3 shows a single-stage compressor using a refrigerant mixture composed of four refrigerants with descending boiling points to provide four cascade stages in a more complex autocascade system.

The condensation and subsequent expansion of one refrigerant provides the cooling required to condense the next lower temperature refrigerant in the heat exchanger downstream. The process continues until the lowest temperature refrigerant is liquefied. This refrigerant boils in the low temperature evaporator providing the desired cooling effect.

The most common use for autocascade systems is low temperature environmental chambers. The chambers with their autocascade systems are provided as complete packaged units. The component selection and refrigerant mixtures are proprietary, so little can be said here about specific designs. Equipment manufacturers and suppliers of these systems can provide details on their design.

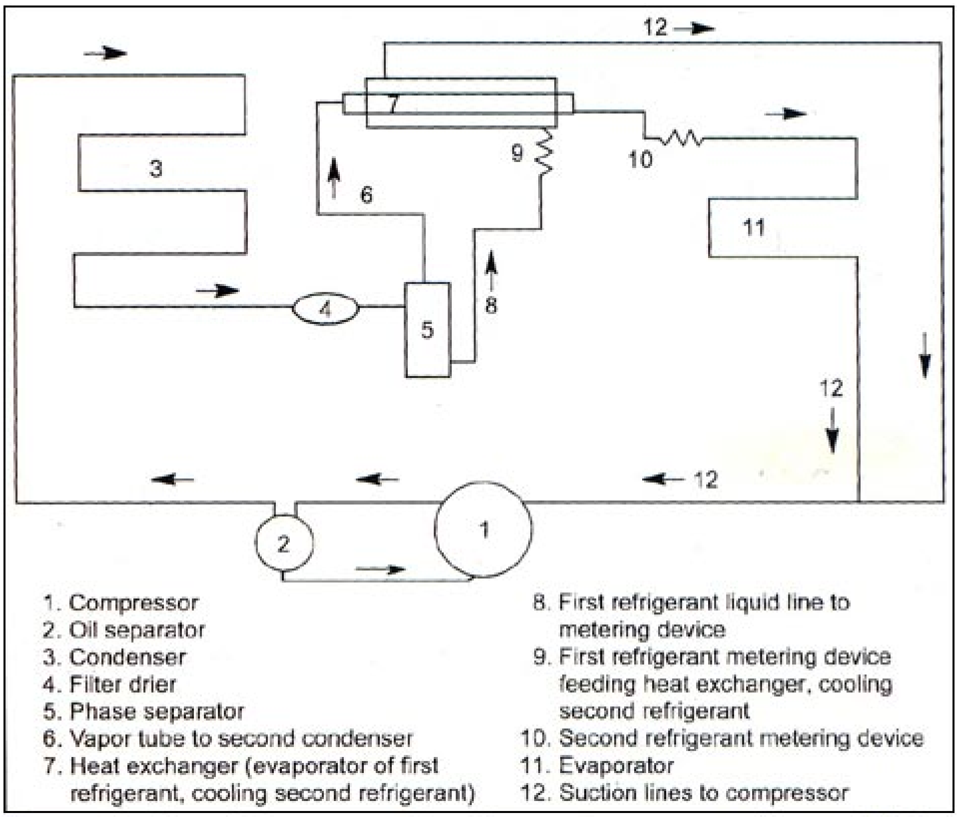

Figure 2: Simple autocascade refrigeration system (from 1998 ASHRAE Handbook – Refrigeration, Chap. 39).

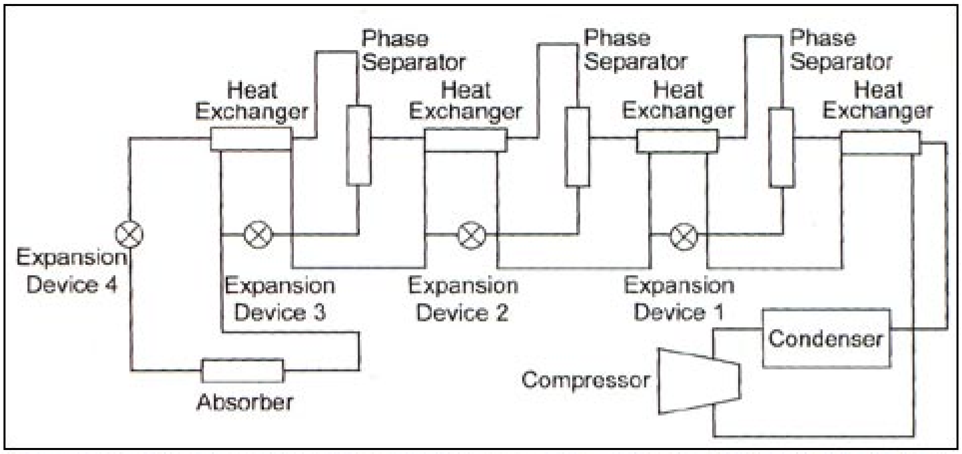

Figure 3: Four-stage autocascade system (from 1998 ASHRAE Handbook – Refrigeration, Chap. 39).

System Selection

Many factors need to be considered in selecting the type of system and its components for low temperature applications:

1. *The temperature required for the project. Temperature requirements will influence the refrigerant selections, materials of construction, insulation, compressor selections, heat exchangers, and vessels. These factors are discussed individually later.*
2. *The fluid to be cooled. In general, air is the medium in direct contact with the cooling coil. However, secondary liquid coolants are sometimes used to achieve the desired temperature.*
3. *Pull-down and operating conditions such as whether the duty is for batch cooling or a continuous operation:*

Table 1: Refrigerants for single-stage and two-stage systems and the high side of he cascade system.

Refrigerant	Saturated Temperature	Saturated Pressure
HFC-134a	-55°F/-48°C	4.7 psia/32 kPa
HCFC-22	-80°F/-62°C	4.8 psia/33 kPa
R-507 (50/50 HFC-125/143a)	-90°F/68°C	4.8 psia/33 kPa
R-717 (ammonia)	-65°F/-54°C	4.7 psia/32 kPa

Table 2: Low temperature cascade refrigerants.

Refrigerant	Saturated Temperature	Saturated Pressure
HFC-23	-60°F/-51°C -140°F/-96°C	66.7 psia/460 kPa 6.3 psia/43 kPa
R-508h	-60°F/-51°C -140°F/-96°C	82.5 psia/569 kPa 9.3 psia/64 kPa

Refrigerants

The refrigerants for single-stage systems, two-stage systems, and the high side of the cascade system are those commonly used in the industrial refrigeration field. **Table1** indicates the refrigerants and their saturated conditions at their minimum temperatures.

There are fewer low temperature cascade refrigerants to choose from now that CFCs are no longer commercially available. Two refrigerants, both HFCs, are currently in use. These are shown in **Table 2**.

R-508b is an azeotrope of 46% HFC-23 and 54% HFC-11. The pressure/temperature relationships are quite similar to those of HFC-23, but the capacity and efficiency are much better than HFC-23. The discharge temperature of R-508b is much lower than that of HFC-23. R-508b is the preferred refrigerant for low temperature applications at this time.

Some hydrocarbon refrigerants have good low temperature characteristics, but they are all flammable. As such, they are not normally used in industrial situations. Refineries, however, require low temperature refrigeration. They are typically prepared to handle flammable gases in their processes and may request the use of a specific hydrocarbon gas for their systems. When flammable refrigerants are used, electrical components must be rated for hazardous (classified) environments.

Choosing the refrigerants for a low temperature system requires a study to determine the optimum balance for efficiency and coverage of the full range of specified temperatures. The study will include choosing the interstage temperature and the cascade condensing temperature. Varying theses conditions affects both compressor size and operating horsepower. Perhaps the best place to begin this analysis is to determine the refrigerant pressures where the compression ratios for each stage to determine the refrigerant pressures where the compression ratios for each stage are approximately equal. This arrangement usually results in the lowest power input, although interstage cooling affects horse-power and capacity. These days, with computerized compressor rating data readily available, it is relatively easy to make several selections to find an economical balance that satisfies the load with a good match of available compressors.

The cascade refrigerants HFC-23 and R-508b have saturated pressures in the range of 600 psig (400 kPa) when the liquid refrigerant is warmed to room temperature. This condition would require that all components in the low temperature circuit be suitable for this high pressure. This is economically impractical

To permit the use of these refrigerants, realizing that the system from time to time will be warmed to room temperature, a fade-out vessel is installed on the cascade circuit. A fade-out vessel is simple an empty pressure vessel that is open to the cascade refrigerant. When the system is shut down and the temperature rises, the combined volume of the fade-out vessel and the remainder of the system is large enough for all of the liquid refrigerant to expand to a vapor without exceeding a reasonable limiting pressure.

For example, the total volume of the fade-out vessel and the cascade system can be sized so that at a 120°F (49°C) equalization temperature, the cascade refrigerant has enough room to expand to a vapor at a pressure no higher than 200 psig (1400 kPa). Any other suitable equalization temperature and pressure limit could be selected. The equalization temperature should be the highest temperature the refrigerant is likely to reach during the shut down. The design pressure is a balance between vessel size and design pressure. The lower the design pressure, the larger the required vessel.

Calculating the required volume (Vc) requires knowing the total refrigerant charge (R) and the specific volume of the expanded refrigerant vapor (Vr) at the desired equalization temperature. Since the entire refrigerant charge will be a vapor, it will be superheated. Figure 4 is a P-H diagram for R-508b and can be used to illustrate this calculation for a system with 250lbs (113 kg) of refrigerant and a design limiting pressure of 200 psia (1380 kPa). At the normal operating temperature of -140°F (-96°C) evaporating and -37°F (-38°C) condensing, the pressures are 10 psia (70 kPa) in the evaporator and 130 psia (896 kPa) in the condenser. If liquid and vapor were allowed to coexist in a closed vessel, the temperature could not exceed - 12°F (-24°C) before the pressure would reach the design limit of 200 psia (1380 kPa) Providing additional volume in a fade out vessel for the vapor to expand until all the liquid has evaporated allows the pressure to remain below the design limit of 200 psia (1389 kPa):

Vc = R x Vr

Vc = 250 lbs x 0.30 ft^3/Lb (from **Figure 4**)

Vc = 75 ft^3

Compressors

The compressors for low temperature systems are either reciprocating or oil-flooded screw compressors. They may be hermetic or semi-hermetic compressors that will operate with HFC refrigerants. The smaller sizes may be obtained from commercial refrigeration sources. Larger systems will use compressors obtained from industrial refrigerant sources. These will use compressors and may be either reciprocating or oil-flooded screws. The industrial compressors may be used with ammonia (R-717), HFCs, and hydrocarbon refrigerants.

The high temperature circuit is typically a standard industrial refrigeration system whether single or two-stage. It is desirable to take advantage of liquid subcooling or interstages liquid cooling to obtain efficiency and minimum compressor sizing.

The compressors and their components must be compatible with the chosen refrigerant. In the case of the low temperature cascade compressor, it is a good idea contact the compressor manufacturer directly to obtain rating information for the complete duty expected. Since there is little call for this information, the date might be an estimate and not based on actual tests. Therefore, designers should be conservative when selecting the cascade compressor, so there will be sufficient capacity when the system is in service.

Reciprocating compressors have limits of operation based on maximum oil and discharge temperatures. Their capacity and volumetric efficiency go down as their compression ratio increases. Be aware of these factors and operate the compressor within the manufacturer's specifications.

Screw compressors have fewer limits of operation because they are oil flooded. Discharge temperatures can be controlled with amount of oil fed to the compressor. The oil feed to a screw compressor means the unit must have adequate oil separation equipment to prevent oil carryover.

The compressor manufacturer might recommended a minimum temperature of -50°F (-45°C) for suction gas returning to the compressor. If necessary, a suction line heat exchanger can be included to use heat from the liquid line to superheat the suction gas to the desired minimum temperature. As an added benefit, a liquid/suction heat exchanger increases capacity by subcooling the liquid refrigerant. If the suction line heat exchanger does not raise the suction temperature enough, a small amount of hot discharge vapor may be introduced into the suction to achieve the -50°F (-45°C) minimum suction gas temperature.

If superheat is added to the suction vapor, calculate the actual volume of gas flow required at the superheated temperature and select the compressor for that volume flow. Do not use the simple tonnage rating typically presented in the rating data.

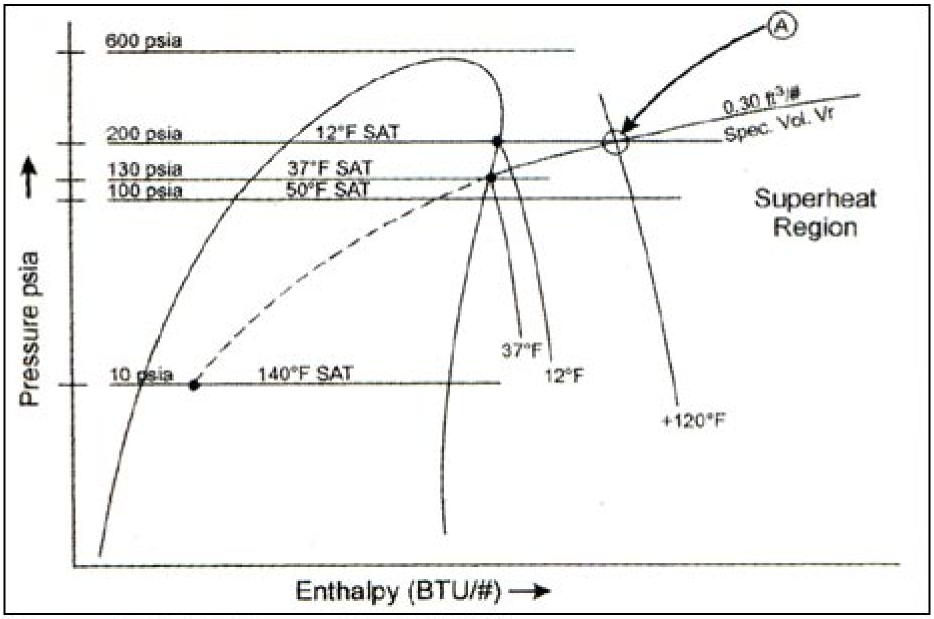

Figure 4: P-H diagram for R-508b

Evaporators, condensers, and miscellaneous system vessels.

Some evaporators, condensers and miscellaneous system vessels may be selected from standard available equipment. However, the low temperature items may have to be designed specifically for the system.

Oil management

Compressor lubricants should be those recommended by the compressor manufacturer. They should also be compatible with the refrigerants and have a sufficiently low pour point to permit recovery from the low side of low pour point to permit recovery from the low side of the system at all expected temperature levels. HFC refrigerants will generally use a polyester synthetic lubricant. For ammonia refrigerants, a hydrotreated paraffinic oil is recommended.

All compressors should have coalescing oil separators sufficient to limit oil carryover to no more than 5 ppm so oil will not concentrate in the evaporators. Oil in the evaporator prevents proper heat transfer and impedes oil recovery.

Most oil recovery is accomplished directly by the refrigerant flow through the evaporator coil and suction line. The refrigerant tends to sweep the oil along. In flooded ammonia systems, oil is recovered through the use of oil pots that are located below the refrigerant level. The heavier oil drains into the oil pots and may be recovered either manually or automatically.

Table 3: Temperature range of construction materials for low temperature systems.

Carbon Steel Seamless Pipe	Minimum Temperature
SA-333 GRI, GR6	-50°F (-45°C)
SA-333 GR7	-100°F (-75°C)
SA-333 GR3	-150°F (-100°C)
Stainless Steel Seamless Pipe	**Minimum Temperature**
ASTM 312 Type 304	-150°F (-100°C)
ASTMA 376 Type 304	-150°F (-100°C)

Table 4: Property variation with temperature decrease.

Property	Change As Temperature Drops
Density of Liquid	Increases
Specific Volume of Vapor	Increases
Enthalpy of Evaporation	Increases
Specific Heat of Liquid	Decreases
Specific Heat of Vapor	Decreases
Viscosity of Vapor	Increases
Viscosity of Vapor	Decreases
Thermal Conductivity of Liquid	Increases

Materials considerations.

The materials chosen for use in construction of the system must be based on ASME Code requirements with consideration given for the low temperature. Special materials and/or treatment may be required. Plain carbon steel passes through a transition zone where it changes from ductile to brittle behavior. The transition temperature depends on several factors, including composition and geometry. As the temperature goes down, it becomes more important to verify that materials involved will retain their ductility and necessary strength. Carbon steel is suitable to -20°F (-30°C) but may be used to -50°F (-45°C) when the coincident low pressure associated with the temperature is considered. An alternative is to use a grade of carbon steel such as SA-333, which remains ductile at low temperature, or one of the stainless steels. **Table 3** indicated the temperature range of these materials.

Field-erected systems must be piped in accordance with the Refrigeration Piping Code ASME B315. This code specifies acceptable materials and other details such as pressure ratings, methods of welding, and attachments.

For larger industrial-sized systems the piping is generally of welded steel construction. Smaller, custom designed factory packaged units quite often use copper tubing when compatible with the refrigerants. Copper tubing is suitable for use at the low temperatures because copper does not lose its ductility the way carbon steel does. Joints may be made with silver solder. Investigate the properties of the filler metal to determine a grade of silver solder suitable for the temperatures involved.

When using standard compressors in the low temperature applications, the compressor manufacturer might not consider the materials of the compressor and the suction connection suitable for low temperature applications. However, most compressors and their components are made of cast iron, and the ASME B31.5 Piping Code permits the use of cast iron to -150°F (-100°C)

Heat Transfer Characteristics

The heat transfer characteristics of the high temperature circuit of the cascade system are well known since they are the same as those of the industrial refrigeration field. However, in the low temperature cascades circuit, the heat transfer characteristic is significantly different due to the lower temperatures and properties of the refrigerants which are less known. Data from laboratory tests and field observations are scarce for low temperature heat transfer coefficients. For these reasons, it is well to be cautious and conservative when selecting heat exchangers for these low temperature conditions. Chapter 4 of the 1997 ASHRAE Handbook - Fundamentals may assist the designer in obtaining reasonable information from equipment manufacturers regarding their specific ratings and quotations.

Some of these expected changes in properties, as the temperature becomes lower, are shown in **Table 4**.

Secondary Coolants

Many low temperature field-erected systems cool a secondary heat transfer fluid to cool the final product. It is often difficult to find a suitable liquid to perform as a low temperature secondary coolant. Some desirable properties and attributes of the secondary coolant are:

Properties: high specific heat, low viscosity, high liquid density, high thermal conductivity.

Attributes: non-toxic, non-flammable, environmentally stable, compatible with standard engineering materials, non-corrosive, low vapor pressure.

The viscosity and freezing point of some secondary coolants are the primary barriers to their use. Although non-flammability is a desirable attribute, moist of the secondary coolant practical for low temperature applications are flammable. Design consideration for using these fluids must include safety features to contain the flammable fluids within their heat transfer systems as well as the necessary alarm devices to be activated in the event of a leak.

Some secondary coolants for two temperature systems.

Accetone, ethanol, and methanol have reasonably low viscosities, high thermal conductivity and high specific heats in the range of 0.45 to 0.55 Btu/lb. ºF (-2.16 to 2.65 kJ/kg. K). They are flammable.

Diethylbenzene is a synthetic aromatic fluid with a freezing point slightly below -100ºF (-73ºC). This fluid is limited to use in the higher end of the flow temperature range.

d-Limonene is a terpene oil extracted from orange and lemon peels. It is economically available as a food grade fluid, but since it is a light oil, it also is flammable. It has a relatively constant low viscosity throughout the low temperature range.

D-Limonene is not recommended for use with certain plastic and rubber materials since it can be corrosive. There are reports of a gradual increase in viscosity with time which may require periodic replacement of the coolant.

Hydrofluoroether is a new fluid, available but expensive. It is non-toxic, non-flammable, and covers most of the low temperature range. Its viscosity increases dramatically with temperature decrease, and it may not be suitable at the very low temperature end of the range due to pumping costs and laminar flow in heat exchangers.

Poydimethylsiloxane, commonly known as silicon oil, is toxic is environmentally friendly and non-toxic; however it is flammable. It can be used through the entire low temperature range. However, at low temperatures, the high viscosity of the fluid results in laminar flow and poor heat transfer characteristics.

TWO CASCADE SYSTEMS

Cascade System 1 (Figures 5 and 6)

Date: 1990

Cascade temperature:
-80°F (-62°F) evap/105°F(41°C) cond.

High temperature circuit:
HTC = HCFC-22 at -35°F/105°F (37°C/41°C)
HTC = two 350 hp (167 kW) economized single-stage screw compressors.

Low temperature circuit:
LTC = HFC-23 AT 85°F/120°F (-65°C/-29°C)
LTC = one 250 hp (187 kW) single-stage screw compressors

Lubricant: HTC & LTC = alkylbenzene ISO vg 68
HFC-23 cascade condenser: HCFC-22 DX shell and tube
HFC-23 cascade evaporator:
HFC-23 flooded shell and tube
LTC secondary coolant: methylene chloride entering at -50°F (46°F)/leaving at -70°F (-57°C)

Notes:
1) The HTC single-stage economized screw compressor units
2) The HFC-23 condenser/HCF-22evaporator.
3) The HFC-23 flooded chiller.
4) TheHFC-23 chiller automatic oil recovery unit.
5) The HFC -23 suction line heat exchanger.
6) The two large HFC-23 expansion (fade-out) tanks.

Cascade System 2 (Figure 7)
Date: 1994

Cascade temperature: -80°F (-62°F) evap./75°F (24°C) cond.

High Temperature circuit:

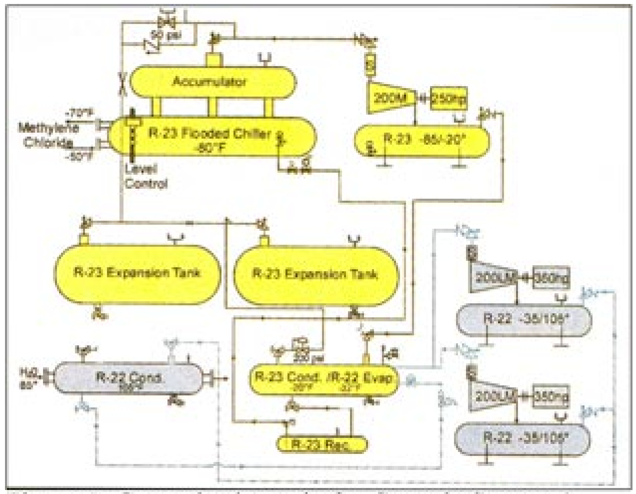

Figure 5: General schematic for Cascade System 1.
Click to view clear picture

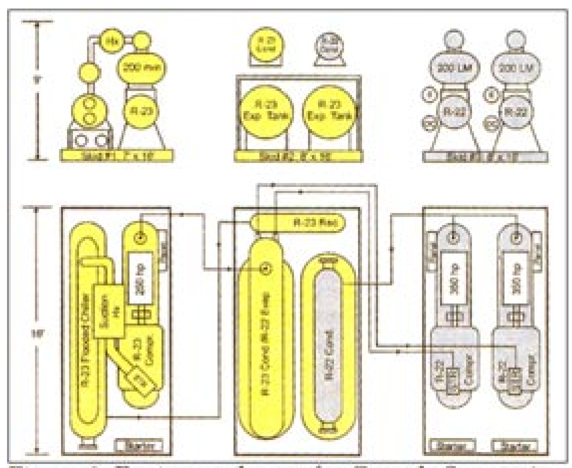
Figure 6: Equipment layout for Cascade System 1.
Click to view clear picture

HTC = HCFC-23 at -10°F/75°F (-23°C/24°C)
HTC = one single-stage 10 hp (7.5 kW) hermetic reciprocating compressor

Low temperature circuit:
LTC = HFC-23 at -80°F/0°F (-62°C/-18°C)
LTC = one single-stage 6.5 hp (5 kW) hermetic reciprocating compressor

Lubricant:
LTC & HTC = alkylbenzene ISO vg 68
HFC-23 cascade condenser: HCFC-22 DX plate heat exchanger
HFC-23 cascade evaporator: HFC-23 DX plate heat exchanger
LTC secondary coolant: d-Limonene entering at -50°F (-46°C)/leaving at -70°F (-57°C)

Notes:

1) The HTC has a single hermetic recip. compressor.
2) The HFC-23 / HCFC-22 condenser/evaporator is a plate heat exchanger.
3) The HFC-23 evaporator is also a plate heat exchanger
4) All piping, including the LTC, is copper.
5) Several flex sections were added to minimize vibration and thermal stress.
6) The HFC-23 suction line heat exchanger.
7) The large HFC-23 expansion (fade-out) tank located under the recip. compressors.
8) The small size of the 16.5 hp (12 kW) factory packaged unit compared to the 950 hp (708 kW) field-erected System 1.

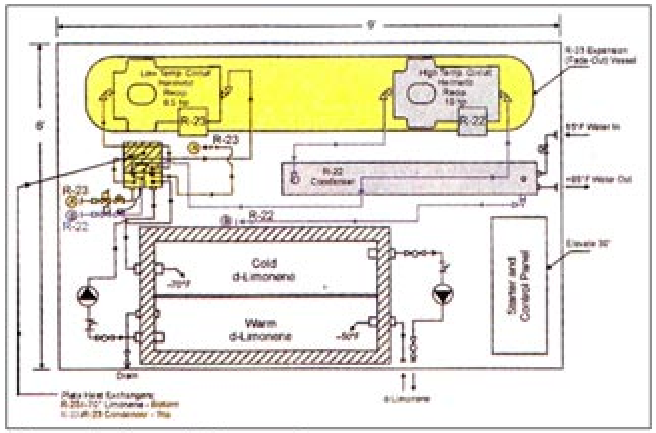

Figure 7: Cascade System 2.
Click to view clear picture

Table 5 presents common secondary coolants and some typical information.

Several other fluids, less frequently chosen, can be used as low temperature secondary coolants. Some of these are: halo-carbon refrigerants (HFCs), hydrocarbon fluids (propane, butane, pentane), and methyl ethyl ketone (MEK).

Any fluid chosen must be thoroughly researched regarding the complete specifications of the fluid throughout the expected range of application (including stand-by shutdown) to assure safe, satisfactory performance.

None of the secondary coolants mentioned here is fully suitable throughout the entire low temperature range. Each has its own range of application and should be applied accordingly.

Insulation

The insulation on low temperature refrigeration systems is critical because the low temperature piping is generally at room temperature and not located within a cold space. The insulation must be thick enough to prevent moisture condensation on the outside of the insulation and must prevent moisture from entering the insulation system.

The insulation should be multi-layered so the insulation can move as the pipe expands and contracts with temperature changes. The outer ply has sealed joints, and the inner plies are to be allowed to slide. **Table 6** presents the components of a low temperature refrigerated pipe insulation system and indicates the functions of each component.

Table 5: Common low temperature secondary coolants.

Name	Formula	Freezing Point (F/C)	Flammable	Toxic	Viscosity Range (lb/f)	
					58F	148 F
Acetone	C_3H_6O	-137/-94	Yes	-	0.0005	0.001
d-Limonene	$C_{10}H_{16}$	-142/-97	Yes	No	0.001	0.0012
Diethyl- benzene		-103/-75	Yes	-	- 0.002	0.007
Ethanol	C_2H_5OH	-178/-117	Yes	No	0.004	0.02
Methanol	CH_3OH	-144/-98	Yes	Yes	0.002	0.01
Hdro-fluoro-ether	$C_4F_9CH_3$	-202/-130	No	No	0.002	0.01
Polydi- methyl-siloxane	Silicon oil	-168/-111	Yes	No	0.004	0.05

Table 6: Low temperature insulation components.

Insulation System Component	Primary Roles	Secondary Roles	Typical materials
Insulation	Efficiently insulate pipe	Limit water move-ment to pipe, protect vapor retrader	Polyurethane polyisocyanurate foam. Extruded poly-styrene foam. Cellular glass
Elastometric Joint Sealant	Limits liquid water movement through insulation cracks	-	Synthetic rubbers and resins
Vapor Retarder	Eliminates moisture transfer toward pipe	-	Mastic/fabric/mastic, laminated membranes
Protective Jacket	Protects vapor retarder from damage	Reduce moisture/ vapor transfer toward pipe	Aluminium, stainless steel, PVC
Jacket Joint Sealant	Prevents water movement through gaps in protective jacket	Limits rate of moisture transfer toward pipe	-
Vapor Stops	Isolate damage caused by moisture	-	Mastic/fabric/mastic

Conclusion

Low temperature cascade systems, especially those custom designed and/or field-erected, present the designer with a number of engineering choices. This article highlights some important factors in the design of low temperature cascade systems and will gives the designer a direction and an awareness of the areas of concern. Designers can refer to Chapter 39 of the 1998 ASHRAE Handbook - Refrigeration for additional information.

The appendix contains information on two industrial low temperature cascade systems that the author designed. The firs system is a large field erected design with a total of 950 hp (710 kW). The second system is a smaller unit that was pre-packaged and has a total of 16.5 hp. (12 kW).