SNLT2

Second Nature Low-Temperature CO2 Secondary Coolant System Installation, Start-Up, and Operating Specifications

Revision 3
April 2011

(Replaces Revision 2, March 2008)

A DOVER COMPANY

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Preface to Revision 3

This third revision was prepared after gathering experience with dozens of installations of the Hill PHOENIX **Second Nature®** **SNLT2** Low-Temperature Carbon Dioxide Secondary Coolant Technology in the field. Information learned during the application, construction, installation, start-up, and commissioning of these systems has been incorporated and includes:

- Updated relief valve specifications
- Updated control setpoints recommendations
- Revised information on recommended thread sealant materials
- Updated evaporator piping details
- Updated defrost control notes
- Expanded display case troubleshooting procedures

Second Nature Low-Temperature CO2 Secondary Coolant System Installation, Start-Up and Operating Specifications

I. SCOPE OF SPECIFICATIONS

These specifications, supplied by Hill PHOENIX, shall be considered as an addition to the common documentation supplied by the customer for complete installation of the supermarket's refrigeration system and are intended to describe the installation, testing, start-up, and operation of a Hill PHOENIX **Second Nature®** SNLT2 Low-Temperature Carbon Dioxide Secondary Coolant System only. Failure to follow these specifications will void the manufacturer's, Hill PHOENIX, warranty.

II. GENERAL NOTICE

A. The secondary coolant system (equipment, devices, piping, insulation, etc.) shall be installed per this "Second Nature SNLT2 Low-Temperature CO2 Secondary Coolant System Installation, Start-Up, and Operating Specifications", the Hill PHOENIX Refrigeration Schedule (Legend) and the secondary coolant system piping diagram and installation drawings (if provided).

B. Any changes to the installation shall be submitted in writing to Hill PHOENIX for review and approval. All changes shall also be confirmed by the customer. Any changes that are not approved by Hill PHOENIX will void the warranty of the system.

C. This specification may change without notice. Contact your Hill PHOENIX representative to verify the most current revision of this document and any of the latest developments which have not yet been published.

III. SNLT2 SYSTEM BASICS

A. INTRODUCTION

Low-Temperature Carbon Dioxide Secondary Coolant Systems *(referred to from here on as SNLT2 Systems)* represent an important part of the Hill PHOENIX **Second Nature**™ product offering of systems that have lower refrigerant charge and lower refrigerant leak rates. Introduced in 2006, the SNLT2 systems are meant to be the low-temperature compliment to the medium-temperature glycol secondary coolant systems or SNMT products.

SNLT2 Systems are considered **Subcritical CO2** systems where the pressure of the CO2 is maintained well below the critical pressure of CO2. Operating pressures for these systems are higher than those in conventional direct-expansion systems but are similar to those seen in air-conditioning applications using R-410A. These systems are not considered Transcritical CO2 systems that operate at pressures above the critical pressure, often up to 1500 psig.

B. DEFINITIONS

1. **Refrigerant** – A fluid used for transferring heat from one source to another.

2. **Primary Refrigerant** – A fluid used to lower the temperature of a secondary coolant (i.e. R-22, R-404a, R-507, R-410A, R-717)

3. **Secondary Coolant** (a.k.a. Secondary Refrigerant, Secondary Fluid) – A fluid used to transfer heat from a heat source (i.e. refrigerated space) to a primary refrigerant.

4. **Single-Phase Secondary Coolant** – A secondary fluid which absorbs heat by means of sensible heat transfer resulting in a change in temperature (i.e. propylene glycol, potassium-based salts, brine).

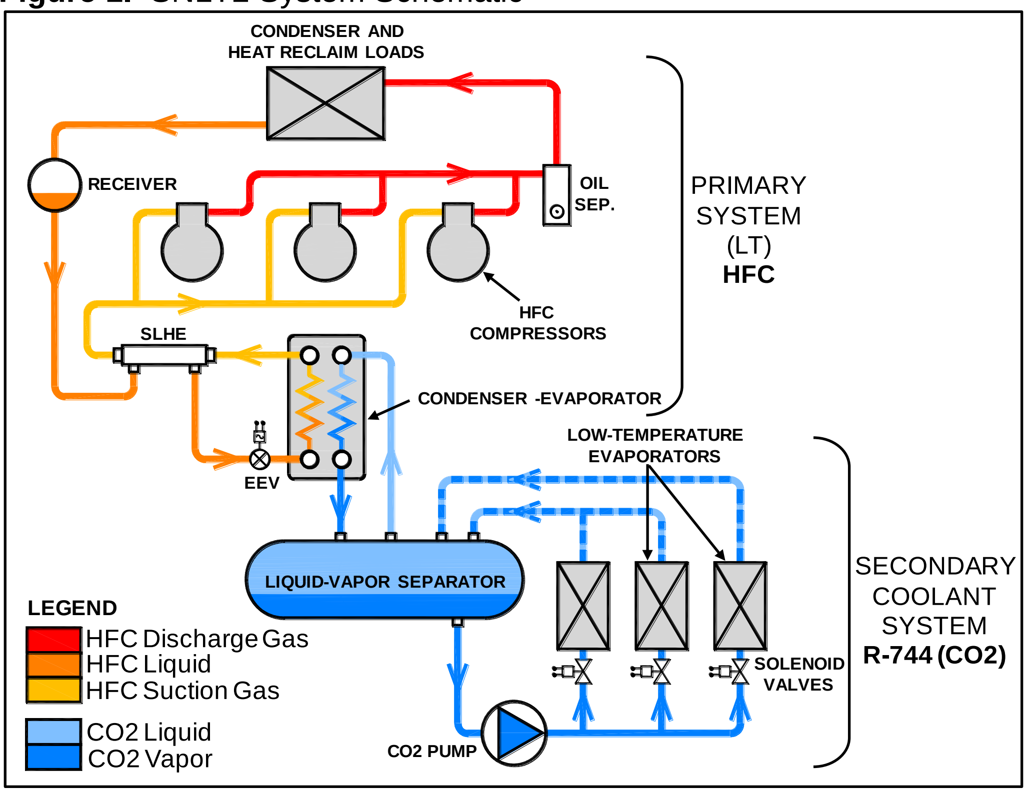
5. **Two-Phase Secondary Coolant** – A secondary fluid which absorbs heat by means of latent heat transfer resulting in a change in phase (i.e. carbon dioxide, ice-slurries).

C. HOW THE SYSTEM WORKS

In a low-temperature carbon dioxide (SNLT2) secondary coolant system, heat is removed from the refrigerated spaces and is absorbed by carbon dioxide (CO2) in the evaporators. Unlike secondary systems using a single-phase fluid (i.e. propylene glycol or brine solutions) where heat is absorbed through an increase in temperature of the fluid (sensible heating), the carbon dioxide absorbs heat through evaporation, changing phase from a liquid to a vapor (latent heating).

Figure 1 shows a schematic of a typical SNLT2 secondary coolant system in simplified form. Two routes of circulation occur in this arrangement. In the first route, CO2 vapor exits the top of the liquid-vapor separator and enters the condenser-evaporator where it is cooled and condensed by the primary refrigeration system; the condensed liquid CO2 then flows by gravity back into the liquid-vapor separator. In the second route, liquid CO2 leaves the bottom of the liquid-vapor separator and is pumped through supply distribution piping to the evaporators in the display cases and freezers, returning to the liquid-vapor separator in two-phase form through the return piping.

Figure 1. SNLT2 System Schematic



The major components of the system and their functions are:

Condenser-Evaporator – This heat exchanger is responsible for transferring heat from the CO2 system to the primary refrigeration system and typically consists of one or more brazed-plate heat exchangers, though other types may be used. In the condenser-evaporator (see Figure 1), the upper-cascade primary refrigerant evaporates on one side, absorbing the heat from the CO2 condensing on the other side. Typically, the condenser-evaporator heat exchanger is piped with a suction line heat exchanger (SLHE) to assist with prevention of liquid flooding of the compressor and to ensure adequate subcooling of liquid entering the expansion device.

Liquid-Vapor Separator – The CO2 liquid-vapor separator is similar in function to the receiver on conventional DX systems and is designed to accommodate the entire charge of CO2 required for proper operation of the system during all times of the year and accommodates changes in charge level during periods of fluctuating loads or defrost. The separator also provides an area of low velocity, allowing the separation of CO2 into liquid and vapor, ensuring that only vapor is directed to the condenser-evaporators and only liquid is directed to the CO2 pumps. The receiver is insulated to prevent excessive heat gain into the system during both normal operation and standby operation when the primary system is not running.

CO2 Liquid Pump – the CO2 pump directs liquid CO2 from the liquid-vapor separator through distribution piping to the evaporators in the display cases or walk-ins. Typically, the pump consists of a hermetic, multi-stage centrifugal pump, though other types may be employed. Most systems include a second back-up pump to increase system redundancy.

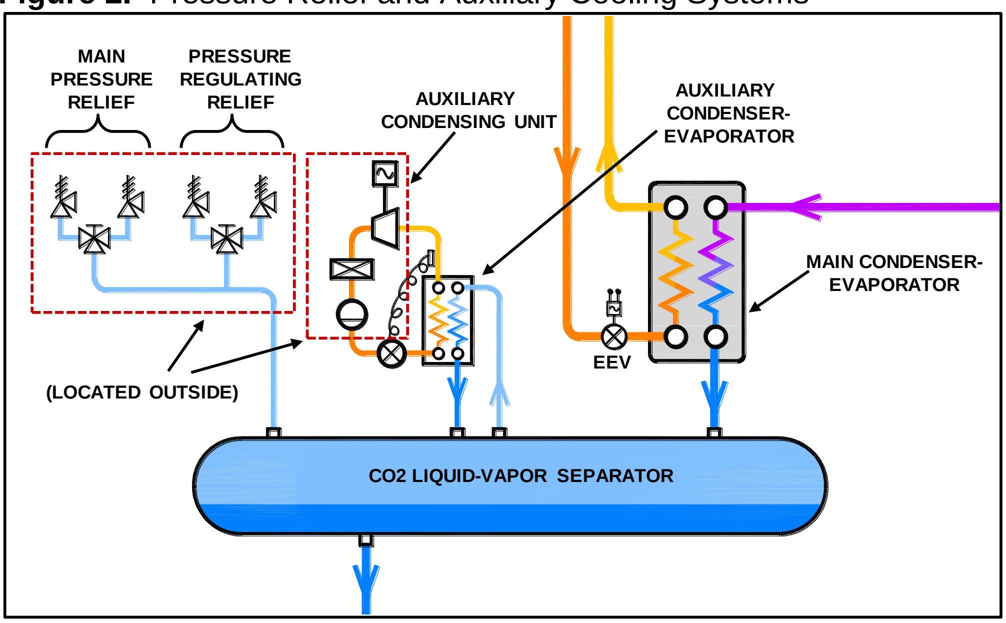
CO2 Evaporators - the evaporators installed in the low-temperature display cases and unit-coolers are specially designed to accommodate the design requirements of SNLT2 CO2 secondary coolant systems. Here, CO2 enters the evaporators in liquid form and is partially evaporated, leaving the heat exchanger in two-phase form (liquid and vapor) similar to that of a flooded or recirculated-liquid refrigeration system. CO2 evaporators are typically constructed of copper-tube and aluminum-fin though other materials can be used.

> **Note:** *Evaporators designed and manufactured for use in conventional direct-expansion systems (for HFC and HCFC application) or single-phase secondary systems are not suitable for use in SNLT2 Systems due to lower design pressures and improper circuiting arrangements.*

Control devices for CO2 secondary evaporators are most commonly a solenoid valve that allows flow of CO2 into the evaporator during refrigeration mode and closes during defrost or to control case temperature. Valves used are designed for the higher pressures associated with CO2 secondary systems and are selected for specific pressure drop. An isolation/balance valve may also be installed on the evaporator which can allow minor adjustments to flow rate during system commissioning if needed.

Pressure Relief System – New requirements in UL and CSA Standards specifically added for application of CO2 require use of a Pressure Regulating Relief Valve in addition to the Pressure Relief Valve that is typically installed. The main Pressure Relief Valve is sized as normal and is set at or below the design pressure of all equipment on the high-side of the system. The Pressure Regulating Relief Valve is set at a pressure equal to or less than 90% of the setting of the main Pressure Relief Valve. Both types of valves will be installed in a dual valve assembly connected to the CO2 receiver as shown in Figure 2. These valves are piped to a common location outside the machine room or mechanical center. For machine room applications, the relief assembly is shipped loose for field installation, and for mechanical center applications this assembly may be factory piped into the wall of the center. Additional relief valves at a higher pressure setting as the main pressure relief valve are installed to protect specific areas or pieces of the equipment during servicing or maintenance.

Figure 2. Pressure Relief and Auxiliary Cooling Systems



Auxiliary Cooling System (Optional) – An additional piece of equipment that may be installed on Hill PHOENIX CO2 systems is an Auxiliary Cooling System. The function of the auxiliary cooling system is to maintain the CO2 in liquid form and at moderate pressures during periods of maintenance of the upper- or lower-cascade system, or during loss of electrical power. The auxiliary cooling system is often connected to a back-up generator so that in power failure situations a loss of CO_2 and resulting re-charging can be prevented. Figure 2 shows a schematic of a typical auxiliary cooling system which consists of an auxiliary condenser-evaporator (a smaller version of the main condenser-evaporator) and a pre-packaged auxiliary condensing unit of small horsepower, typically with an air-cooled condenser.

D. CO2 PROPERTIES AND HANDLING

Before handling Carbon Dioxide (CO_2), the contractor should be familiar with the Material Safety Data Sheet (MSDS) and the materials physical properties. An MSDS for CO_2 is available from any supplier of industrial gases – see page 9 for a list of selected vendors.

Carbon Dioxide is a colorless, odorless, slightly acidic gas that is approximately 50% heavier than air. It is non-flammable and will not support combustion. Table 1 below shows selected properties of CO_2.

Carbon Dioxide has excellent thermophysical properties which make it ideally suited for use as a secondary coolant and as a refrigerant. Table 2 below shows selected properties of CO_2 at -20°F and +20°F. A detailed pressure-temperature chart for CO_2 is also shown in Appendix 1.

Table 1. Selected Properties of Carbon Dioxide

Molecular Weight	44.01
Boiling Point @ 1 atm.	-109.1°F
Triple Point @ 75.1 psia	-69.8°F
Critical Temperature	87.9°F
Critical Pressure	1070 psia
Specific Gravity of Gas @ 1 atm.	1.53
OSHA TLV-TWA[1]	5,000 ppm (0.5%)

Note 1: Threshold Limit Value, Time Weighted Average

Table 2. Selected Thermodynamic Properties of CO_2

Property	@-20°F	@+20°F
Saturation Pressure, Psia Saturation Pressure, Psig	214.9 200.2	421.9 407.2
Liquid Density, Lb/Ft^3	66.9	60.3
Vapor Density, Lb/Ft^3	2.40	4.94
Heat of Vaporization, Btu/Lb	129.6	107.5

E. CO2 SAFETY

Carbon Dioxide is a naturally occurring substance present in air at concentrations of 300-400 parts per million (ppm) or 0.030%-0.040%. The Occupational Safety and Health Administration (OSHA) has listed for CO2 a TLV-TWA level of 5,000 ppm or 0.5%. This Threshold Limit Value – Time Weighted Average is the time-weighted average concentration for a normal 8-hour workday and 40 hour workweek, to which nearly all persons may be repeatedly exposed to without adverse effects. CO2 compares favorably to the TLV-TWA value of 3,000 ppm for typical HFC refrigerants (R-404A and R-507).

Typical operating pressure of an SNLT2 System is 200-275 psig. Rapid depressurization of CO2 in liquid or liquid-vapor form to pressures below 60 psig (75 psia) will cause the liquid to convert directly from a liquid to a solid, forming Dry Ice at a temperature of -109.3°F.

More information on the safe use and handling of Carbon Dioxide can be found from the Compressed Gas Association, Standard CGA-G-6-1997 “Carbon Dioxide”. This and other related standards can be obtained from:

Compressed Gas Association
4221 Walney Road
5th Floor
Chantilly, VA 20151
Ph.: 703-788-2700
Web: www.cganet.com

F. CO2 GRADES

Carbon Dioxide is produced as a byproduct of a number of different manufacturing processes including the formation of hydrocarbons and various distillation and fermentation processes. In addition, CO2 exists naturally in wells. After the CO2 gas has been isolated, it is purified into different levels through the filtration of impurities and removal of moisture and non-condensable gases which result in different grades of CO2 for different applications. Examples of various grades of CO2 are shown in Table 3.

Carbon Dioxide purchased for use in refrigeration systems must be of a purity level high enough to prevent accumulation of non-condensable gases and moisture in the condenser-evaporator. A build-up of these gases can block heat transfer surface and cause inefficient operation or malfunction of the system. Hill PHOENIX recommends using

Coleman (Instrument) Grade CO2 which contains less than 0.01% non-condensable gases and moisture. Table 4 shows typical specifications for Coleman (Instrument) Grade CO2.

Table 3. Common Grades of CO2

Industrial Grade	99.5%
Bone-Dry	99.8%
Anaerobic	99.9%
Coleman (Instrument) Grade	99.99%
Research Grade	99.999%
Ultra-Pure	99.9999%

Table 4. Specifications of Coleman (Instrument) Grade CO2

Minimum Purity of CO2	99.99%
Nitrogen, N_2	< 50 ppm
Oxygen, O_2	< 20 ppm
Water, H_2O	< 10 ppm

Warning: Some CO2 gas suppliers offer a "cap-charge" of helium or other inert gases for liquid cylinders which increases tank pressure in order to speed the charging process – *DO NOT* accept any cylinders with this cap-charge – use only cylinders that are *PURE* CO2. Use of cylinders with a cap-charge is likely to introduce large amounts of non-condensable gas, render the system inoperable, and require purging, evacuation, and recharging of the entire system.

To determine if a cylinder has a cap-charge, measure the tank pressure using a regulator and compare this with the saturation pressure at the approximate storage temperature of the tanks – tanks with a cap-charge will have a pressure significantly higher (>200 psig) than the corresponding saturation pressure.

Introduction of lower-grade CO2 with purity-levels less than those of Coleman Grade is not recommended and should only be done in emergency situations. Use of lower-grade CO2 may result in decreased system performance and require specific procedures to purge non-condensable gases from the system. Examples of CO2 grades of lower purity levels include but are not limited to "Industrial Grade" and "Bone Dry Grade".

Use of Carbon Dioxide of a higher purity level than Coleman Grade is acceptable though typically not cost effective. An example of a CO2 grade of higher purity levels includes "Research Grade".

Coleman Grade CO_2 is widely available throughout North America by suppliers of industrial gases. Typical sources include:

Air Liquide America L.P.
2700 Post Oak Boulevard, Suite 1800
Houston, TX 77056
Ph.: 866-822-5638
Web: www.airliquide.com

Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810
Ph.: 203-837-2000
Web: www.praxair.com

Linde Gas
6055 Rockside Woods Blvd.
Independence, OH 44131
Ph.: 216-642-6600
Web: www.us.lindegas.com

G. CO2 CYLINDERS

CO_2 is available in both liquid and vapor form and in a variety of cylinder sizes. The most common types and sizes of CO_2 Cylinders are shown schematically in Figure 3 and are:

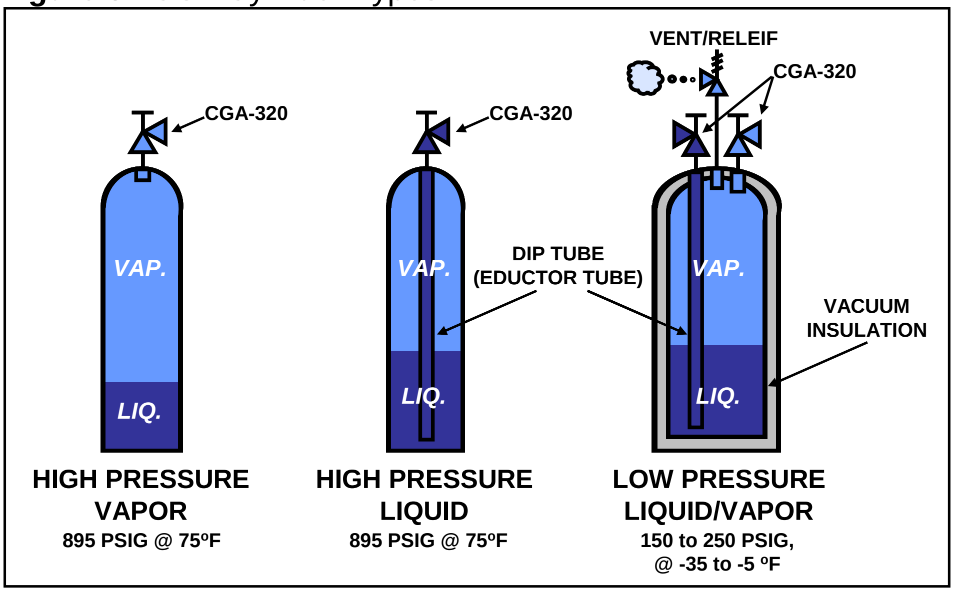
- High-Pressure Vapor Cylinder, 50 lbs. of CO_2
- High-Pressure Liquid Cylinder, 50 lbs. of CO_2
- Low-Pressure Liquid/Vapor Cylinder, 350 lbs of CO_2

High-pressure cylinders are the recommended container for charging SNLT2 systems and contain CO_2 at a saturation pressure corresponding to the temperature of their surroundings. At a room temperature of 75°F this corresponds to 895 psig. CO_2 can be stored in high-pressure cylinders indefinitely.

Low-pressure cylinders contain CO_2 at a saturation pressure corresponding to the pressure setting of the vent/relief valve installed on the tank, typically between 200 to 300 psig, maintaining the temperature of the CO_2 between -20°F and 0°F. The cylinder is a double-walled construction with a vacuum between the inner- and outer-tanks which acts as insulation to minimize heat transfer. As heat enters the tank, the CO_2 pressure rises until the vent/relief valve opens, releasing vapor CO_2. This causes a small amount of CO_2

liquid to evaporate, cooling the remaining CO2 in the tank and lowering the pressure. The frequency and duration of the opening of the relief valve varies and depends on the valve setpoint and the temperature of the surroundings. CO2 stored in low-pressure cylinders will last for 1-5 months before completely venting through the relief valves.

Figure 3. CO2 Cylinder Types



CO2 can be charged in both liquid and vapor form. Breaking the vacuum and initial system pressurization must be performed using vapor. Field experience has shown that once this has been completed, the remainder of the charging should be performed using high-pressure liquid tanks – use of low-pressure tanks for liquid charging will increase the time required for the charging process. Section V-A details the various equipment needed for both methods of charging and the different procedures that are required.

H. CO2 LEAK DETECTION

Since CO2 is both present in the atmosphere at concentrations of 300-400 ppm, and is also a byproduct of human respiration and other processes, detection of leaks in a piping network can be more difficult than with conventional refrigerants.

Leaks occurring on liquid lines will often be visible, emitting a small amount of CO2 vapor which can appear cloudy. Larger leaks will show evidence of a very cold ice-ball and possibly the formation of dry ice on the outside of the insulation.

For detecting small liquid or vapor leaks, hand-held detectors are available. These typically consist of a detector element connected to a hand-held display containing the electronics. Response time on these instruments can be slower and should be taken into consideration when moving the detector element from one position to another. Figure 4 below shows different examples of leak detectors which have been used successfully.

Figure 4. Examples of Carbon Dioxide Leak Detectors

FIXED PROBES **HAND-HELD PROBES**

Inficon manufactures a hand-held, portable detector that is similar in operation to portable meters used for HFC and HCFC leak detection. Response time is quick and this is the preferred leak detector for use with CO2. Vaisala also manufactures a variety of detectors for both mechanical room (wall-mounted), duct-mounted, and hand-held applications. Response time for the Vaisala hand-held probe is slower (20-30 seconds) and is less well-suited for finding leaks in the field.

Additional information on CO2 leak detectors can be obtained from:

Inficon
Two Technology Place
East Syracuse, NY 13057
Ph. 315-434-1100
Web: www.inficon.com

Vaisala Inc.
Boston Office
10-D Gill Street
Woburn, MA 01801
Ph.: 781-933-4500
Web: www.vaisala.com

A variety of manufacturers supply fixed-location probes for CO2 monitoring of mechanical rooms and other non-refrigerated spaces including suppliers of rack controllers for commercial refrigeration systems (CPC/Emerson, Danfoss, etc…). The recommended range for fixed-location probes is 0-10,000 ppm. Since CO2 is heavier than air, fixed-location probes should be mounted near the floor (around 12" above the floor). CO2 sensors should also not be mounted near sources of combustion including furnaces, gas heaters, and loading docks as higher levels of CO2 can be present in these locations.

I. CO2 AND LUBRICATION

Hill PHOENIX CO_2 secondary coolant systems are generally designed to operate without the addition of oil. Experiences at selected installations have indicated that the addition of a small amount of soluble oil, in the amount of 0.5% to 1.0% by weight, may assist with the lubrication of valves and may prevent some small nuisance leaks of CO_2. The addition of this small amount of oil has not shown to have any detrimental effects on the operation of the system or any negative impact on heat transfer surfaces and is now recommended for all installations.

The oil recommended for installation in SNLT2 systems is **Emkarate RL-68HB**, a POE oil with inhibitors that have proven to work well with CO_2. This is the same oil recommend for subcritical CO_2 cascade systems using scroll-type compressors. Additional information on this oil can be obtained from:

Nu-Calgon
2008 Altom Court
St. Louis, MO 63146
Ph.: 800-554-5499
Web: www.nucalgon.com

IV. SYSTEM INSTALLATION

A. GENERAL

1. As with any refrigeration system, the installation of the refrigeration shall comply with the "Safety Standard for Refrigeration Systems" (ANSI/ASHRAE Standard 15), ASME B31.5 Refrigeration Piping Standard, and locally adopted building codes.

2. The scope of work must be defined in the "Refrigeration System Specifications" provided by the customer.

3. The customer shall be contacted to determine if any documents are available relating to local codes or regulations.

4. The contractor shall install all SNLT2 system components according to Hill PHOENIX detail drawings.

5. Prior to installation, the installing contractor shall inspect all materials, piping, fittings, and controls of the SNLT2 system. These components must be free of manufactured defects, grease, and foreign particles, shall comply with the minimum temperature and pressure ratings shown in Table 5 below, and shall satisfy material compatibility requirements with CO2.

Table 5. SNLT2 System Temperature-Pressure Ratings

Application	Temperature Rating	Pressure Rating
All SNLT2 Piping	-25°F to +100°F	450 psig

6. All field installed materials such as pipes, valves, fittings, gaskets, or any other materials used for the SNLT2 system shall be checked for material compatibility with CO2.

B. CO2 LINE SIZING

1. In general, CO2 lines sizes are specified on the Hill PHOENIX Refrigeration Schedule and/or the supplied installation drawings. If line sizes have not been provided or are missing, the contractor should contact the Hill PHOENIX Inside Sales Engineering Department for additional information. It is typical for CO2 line sizes to be one to two sizes smaller than sizes for an HFC application.

2. Deviation from the line sizes recommended by Hill PHOENIX may result in improper operation of the system.

3. <u>Liquid Supply Lines</u> for low-temperature systems have been sized to ensure proper and evenly distributed pressure drop and velocity of the CO2 liquid. A minimum line size of 3/8" OD has been used to insure structural integrity of the piping system. Changing 3/8" liquid lines to 1/2" size is not recommended as it increases the charge of CO2 required for proper system operation and may impact the system flow balancing.

4. <u>Two-Phase Secondary Return Lines</u> carrying liquid and vapor in both horizontal lines and vertical risers have been sized to ensure proper pressure drop and effective return of recirculated liquid CO2 back to the liquid-vapor separator. A minimum line size of 3/8" OD has been used to ensure structural integrity of the piping system. Increasing 3/8" lines to 1/2" size **must not be done with vertical risers** as the change in velocity may result in improper operation of the system. Any time a return line turns vertically upward, this is considered to be a vertical riser and the line size should be changed to the riser size as specified on the refrigeration schedule or drawings.

C. COPPER PIPING GUIDELINES

1. Copper pipe is the recommended material for use in SNLT2 systems. Contractors wishing to pursue use of alternative piping materials should contact their Hill PHOENIX representative.

2. The SNLT2 system Maximum Allowable Working Pressure (MAWP) is generally 400 psig and matches the setting of the main Pressure Relief Valves installed on the system (reference factory supplied piping diagram to confirm relief settings). Relief valves set at a higher pressure than the main relief are additionally located in selected positions throughout the system

to protect specific equipment against hydrostatic pressure increases. Type L copper piping can be used on some pipe sizes, however Type K copper must be used on larger sizes. Table 6 and 7 below show specifications for Type L and Type K copper tubing based on a maximum design temperature of 100°F which is applicable for liquid and suction line applications for field installations.

Example:

Main Relief set at 400 psig, with additional protective relief valves set at 425 psig.

Use Type L copper up to 1-3/8”

Use Type K copper 1-5/8” and 2-1/8” (max.)

Table 6. Type L Copper Tube Specifications for Field-Installed Piping

Tube Size OD, Inches	Tube Wall Inches	Tube MAWP[1]
3/8”	0.030	912 psig
1/2”	0.035	779 psig
5/8”	0.040	722 psig
7/8”	0.045	582 psig
1-1/8”	0.050	494 psig
1-3/8”	0.055	439 psig
1-5/8”	0.060	408 psig
2-1/8”	0.070	364 psig

Note 1. Maximum Allowable Working Pressure based on allowable stress for 100°F maximum operating temperature

Table 7. Type K Copper Tube Specifications for Field-Installed Piping

Tube Size OD, Inches	Tube Wall Inches	Tube MAWP[1]
3/8”	0.035	1074 psig
1/2”	0.049	1130 psig
5/8”	0.049	891 psig
7/8”	0.065	852 psig
1-1/8”	0.065	655 psig
1-3/8”	0.065	532 psig
1-5/8”	0.072	494 psig
2-1/8”	0.083	435 psig

Note 1. Maximum Allowable Working Pressure based on allowable stress for 100°F maximum operating temperature

3. For additional information on copper tube stress and design temperature effects, see “The Copper Tube Handbook” available from:

   The Copper Development Association
   260 Madison Ave.
   New York, NY 10016
   Ph.: 212-251-7200
   Web: www.copper.org

4. Brazing: Joints in the copper piping for the CO2 system shall be brazed identically to that of the primary refrigeration system. Nitrogen must be used to reduce oxidation of the piping during the brazing process.

5. Mechanical Joints: Threaded or flared joints should be avoided whenever possible to reduce the likelihood of leaks developing over the lifetime of the system. If these joints must be applied, the following guidelines should be applied to ensure a leak-free joint.

6. Flared Joints: Joints installed with flare fittings shall be installed with Flaretite seals to ensure leak-free operation. Additional information on these seals can be obtained from:

   Flaretite Inc.
   2284 Golden Pond Ct.
   Fenton, MI 48430
   Ph. 810-750-4140
   Web: www.flaretite.com

7. Joint Sealants: Threaded joints that are applied to CO2 systems must use approved thread sealants. The sealant approved for this application is Loctite 554. Teflon tape should not be used in combination with this material. Use of thread sealants other than this may result in improper system operation and leakage of CO2. Additional information on this material can be obtained from:

   Henkel Corporation
   1001 Trout Brook Crossing
   Rocky Hill, CT 06067
   Ph. 860-571-5100

8. Sloping Lines: All CO2 piping (liquid supply and suction return lines) shall be installed to slope or pitch downward towards the

machine room to assist with proper return of liquid (MT returns) and refrigerant oil (LT returns), the same common practice used for conventional DX systems with HFCs.

Example slope: 1" per 20 Ft.

9. Expansion Joints: Installation of expansion joints is recommended to minimize stress on the piping network. Most expansion requirements can be accommodated through the normal direction changes of the piping network. Long straight runs of pipe should include extra changes in direction to accommodate this expansion; a horizontal offset or "Z-bend" can be applied in these circumstances. Additional information regarding expansion joints can be found in the ASHRAE HVAC Systems and Equipment Handbook (Chapter 45 in the 2008 edition).

10. Traps: Traps are not necessary on low-temperature return lines when transitioning to piping that runs vertically upward (risers). Typically, the riser pipe size is one to two sizes smaller than the horizontal pipe size. Transition from the horizontal to the riser size shall be made in the horizontal line just prior to the trap piping.

11. Inverted Traps: Inverted or reverse traps shall be installed at the top of the low-temperature two-phase return risers prior to entering horizontal piping. These inverted traps prevent liquid back-flow during defrost periods.

D. CO2 PIPING DETAILS

1. In general, piping that is installed for an SNLT2 system is very similar to that of direct-expansion refrigeration systems. Pipe sizes, however, are considerably smaller than those sized for typical HFC application. In addition, there are several specific piping details that are unique for the low-temperature two-phase secondary return lines which are detailed in this section.

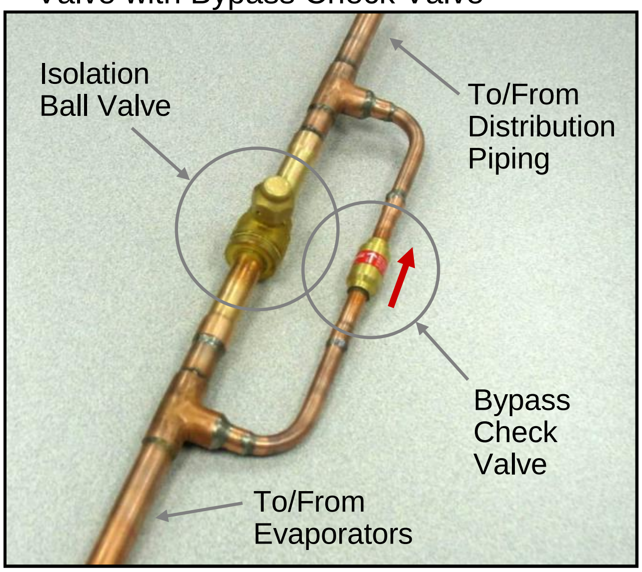
2. Loads are combined into line-ups or circuits similar to those for HFC applications. Piping between multiple adjacent display cases on a common circuit or line-up may be installed either internally or externally (inside or outside the display case).

3. Isolation valves should not be installed in the field unless specifically indicated on the field installation drawings. The distribution piping network has been specifically designed to

remain protected from overpressure by relief valves located on the refrigeration system.

4. When isolation valves are installed in the field or in the factory, they shall be equipped with bypass check valves as shown in Figure 8-9. The isolation valves and check valve may be supplied as pre-piped assemblies as shown in Figure 5, or they may be shipped as separate pieces to be combined in the field. In either instance, it is critical that **the directional arrow on the check valve shall point to the rack, and away from the display case or unit-cooler being isolated**. Isolation valves and bypass check valves may be installed internal or external to the display cases; the CO2 installation drawings should indicate where the valves are to be located for each circuit.

Figure 5. Sample Piping Assembly of Isolation Valve with Bypass Check Valve



5. All low-temperature secondary coolant evaporators shall be equipped with the following components:
   - Solenoid Valve
   - Isolation/Balance Valve

   These components may be factory- or field-installed depending on the specific order and application. Figure 6 shows an example of a low-temperature display case with control valves installed. It is important to note the order of the solenoid and isolation valves in supply piping – it is *essential* that the isolation/balance valve is located *after* the solenoid valve such that if the balance valve is completely closed, any trapped liquid can expand backward through the solenoid without a dangerous increase in pressure. Figure 7 illustrates the proper orientation of these valves.

Figure 6. Low-Temperature Secondary Display Case Piping Detail

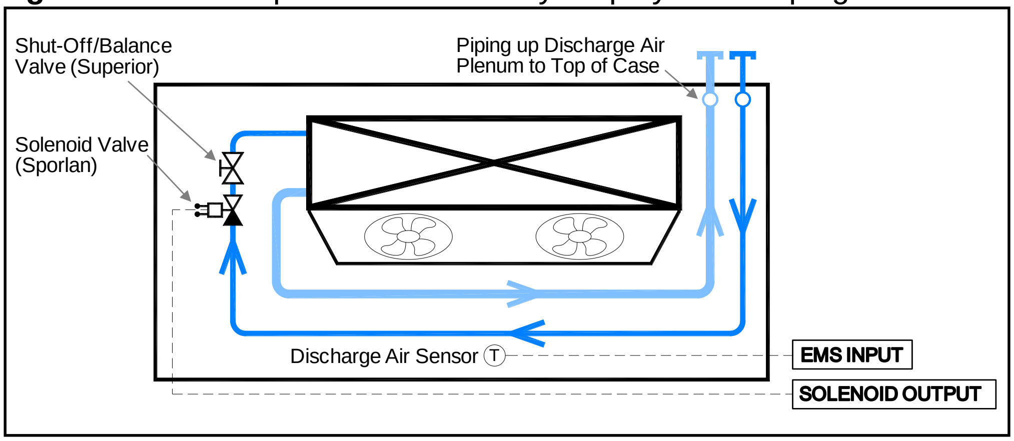
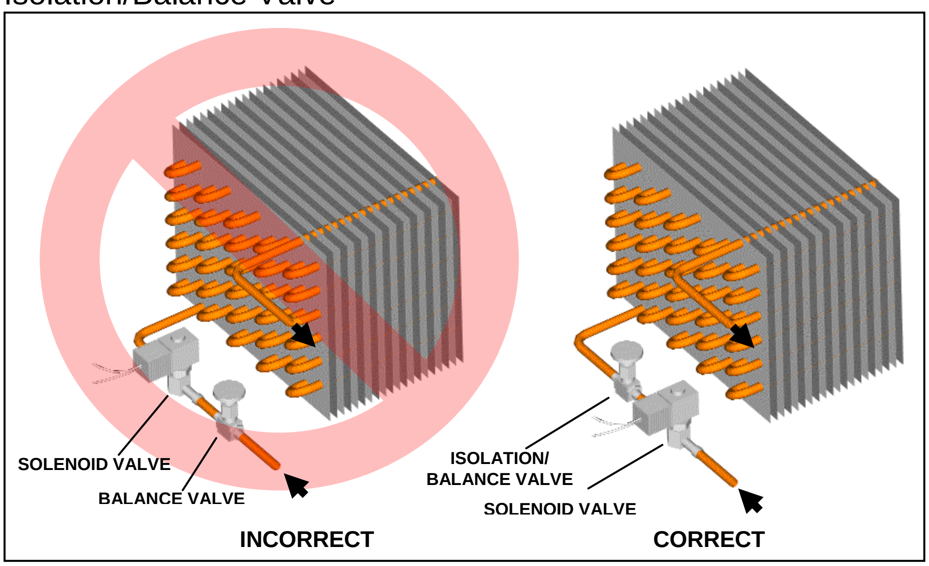


Figure 7. Secondary System Evaporator Piping with Solenoid and Isolation/Balance Valve



6. Multiple low-temperature display cases can be piped to each other with either an internal or external piping configuration. Figure 9 shows an example of external case-to-case piping where the interconnecting pipes are located behind or above the display cases and are appropriately insulated. In this situation, each display case is piped up the rear discharge air plenum at the factory.

   Figure 10 shows an example of internal case-to-case piping where the interconnecting pipes are located inside the refrigerated space and do not require insulation. In this situation, the first case in the line-up contains the supply line piped up the rear discharge air plenum, and the case at the opposite end of the line-up contains the return line piped up the rear, matching the return riser size for the entire line-up.

Figure 9. Low-Temperature Secondary Display Case Piping Detail with External Case-To-Case Piping

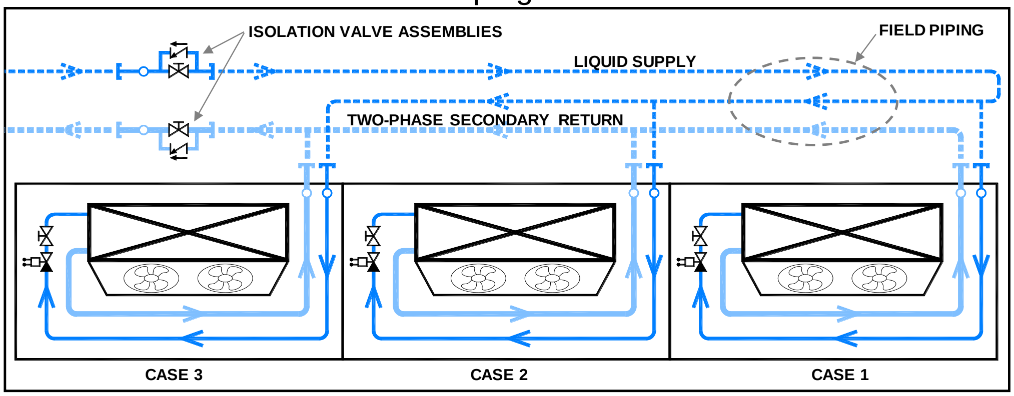
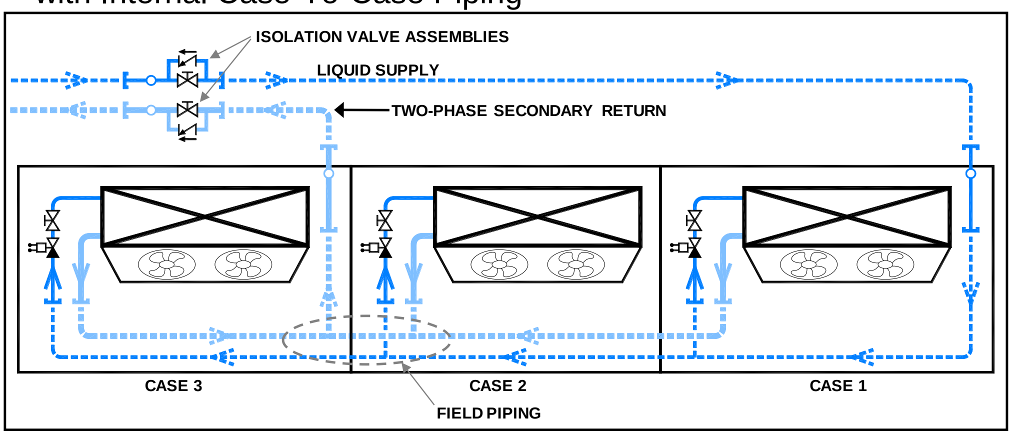


Figure 10. Low-Temperature Secondary Display Case Piping Detail with Internal Case-To-Case Piping



7. Unit-Coolers in walk-in coolers and preparation rooms require similar accessories and piping methods as display cases. An example of low-temperature unit-cooler piping is shown in Figure 11. When multiple unit-coolers are piped in the same walk-in, the individual supply and return lines for each unit-cooler are typically brought out to the top of the walk-in box separately. These lines are then piped to each other above the walk-in box.

8. Low-Temp Secondary Two-Phase Return Lines Entering Risers – for CO2 secondary systems, riser sizes can be from 1 to 3 pipe sizes smaller than the horizontal line size in order to ensure that enough velocity is provided to adequately return the CO2 liquid. Transition from the horizontal pipe size to the riser pipe

size should be done in the horizontal line just prior to the elbow at the bottom of the riser. Figure 12 illustrates the recommended method of piping this transition. P-traps (typical to a DX system) are not required as any oil in the line will be dissolved in the liquid CO2 leaving the evaporator.

Figure 11. Low-Temperature Secondary Unit-Cooler Piping Detail

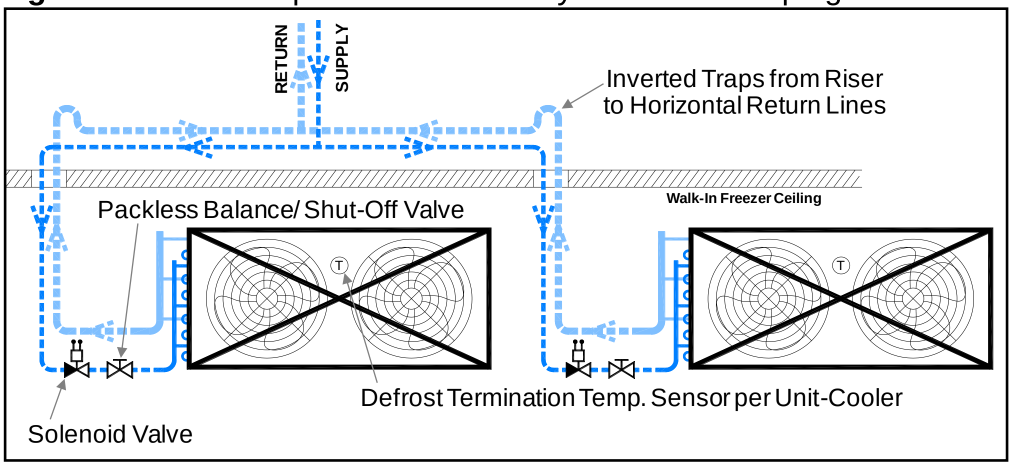
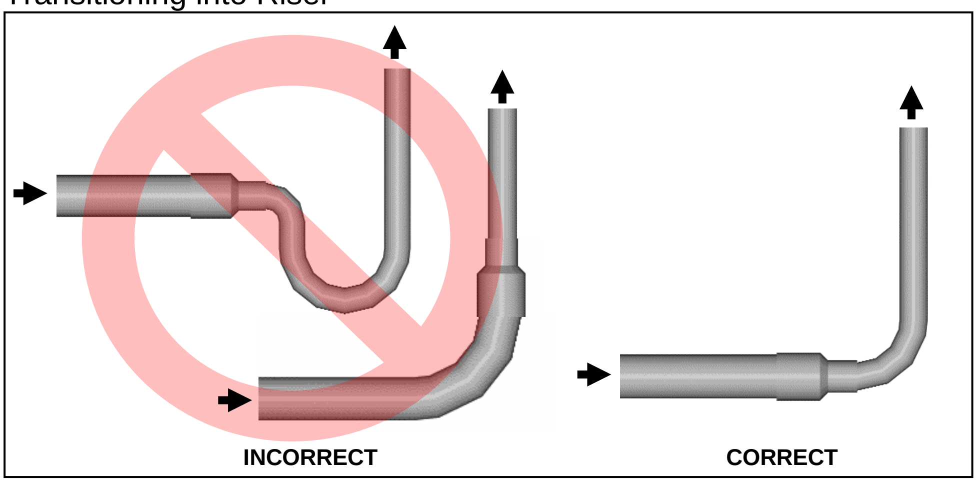
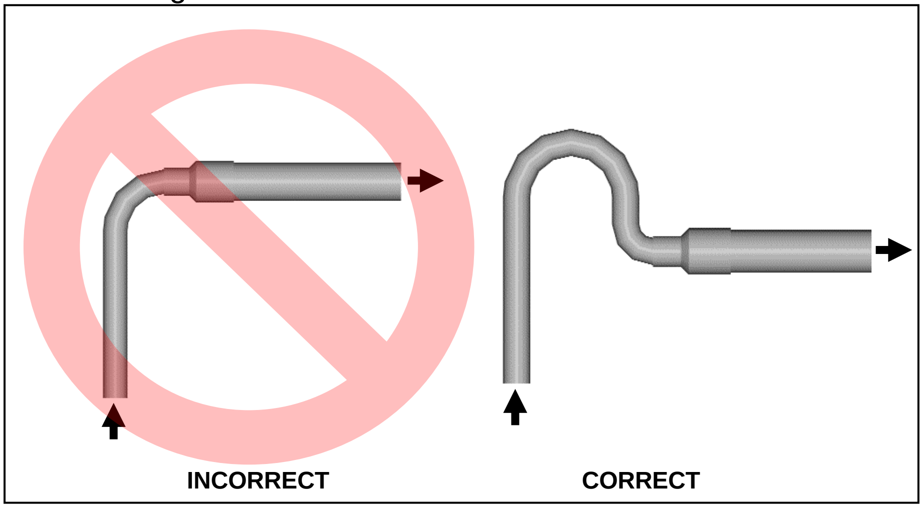


Figure 12. Horizontal Run into Two-Phase Secondary Return Line Transitioning into Riser



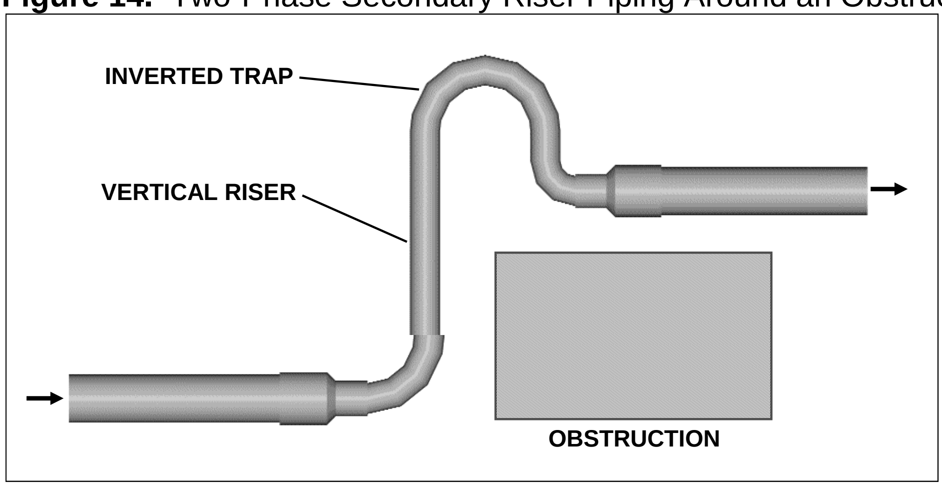
9. Low-Temp Secondary Two-Phase Return Lines Exiting Risers – return lines exiting a riser and transitioning into a horizontal run must be piped using an inverted trap. This ensures that any liquid in the horizontal line cannot travel back into the riser and inhibit proper flow of the CO2. Figure 13 below illustrates the recommended method of piping this transition.

Figure 13. Riser in Two-Phase Secondary Return Line Transitioning into Horizontal Run



10. Return Piping Around An Obstruction – If field requirements dictate that piping elevation is raised in order to pass an obstruction, the vertical upward portion of the return pipe shall be considered to be a riser and the pipe shall be run using the riser line size and an inverted trap shall be installed prior to transitioning back to the horizontal line size. Figure 14 below illustrates the recommended piping to raise the elevation around an obstruction for a medium-temperature two-phase return line.

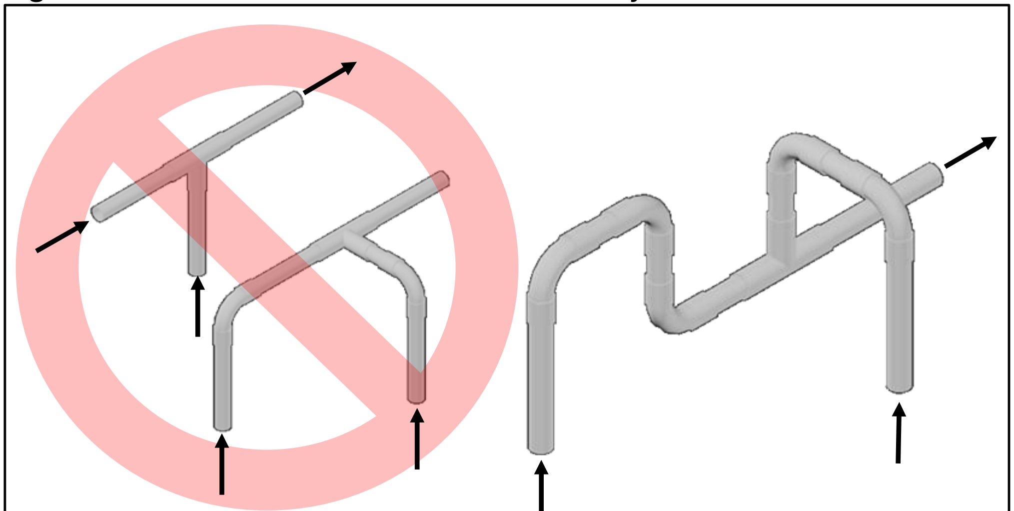
Figure 14. Two-Phase Secondary Riser Piping Around an Obstruction



11. Combined Low-Temperature Two-Phase Return Lines – when an individual two-phase return line is combined into a common return main, inverted traps should also be used, allowing the individual line to enter the main line from the top and preventing any backflow of liquid CO_2 into the individual riser. Figure 15

below illustrates the recommended method of piping this connection.

Figure 15. Combined Two-Phase Secondary Return Lines



12. <u>Relief Valves:</u> Relief valves have been installed in selected locations on the piping system where it is possible to accidentally trap CO2 liquid between two valves in order to prevent an unsafe situation. Relief valves should not be field-installed on equipment in the field unless specifically directed by the installation drawings. In general, all equipment in the sales area of the store is protected by the relief valves located on the refrigeration system.

13. Relief valves used for service with Carbon Dioxide are designed for use on cryogenic systems and should not be replaced with relief devices typically installed on commercial refrigeration systems. Replacement relief valves should be obtained from Hill PHOENIX - Service Parts Department

    Hill PHOENIX – Service Parts Dept.
    Ph. 800-283-1109
    Fax. 800-526-3897
    Web: www.HillPHOENIX.com

14. Relief valves for CO2 that are field-installed on the refrigeration system and as directed by the installation drawings should always be located at the end of the relief pipes and oriented to discharge outside the building – additional piping should never be installed at the outlet of CO2 relief valves as this pipe may

become clogged with dry ice and prohibit proper operation of the valve.

E. SUPPORTS

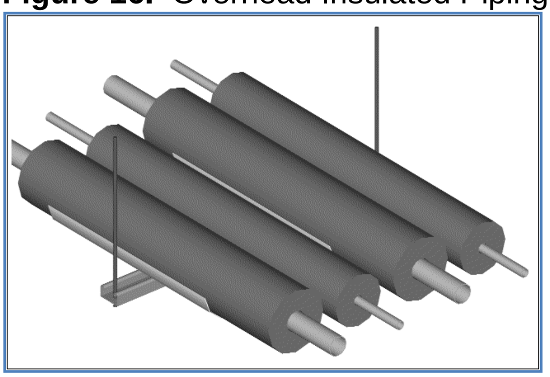
1. All insulated pipes should use supports that have a plastic (e.g. PVC) or metal saddle with a smooth bearing surface, is a length of at least three (3) times the external diameter of the insulation, and cradles the bottom 120 degrees of the pipe (see Figure 21 below). Edges should be rounded to minimize cutting into the insulation. This will minimize possible stress concentrations and protect the insulation from damage.

2. A minimum air space of one inch (1") shall be provided between insulated lines to prevent condensation on the surface of the insulation (see Figure 16).

3. If underground, closed trenches (not open and accessible) are used, they shall be designed such that the pipe may be installed without damage to the insulation.

4. The use of rigid clamps directly supporting the piping should be avoided as they conduct heat from the piping, are difficult to insulate, and will cause continuous condensation during system operation.

Figure 16. Overhead Insulated Piping Supports



F. TESTING AND EVACUATION

1. In general, field-installed CO2 piping shall be treated identically to field-installed primary refrigeration system piping (as with conventional direct expansion systems). Hill PHOENIX recommends triple-evacuation to ensure proper elimination of moisture and non-condensable gases.

2. Procedures for pressure testing, leak checking, and system evacuation should follow the customer's specifications for installation of the primary refrigeration system.

3. In the absence of customer guidelines, Hill PHOENIX recommends applying procedures in the "GreenChill Best Practice Guideline: Ensuring Leak-Tight Installations of Commercial Refrigeration Equipment". Additional information on this guideline can be found at:

   US EPA
   Mail Code 6205J
   1200 Pennsylvania Avenue, NW
   Washington, D.C. 20460
   Ph. 800-296-1996
   Web: www.epa.gov/greenchill/

4. Non-condensable gases and/or moisture trapped in the CO2 piping system will have similar detrimental effects on system operation as they do in conventional DX systems. It is important to exercise care to avoid chance of this type of contamination. During evacuation, all valving must be in the open position to eliminate trapping of non-condensable gases. Care should be taken to ensure that valves inside walk-ins before the unit-coolers and inside the display cases are also opened. Solenoid valves and electronic expansion valves should be opened by powering the solenoids coils or other controls; if the control system is not yet operational, the valves must be manually opened to ensure a successful evacuation.

5. If multiple evacuations are performed (e.g. triple-evacuation), the vacuum should only be broken in between successive evacuations using CO2 vapor, not CO2 liquid or other gases.

6. In some applications or depending on local regulations, a separate field pressure test may be required once the CO2 piping has been completed. This testing must be coordinated with the customer, the local officials requiring the testing, and the Hill PHOENIX Field Service Department. Contact your Hill PHOENIX representative for additional information.

G. INSULATION

1. General Guidelines

a. In general, insulation shall be in accordance with local building codes and the customer's and insulation manufacturer's specifications.

b. The use of insulation material other than those listed in this specification requires the written approval of Hill PHOENIX and the customer.

c. The purpose of insulation on the piping system is to reduce heat transfer between the fluid lines and surrounding ambient, prevent condensation or ice formation on the pipe surfaces, and minimize corrosion of the piping materials. When insulation requirements are determined, the following major factors are considered:

- Application (Fluid) Temperature
- Ambient Conditions including:
  - Dry-Bulb Temperature
  - Relative Humidity
  - Surrounding Air Velocity
- Insulation Material
- Desired Performance

The application temperature considered in this manual is a CO_2 supply temperature of -15 to -20°F. Systems with significantly higher or lower temperatures should consult the insulation manufacturer for proper thickness recommendations.

Insulation has been sized for two different ambient conditions. These are:

- **Normal Conditions:** Maximum severity of 85°F dry bulb temperature, 70% relative humidity, and 0 ft/min air velocity.
- **Severe Conditions:** Maximum severity of 90°F dry bulb temperature, 80% relative humidity, and 0 ft/min air velocity.

The normal design condition is applicable for most indoor air-conditioned environments in the U.S. A typical supermarket indoor design point of 75°F dry bulb temperature and 55% relative humidity can be considered equivalent to this normal condition for the purpose of sizing insulation. Although insulation thickness is given for the more difficult condition of "severe", determination of which of these to use will be dependent on local ambient conditions and should be evaluated for each installation site. It is also important to realize that in some air-conditioned environments, air at or near the ceiling or roof can be higher in temperature and that evaluation of these conditions is extremely important for systems containing overhead piping.

d. The insulation sizes recommended in this section are designed to limit heat gain into the piping network and as a rule, are one size larger than for control of condensation only. Although insulation could be sized and installed for the purpose of prevention of condensation only, the additional heat transfer through the insulation would result in lower energy efficiency of the refrigeration system, and possible system malfunction during peak load and/or high ambient conditions.

Hill PHOENIX recommends the use of insulation sized for "Normal-Conditions" for typical indoor air-conditioned space and insulation sized for "Severe-Conditions" for outdoor applications and non-conditioned spaces.

f. All valves, controls, and fittings in contact with CO2 shall be insulated in a manner which facilitates easy removal for component servicing. Components shall also be insulated to minimize air pockets or voids which can, over time, collect moisture.

g. To minimize insulation thickness requirements and reduce heat gain to the refrigerated piping, it is strongly recommended that the contractor avoid, wherever possible, running piping in non-air-conditioned spaces.

2. **Insulation Materials**

a. The following materials are recommended as insulation for field-installed SNLT2 system piping:
- Flexible Closed-Cell Elastomeric Foam
- Styrofoam
- Trymer

b. The most common materials used for field-installed piping are flexible, closed-cell, elastomeric materials. Products of this type are manufactured by both Armacell and Nomaco. Technical information and detailed installation instructions for these materials may be obtained from the contacts below:

Armacell LLC
7600 Oakwood St. Ext.
Mebane, NC 27302
Ph.: 919-304-3846
Web: www.armaflex.com

Nomaco K-Flex
100 Nomaco Drive
Youngsville, NC 27596
Ph: 800-765-6475
Web: www.kflexusa.com

c. Also acceptable for field-installed piping are Styrofoam and Trymer. Both products of the Dow Chemical Company, these materials are manufactured in rectangular bunstock and fabricated into sheets, pipes, and fittings. Styrofoam is an expanded, extruded, closed-cell polystyrene foam and Trymer is a polyurethane-modified polyisocyanurate cellular foam. Both materials have a minimum insulation thickness of 1" and both should be covered with appropriate vapor-barrier (e.g. Saran) and jacketing material. Additional information on these materials may be obtained from:

Dow Plastics
The Dow Chemical Company
PO BOX 1206
Midland, MI 48641
Ph.: 866-583-2583
Web: www.dow.com

d. Table 8 indicates thickness for elastomeric and rigid insulation materials for SNLT2 applications for normal and severe ambient conditions. The normal condition applies to most indoor air-conditioned environments. The severe condition applies to any outdoor applications or when piping is installed in most non-conditioned spaces.

Table 8. Recommended Insulation Thickness for Normal and Severe Conditions

PIPE SIZE (OD)	NORMAL CONDITIONS 85°F Dry Bulb 70%RH, 0 fpm	SEVERE CONDITIONS 90°F Dry Bulb 80%RH, 0 fpm
3/8"	1-1/2" *	1-1/2" *
1/2"	1-1/2" *	1-1/2" *
5/8"	1-1/2"	1-1/2" *
3/4"	1-1/2"	2"
7/8"	1-1/2"	2"
1-1/8"	1-1/2"	2"
1-3/8"	1-1/2"	2"
1-5/8"	1-1/2"	2"
2-1/8"	1-1/2"	2"

* - For closed-cell elastomeric insulation materials, more than one layer may be required.

3. **Under-Floor and Under-Ground Pipe Installations**

a. In locations where it is not possible to install piping overhead, under-floor piping is permitted, though not recommended. Under-floor piping shall be insulated with a minimum of 1" insulation and shall be installed inside PVC piping or equivalent rigid pipe to prevent damage to the insulation material. Where the insulated piping exits the PVC pipe, the void between the insulation and the PVC pipe shall be filled with expanded polyurethane foam to prevent air from entering the pipe.

b. Hill PHOENIX does not recommend "direct burial" of insulated piping – for applications where this is required, the insulation manufacturer shall be consulted.

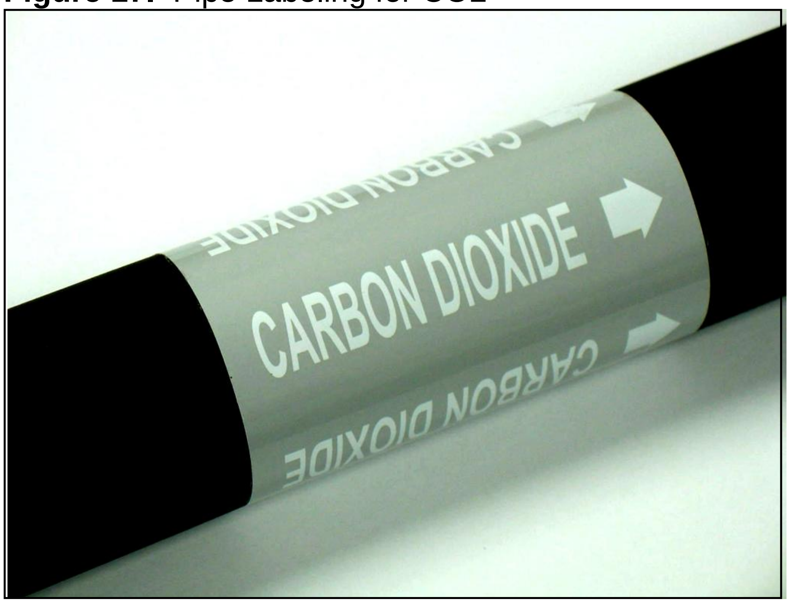
H. LABELING INFORMATION

1. All CO2 containing piping, whether factory or field installed, shall be provided with labels which provide the following information:

   - Fluid Type, i.e. Carbon Dioxide
   - Arrows indicating direction of flow

   Figure 17 below shows an example of proper labeling for CO2 piping.

   Figure 17. Pipe Labeling for CO2



2. In general, it is recommended that labeling comply with ANSI/ASME Standard A13.1-81, “Scheme for the Identification of Piping Systems”.

3. Pipe labeling materials may be obtained from a variety of suppliers of pipe identification products including Brimar Industries and Seton. Additional information may be obtained from:

Brimar Industries
64 Outwater Lane
Garfield, NJ 07026
Ph. 800-274-6271
Web: www.brimar.com

Seton
20 Thompson Road
Branford, CT 06405
Ph. 800-243-6624
Web: www.seton.com

V. SYSTEM OPERATION

A. START-UP ORDER

The general sequence of operation of the start-up of the SNLT2 System is as follows:

1. Start Primary System (Low-Temperature HFC System).
2. Break Vacuum on CO2 system and pressurize low-side (low-temperature suction) to 250 psig with CO2 Vapor with all valves in open position.
3. Turn on ACU, if equipped, charging refrigerant if necessary
4. Close liquid solenoids on all circuits and inside all display cases and unit-coolers.
5. Close liquid isolation valves on each circuit or loop leaving the CO2 rack.
6. With the ACU operational (if installed) and at least one Condenser-Evaporator operating, charge CO2 liquid into the liquid-vapor separator to the 80% level, adjusting charge in the ACU and primary refrigeration system as necessary.
7. Verify direction of pump rotation once pumps have been cooled.
8. Start-up CO2 Pump and turn on low-temperature circuits one at a time.

B. CHARGING CO2

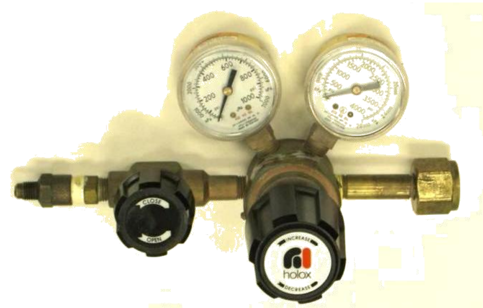
1. <u>Required Equipment and Materials:</u> The following parts and materials will be needed to perform charging of CO2 into the system. Unless otherwise specifically noted, obtaining these materials is the responsibility of the refrigeration contractor starting up the system.
   - **CO2 Vapor Cylinders** – Enough Coleman-Grade CO2 Vapor to pressurize the system to 250 psig. Three 50 lb. cylinders are generally adequate for average-sized systems.
   - **CO2 Liquid Cylinders** – Enough Coleman-Grade CO2 to fill the receiver to the 80% level. The amount of required charge is supplied by your Hill PHOENIX representative. High-pressure tanks are recommended for this process.
   - **Charging Hoses** – 3/8” or larger, rated to at least 900 psig working pressure, with check valves removed. 3/8” hoses will increase the rate of charging compared with 1/4” hoses.
   - **CGA-320 Adapter Fitting** - for CO2 cylinder to connect to flare connection on charging hoses for liquid charging.
   - **Gas Regulator** for vapor charging with CGA-320 connection, designed for at least 300 psig supply (outlet) pressure.
   - **Filter/Drier** - for charging vapor and liquid CO2.

All connections on CO2 cylinders (liquid and vapor) are CGA-320 fittings. Adapters for this fitting type are required in order to connect charging hoses directly to these tanks. Figure 18 below shows a typical adapter fitting for connecting hose with flare connection to a CGA-320 connector.

Regulators are required for charging vapor CO2 into the system to ensure that the maximum allowable working pressure is not exceeded. Regulators for CO2 come equipped with a CGA-320 connection. Regulators for CO2 can be obtained from the supplier of the CO2 and should be equipped for a downstream supply pressure of at least 300 psig. Figure 18 shows a typical regulator suitable for use with CO2.

Figure 18. CGA-320 Adapter Fitting and Regulator

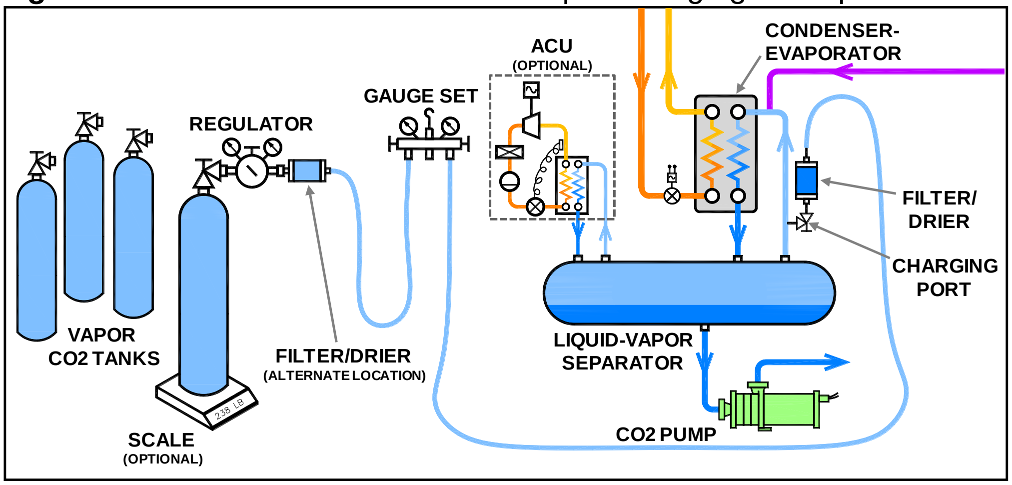
CGA-320 HOSE ADAPTER



CGA-320 REGULATOR

2. Charging Set-Up: Once the CO2 piping network has been verified to be leak free and has passed pressure testing and evacuation per customer specifications, the system is ready to be charged with CO2. Figure 19 illustrates the proper set-up for breaking the vacuum and charging CO2 Vapor. A filter/drier should be installed in between the CO2 cylinder and the charging connection to help prevent unwanted moisture from entering the system – this drier may be located on the system at the location of the charging port. Typical of any charging procedure, the hoses and manifold gauge should be purged of air using CO2 vapor prior to hooking the hose up to system. All hoses and manifold gauges used should be designed for a working pressure of at least 900 psig. Hoses suitable for use with R-410A typically are designed for this pressure; consult the manufacturer of the hose to verify pressure ratings.

Figure 19. Vacuum Break and CO2 Vapor Charging Set-Up



3. <u>Breaking the Vacuum:</u> The vacuum should be broken only with CO2 vapor. CO2 liquid introduced into evacuated piping will immediately form dry ice, very cold temperatures, and could present a serious safety risk along with damage to the equipment. The vacuum should be broken with CO2 vapor in all parts of the CO2 side of the system and with all valves in the open position. This includes liquid lines, suction lines, evaporators, filter/driers, and all main and auxiliary condenser-evaporators.

4. <u>Initial Vapor Charge:</u> Enough CO2 vapor should be charged into the entire system and piping distribution network to bring the CO2 pressure up to 250 psig.

   Note: Further charging should only be performed when the Primary (Low-Temperature HFC) Refrigeration System is ready to operate continuously or reliable operation of the optional Auxiliary Condensing Unit (ACU) has been established.

   Note: Prior to charging liquid refrigerant, the solenoid valves located at the low-temperature display cases and unit-coolers should all be in the closed position.

5. <u>Charging Methods:</u> Procedures for charging both liquid and vapor follow. Experience in the laboratory and in the field with other CO2 systems has shown that charging with high-pressure liquid cylinders is the preferred method in terms of both simplicity and speed.

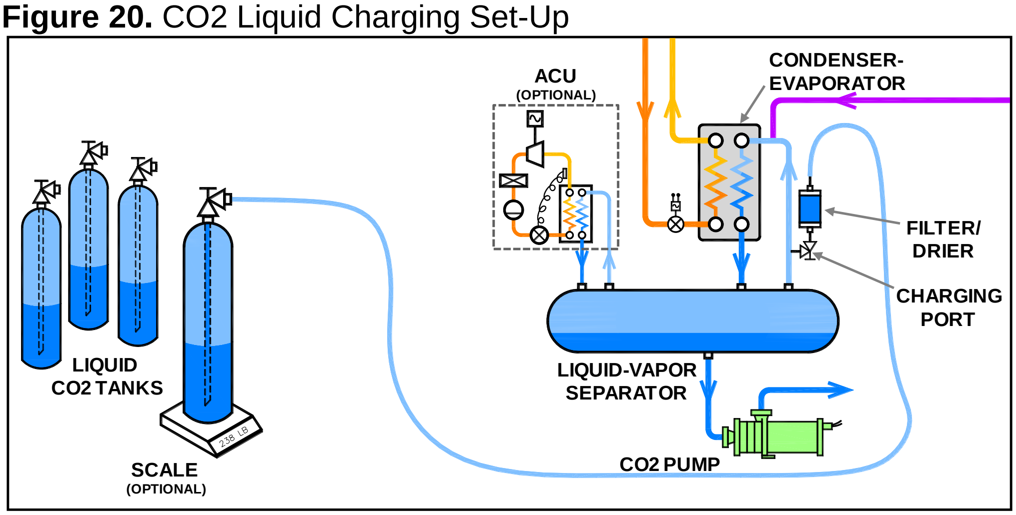
6. <u>Charging with CO2 Liquid:</u> This method of charging relies on the higher pressure in the CO2 liquid cylinders to force the liquid from the cylinders into the system. Equipment set-up for

charging CO2 from high-pressure liquid tanks is shown below in Figure 20. No regulator is used when charging liquid – regulators are designed for use with vapor only - throttling from the higher pressure tank to the lower pressure system is done by the valve on the CO2 cylinder. **Care should be taken to open the valve slowly** such that the tank empties in about 5 minutes. Having a scale under the tank is useful for assessing the charging rate. Charging should be discontinued when the 80% level in the separator is reached.

Safety recommendations by the Compressed Gas Association should be followed closely. Care should be taken to never trap liquid CO2 in a hose between two valves without protection by pressure relief valves as the pressure can rise quickly resulting in a dangerous condition.

A typical full 100 lb. cylinder contains approximately 50 lbs. of useable CO2 that can be charged into the system. Unlike vapor charging, liquid charging enables the removal of the full 50 lbs. of CO2 from the cylinder. When the cylinder is empty, a small amount of frost will form at the base of the tank indicating that the last available amount of liquid has been removed and only vapor remains. At this time, the tank valve should be closed and the tank changed. The hose should be purged of air using CO2 vapor from the system prior to charging from a fresh tank of liquid CO2. Do not purge the hose with CO2 liquid as dry ice may form, clogging the hose and creating an unsafe condition.

Figure 20. CO2 Liquid Charging Set-Up



7. <u>Charging with CO2 Vapor:</u> This method of charging relies on the refrigerating effect of the upper-cascade refrigeration system for charging. CO2 vapor enters the system where it liquefies in the condenser-evaporator and drains into the separator. As vapor

is drawn from the CO2 cylinders, a small amount of liquid will evaporate at the bottom of the tank, dropping the temperature and pressure of the tank contents, and reducing the rate of flow of vapor into the system. This process will be evident by the formation of frost on the lower outside surface of the tank. Once flow from the tank has slowed to a low level, the cold cylinder should be disconnected and allowed to warm (See "Warming CO2 Cylinders" below). A fresh (warm) tank should then be connected to the system to continue the charging process. Charging should be discontinued when the 80% level in the separator is reached (see "Charge Capacity" below). Equipment set-up for this type of charging is shown in Figure 19.

A typical full 100 lb. cylinder contains approximately 50 lbs. of useable CO2 that can be charged into the system. On the first charge attempt, 20-25 lbs. of CO2 vapor can typically be obtained from the cylinder prior to reaching a low-temperature/pressure of the tank. After the tank warms, additional CO2 can be obtained from the cylinder.

8. Warming CO2 Cylinders: Recommended procedures to warm tanks include the following:

   - Placing the tanks in a warm environment (outside or in sun)
   - Directing airflow at the tanks using an un-heated fan

   Hill PHOENIX does *NOT* recommend direct heating of CO2 cylinders to raise the pressure/temperature of the contents. Safe use and handling of the CO2 cylinders should always follow proper guidelines as recommended by the Compressed Gas Association. Additional information on CO2 cylinder handling may be obtained from:

   Compressed Gas Association
   4221 Walney Road
   5th Floor
   Chantilly, VA 20151
   Ph.: 703-788-2700
   Web: www.cganet.com

9. Charge Capacity: The CO2 Separator has been sized to accommodate the entire charge of CO2 required for proper operation of the refrigeration system. The level switches mounted on the receiver should be monitored during charging

and the separator should be filled to the 80% level. When this level is reached, charging should be discontinued.

Note: *DO NOT FILL THE SEPARATOR ABOVE THE 80% LEVEL. Overfilling of the CO2 separator can result in unexpected release of CO2 by the relief system.*

10. ACU Testing: Once the CO2 Separator has been charged with CO2 to the 80% level, and prior to start-up of the CO2 compressors, the operation of the Auxiliary Condensing Unit, if equipped, should be tested. The Auxiliary Condensing Unit may need to be charged with refrigerant and this should be done per the condensing unit manufacturer's specifications.

    The Auxiliary Condensing Unit (ACU) has been designed to maintain the CO2 pressure in the separator at a saturation temperature of around +16°F, which is equivalent to about 380 psig. Proper evaporating temperature in the primary side of the ACU should be around 10°F. Evaporating pressure will depend on the primary refrigerant being used.

C. STARTING THE CO2 PUMP

1. Preparation: Prior to starting the CO2 pumps, the following requirements should be met:
    - The primary (HFC) system has been started and is able to run continuously
    - The Auxiliary Condensing Unit (ACU) is available to run - if needed - and proper operation has been verified.
    - The CO2 Separator has been charged with liquid to the 80% level.
    - Controller Programming is Complete.
    - Electrical Connections to the Display Cases and Walk-Ins have been completed and proper operation of lights, fans, and anti-sweat heaters has been established.

2. Cool-Down: Valves surrounding the pump should have been opened prior to charging the separator with CO2. If this was not done during the charging process, these valves should be slowly opened to allow liquid CO2 to flow into the suction strainers and the primary and secondary pumps. After these have cooled for a few minutes, the valves connecting the pumps to the liquid supply manifold may be opened. At this point, the pumps and connecting piping should be allowed to completely cool down to the temperature of the liquid CO2 - this may take up to 30 minutes.

Note: *Prematurely starting the CO_2 pump may result in permanent damage to the pump motor from cavitation and overheating.*

Once complete cool-down of the pumps and connecting piping has been accomplished, the pumps are ready to be started and proper rotation verified.

3. Pump Bypass: All CO_2 pumps are equipped with a bypass line which directs a minimum amount of CO_2 liquid flow from the pump discharge, through an orifice of specific size, and then into the liquid-vapor separator. Any valves located in the bypass lines should be in the open position whenever the pump is operational and should only be closed for maintenance of the pump. The CO_2 pump includes a hermetic liquid-cooled motor which relies on a steady flow of CO_2 liquid to keep the motor at a safe operating temperature. Closing the discharge path of CO_2 flow, or "dead-heading" the pump can quickly lead to overheating of the motor and subsequent pump failure.

   Note: *The CO_2 pump should NEVER be operated with the bypass valves in a closed position – this can cause reduced flow of CO_2 to the motor and result in serious malfunction or failure of the pump.*

5. Pump Rotation: Prior to starting refrigeration to the circuits, the proper rotation of each pump should be verified. This verification is based on obtaining the proper pump differential pressure during brief operation of the pump with flow through the bypass only.

   With the bypass valves in the open position, and flow to the liquid circuits still in the closed position, the pump should be turned on for a brief period of 5 to 10 seconds to check the pump differential pressure (outlet pressure minus inlet pressure) and current draw of the pump motor. In a reverse rotation condition, the differential pressure produced by the pump will be 60-70% of the head produced with the proper rotation.

Note: *Centrifugal pumps will produce a positive pressure increase regardless of direction of rotation. Verification of a positive pump differential pressure is NOT an indication of proper rotational direction.*

Once the differential pressure and current draw have been noted for one direction of rotation, the wiring entering the contactor should be reversed in phase and the process repeated. Whichever phase wiring results in the higher pump differential pressure and higher current draw represents the proper rotational direction.

Information on design pump head at the minimum flow condition along with expected current draw of the pump motor should be indicated in the Instruction Manual shipped with the refrigeration system.

Verification of proper rotational direction should be performed for each of the CO2 pumps independently. Following this procedure, the evaporator circuits can be started.

Most SNLT2 systems are designed as two pump systems with only one pump operating at a time. Hill PHOENIX recommends an “equal runtime” control strategy where the pumps are switched every 24 hours.

D. STARTING THE LOW-TEMPERATURE EVAPORATOR CIRCUITS

1. Prior to starting the flow of CO2 to the low-temperature evaporators, verification of the operation of the solenoid valves and evaporator fans at the display cases and unit-coolers should be performed.

2. The best results will be obtained by starting supply of refrigeration to the evaporator circuits one at a time rather than all at once. This will prevent excessive pressure increase in the liquid-vapor separator which will automatically turn off the pump. Before each circuit is turned on, verification of operational fans should be made, and defrost heaters, if equipped, should be off.

3. As circuits are turned on and additional load is applied to the system, the remaining condenser-evaporators should be turned on. During this process, the HFC charge and oil levels of the upper-cascade rack should monitored closely.

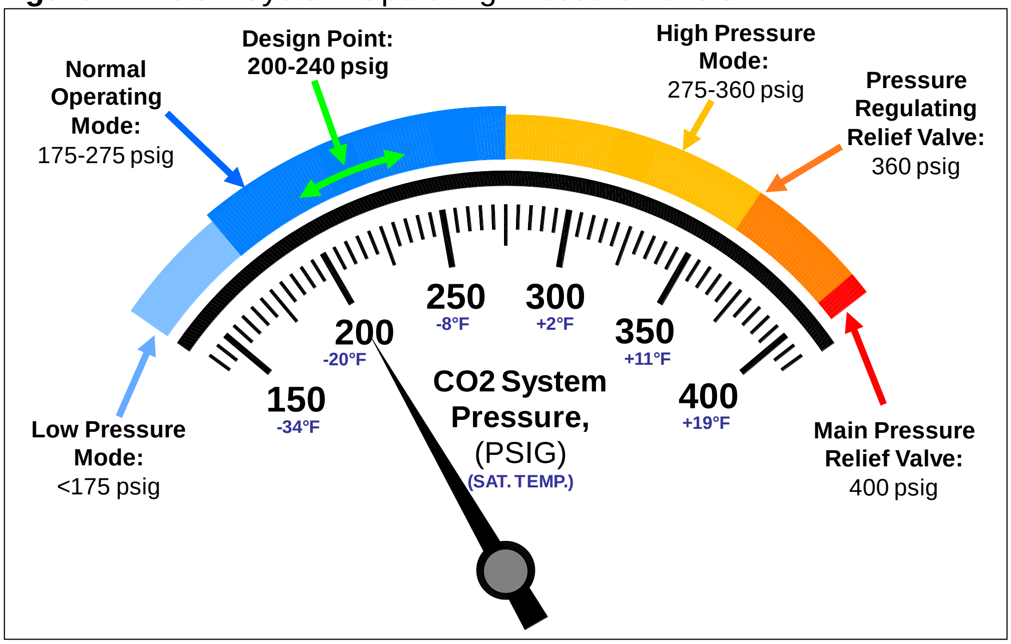
4. A Remote Defrost Panel is typically installed which controls the valves, defrost heaters and evaporator fans for all circuits (display cases and walk-ins). Power to this panel is disconnected any time the CO2 pumps are off, as detailed in the section on system controls, operation, and setpoints.

E. SYSTEM OPERATION, CONTROLS, AND SETPOINTS

1. **Operating Pressures** – Figure 21 shows typical operating pressures for the SNLT2 system designed for a typical -20°F evap. temp. for low-temperature refrigeration.

   NOTE: *For systems designed at lower or higher evaporating temperatures, lower or higher CO2 pressures may be experienced – see the refrigeration schedule supplied with the equipment for actual design conditions.*

Figure 21. CO2 System Operating Pressure Levels



Operating Pressures: *(for -20°F design conditions)*

Normal Operating Pressure:	*175-275* psig
Low Pressure:	*<175 psig*
High Pressure:	*275-360 psig*
Pressure Regulating Relief:	*360 psig*
Main Pressure Relief:	*400 psig*

Pressures lower than 175 psig should only be encountered in the event of a significant leak of CO2 out of the system.

System Max. Pressure: *400 psig*
This is the system MAWP or Maximum Allowable Working Pressure and is the pressure at which the main relief valves will release CO2 to the atmosphere.

2. **Pressure Controls** – A number of controls have been provided to prevent excessive high-side pressure in the event of unusually high load, or lack of cooling capability from the upper-cascade HFC system.

- Pump Shutdown: As the separator pressure reaches 300 psig, a CO_2 Pump Shutdown is initiated by the system controller. This turns off the CO_2 pumps which reduces load on the system. The pumps are also shutdown if the liquid level in the liquid-vapor separator falls below the 5% level.
- Master Defrost Shutdown: As the separator pressure rises to 325 psig, the controller initiates a Master Defrost Shutdown Alarm. This alarm is designed to remove the majority of heat load into the CO_2 system while the primary HFC system cools the CO_2 and brings pressures down to an acceptable level. During the Master Defrost Shutdown Alarm, all solenoid valves in the low-temperature evaporators are closed, all evaporator fans are turned off, and defrost heaters are disabled. Control of the evaporator valves, fans, and defrost heaters may be located within a Remote Defrost Panel (RDP) – in this situation, control power is removed to the RDP performing the various shutdown functions simultaneously.
- CO_2 Relief: If the discharge pressure still continues to rise, the Pressure Regulating Relief Valve will open at a setting of 360 psig to allow a small amount of CO_2 out of the separator vessel. The removed volume of this CO_2 will be replaced by a small amount of CO_2 liquid evaporating from the vessel which cools the surrounding liquid. The Pressure Regulating Relief Valve is designed to reseat once pressure is reduced. If pressure continues to rise, the Main CO_2 Pressure Relief Valves will open at a pressure of 400 psig.

3. **CO_2 Separator Liquid Level Switches** – A number of liquid level switches have been provided to give information on the amount of CO_2 liquid inside the liquid-vapor separator. The switches may be installed either directly on the separator shell or on a column adjacent to the separator.

- **Low Liquid Level Switches** – Low liquid level switches have been installed at the 15% and 5% levels of the separator. If the level falls below the 15% level, a warning should be initiated to indicate that the CO_2 level is low and that additional CO_2 should be added. The 5% level switch allows operation of the CO_2 pump when the level is at or above this position. If the level falls below 5%, the pump will automatically turn off and an alarm should be initiated to indicate that the CO_2 level has fallen below the safe operating level for the pump and that additional CO_2 must be added to raise the level to at least 15% during normal system operation.

- **High Liquid Level Switch** – A high liquid level switches has been installed at the 80% level on the separator. The 80% level switch indicates the maximum level to which the separator should be filled for safely operating the system – this switch is used primarily for CO_2 charging during system start-up. An additional 90% level switch, if installed, indicates that and excessive amount of CO_2 has been charged into the system. If this level is reached, an alarm should be initiated and CO_2 should be removed from the system until the 80% level is reached.

Additional switches between the 15% and 80% levels may be installed on the separator for informational purposes and to give an idea of the level of CO_2 present in the separator during normal system operation.

4. **Auxiliary Condensing Unit Controls** – The ACU, if equipped, is designed to turn on when any of the following conditions occur:
   - Manual Switch is turned ON
   - Rack experiences a Master Defrost Shutdown Alarm
   - Rack experiences a Phase-Loss Alarm
   - ACU EMS Output Closes, based on CO_2 separator pressure reaching 350 psig.

   When the ACU Manual Switch is turned from the AUTO to the ON position for any reason, a relay will alert the controller to initiate a NOTICE.

5. **CO_2 Pressure Transducers** – Pressure transducers are to be 0-500 psig or higher and may vary with controller manufacturer.

6. **Upper-Cascade Main Liquid Solenoid Valve to CO_2 Condenser-Evaporators** – the solenoid valve located on the upper-cascade liquid line supplying the condenser evaporators should close when any of the following occur:
   - Controller Output OPENS when all MT compressors are out on Oil Failure or Run Proof
   - Rack experiences a Phase-Loss Alarm
   - Upper Cascade Main Liquid Line SV Manual Switch is turned OFF

7. **Alarms Specific to SNLT2 System** – The following additional alarms should be programmed into the controller and are specific to this system.
   - Low CO2 Pressure Alarm – Any CO2 pressure transducer reaching 150 psig Cut-Out, 170 psig Cut-In.
   - High CO2 High-Side Pressure Alarm – Any High-Side CO2 pressure transducer reaching 550 psig Cut-In, 490 psig Cut-Out.
   - High CO2 Low-Side Pressure Alarm – Any Low-Side CO2 pressure transducer reaching 325 psig Cut-In, 325 psig Cut-Out after 10 minute delay.
   - Master Defrost Shutdown Alarm – on initiation of alarm signal
   - Pump Failure Alarm – on initiation of alarm signal

F. EVAPORATOR TEMPERATURE CONTROLS AND BALANCING

1. **Balancing Through Proper Piping and Circulation Rate** – The piping system layout and pipe sizes have been sized to provide equivalent pressure drop and proper flow rate to all the evaporators connected to the system. Combining this with flooded coil operation should ensure that additional balancing using a balance valve is not required. In this manner, strict attention should be followed to installing the pipe sizes as specified on the refrigeration schedule and installation drawings, if provided. For circuits that are operating too cold or at too low of a discharge air temperature, warming can be accomplished through use of temperature control (see section 2. Temperature Control below). An example of this is a Produce case operating on a system designed for Fresh Meat temperatures.

2. **Low-Temp CO2 Evaporator Temperature Control** – For systems containing only one supply temperature of CO2, it may be desired to raise the temperature of some cases to warmer conditions rather than operate all cases at the coldest temperatures (e.g. ice cream vs. frozen food cases). This is accomplished by cycling (opening and closing) the refrigeration solenoid valve based on the status of the discharge air temperature and its proximity to the desired setpoint. Setpoints for controlling discharge air temperature should be limited to a deadband of 1°F or less to maintain steady control.

3. **Balancing with the Isolation/Balance Valves** – On some systems, isolation/balance valves have been included as part of the evaporator piping. If installed, and only as a final measure, these valves can be used to adjust the distribution of the supply

of CO_2 to the various circuits. Prior to adjustment of any balance valve, any other factors that may affect display case operation should be eliminated. These include improper size or installation of the piping, improper trapping of the risers into the horizontal runs, malfunctioning of display case fans or drains, etc. Field experience has indicated that use of the balancing valves supplied with the cases should not be necessary.

Evidence that an evaporator is not receiving enough CO_2 liquid is the presence of superheat at the exit of the coil. This can be observed by measuring the temperature of the supply and return lines entering and leaving the coil. A properly functioning coil will have a return line temperature equal to or slightly less than the temperature entering the coil which is an indication that some amount of liquid CO_2 is exiting the coil with the vapor. If all the liquid evaporates in the coil, the vapor will warm and rise above the supply CO_2 temperature indicating a superheat condition and a starving coil. To increase the flow of liquid to this evaporator, the balance valves on surrounding evaporators should be closed slightly, diverting additional liquid into the starving coil.

Evaporators which have solenoid valves configured in the controller to perform either temperature control or dual-temp. operation may exhibit superheated vapor leaving coil during certain periods. These temperature control operations should be disabled while attempting to balance flow between evaporators.

4. **Dual-Temperature Operation of Low-Temp Cases** – Dual-temp. operation of a display cases is obtained by cycling the solenoid valve based on the status of the discharge air temperature setpoint. Dual temp. operation is initiated by either a change in programming at the controller, or through the use of a switch located at the display case which alerts the controller to the desired change in operation.

   Information on recommended discharge air temperatures for display cases can be obtained from the display case manufacturer. For Hill PHOENIX cases, this information is found in the “Display Case Refrigeration Requirements Table” which is available from your local Hill PHOENIX representative. Additional information can be obtained from:

   Web: www.hillphoenix.com

G. EVAPORATOR DEFROSTING

1. Defrost Type: Low-temperature CO2 evaporators, and some selected medium-temperature evaporators are operated with electric defrost as outlined below.

2. Electric Defrost Process: Defrosting of the CO2 evaporators in display cases and freezers is very similar to that of direct expansion systems with conventional refrigerants using electric defrost. There are three phases of evaporator electric defrost: pumpdown mode, heating mode, and drip-mode.

   - **Pumpdown Mode** – At the initiation of the defrost cycle, the refrigeration solenoid valve or EEV is closed for a 13-20 minute period. This allows any liquid CO2 remaining in the coil to evaporate or boil-off prior to the start of the heating cycle. The term “pumpdown” is used to equate this process to that of a direct expansion process, though no change in pressure will occur in the coil. During this pumpdown period, the evaporator fans MUST BE RUNNING to properly evaporate the remaining liquid CO2 inside the coil.

   - **Heating Mode** – During heating mode, the electric defrost heaters are turned on, raising the temperature of the coil and melting the accumulated ice. Heating mode is typically terminated when a certain location on the coil surface has reached a desired termination temperature and lasts from 30 to 60 minutes depending on the case model. For walk-in unit-coolers, the temperature probe is located on the coil u-bend where the defrost klixon or thermostat is normally located. For all CO2 coil types, the set-points for termination temperature and maximum defrost time (fail-safe time) are identical to those for electric defrost in traditional direct expansion systems.

     Defrost Termination Note: If a wide variety of case lengths have been installed on a common circuit, the smaller cases have a tendency to reach termination faster than larger cases. A defrost klixon and relay is recommended on the smaller cases to allow termination of the heating mode and prevent over-heating while the larger cases are allowed to continue defrosting. These controls can be either factory- or field-installed.

Controller Programming Note: Some EMS controllers include the pumpdown time as part of the fail-safe time total – in these situations, the failsafe time should be increased by the amount of the pumpdown time to ensure proper defrost. Consult manual for the EMS system for further information.

- **Drip Mode** – The drip mode (drain-time, run-off mode) is the period of time following termination of heating and prior to opening of the refrigeration solenoid valve. During this time, the condensate melted during defrost is allowed to drip off the coil and make its way to the case or evaporator drain. For CO2 coils, the set-point for the drip time is identical to that of the direct expansion setpoints for electric defrost and lasts from 6 to 15 minutes depending on case model.

3 Evaporator Fan Controls: During defrost, the evaporator fans for display cases and walk-ins are controlled differently:

- **Display Cases:** Control of fans during defrost in display cases is automatic and no additional controls are required. Coffin-style or open-multideck cases operate the fan continuously during all modes of defrost. Reach-In cases contain a fan klixon which will automatically turn off the evaporator fans when the coil temperature rises to a pre-determined level and turn the fans back on once the coil is cooled after the start of refrigeration – the fans are off primarily during the heating and drip modes of the defrost cycle.

- **Walk-In Unit-Coolers:** Control of fans during defrost in walk-in freezers is performed by the system controls. The fan contactors for low-temperature walk-ins are typically installed at the location of the refrigeration system and are field-wired to the walk-in unit-coolers. The fans will be left on during the pumpdown mode, then turned off during the heating and drip modes. The fan contactor will be turned on at the start of refrigeration, though a fan-delay thermostat mounted on the unit-cooler may delay start of fan operation until the coil surface is cooled to a predetermined value. Fans in medium-temperature walk-ins operate continuously.

4. Defrost Schedules: Standard defrost schedules can be applied to CO2 evaporators. The number of defrosts required per day is identical to that of a conventional direct expansion system.

As with any refrigeration system, defrosts should be scheduled such that no more than 20% of the system is in defrost at one time. This will ensure that the pressure in the receiver does not rise to an unacceptable level when the defrosted circuits return to refrigeration operation.

H. WALK-IN FREEZER DOOR SWITCHES

The control of refrigeration in walk-in freezers using door switches is strongly recommended, and door switches should be wired directly to the EMS system to facilitate the best controls. When a walk-in freezer door is opened, the evaporator fan should be turned off and the EEV should be given a closure signal immediately. The control must also be programmed such that if the door is opened during the pumpdown mode of the defrost cycle, the fan shutdown is over-ridden to ensure successful pumpdown and subsequent defrost of the unit-coolers.

I. TROUBLESHOOTING AND REPAIRS

1. High CO2 Pressure: High pressure in the CO2 system can be a result of problems experienced on either the Primary (HFC) system or the Secondary (CO2-side) of the system.

   Primary System Causes of High CO2 Pressure:
   - Low Refrigeration Capacity of Upper-Cascade System
   - High Evaporating Pressure on Upper-Cascade caused by:
     - High Refrigeration Load
     - Low Capacity of Refrigeration System
     - Malfunction of Primary-Side Expansion Device

   Secondary System Causes of High CO2 Pressure:
   - Non-Condensable Gases in Condenser-Evaporator
   - High Evaporator Load
   - High Store Ambient Conditions (Temperature or Humidity)

2. Non-Condensable Gases: Non-condensable gases can enter a CO2 system through insufficient evacuation, improper venting of charging hose, or impurities in the CO2 charged into the piping. As in conventional refrigeration systems, non-condensable gases will tend to collect in or near the condensers and at high points in the system. If non-condensable gases are suspected, these can be purged from the piping using the vent valves located in the CO2 line entering each of the condenser-evaporator heat exchangers.

3. <u>Leak Repairs:</u> If the piping network must be opened to perform maintenance on or to replace a piece of equipment, or to repair a leak, the following procedure should be followed:

    1. If possible, close isolation valves in a manner that allows liquid to drain from the section of pipe in between the valves. (Example: in a vertical line, close the upper valve first, then allow liquid to drain from the section of pipe and be replaced by vapor, then close the lower valve.)

    2. If liquid will not drain naturally into the surrounding piping, CO2 vapor (from a cylinder with regulator at 200-300 psig) can be introduced into a access or vent connection to force or "push" the liquid into surrounding piping.

    3. For display cases or walk-in freezers, the supply isolation valve should be closed and the case can then be put through a short defrost cycle – the heat provided by the defrost heaters will boil remaining CO2 liquid which will return to the system through the return lines.

    4. Once isolation valves are closed, remaining liquid can be drained from access valves at a low point in the piping. If liquid is to be drained from the piping, a gauge should be installed at a high point in the piping to ensure that the pressure does not fall below 100 psig while liquid remains in the pipe.

    5. After all liquid has been removed, the remaining vapor pressure can be released from the piping and the pipe opened safely.

    6. While the piping network is open, it is a good idea to allow small amount of CO2 vapor to continuously circulate through the pipe (regulator set at 10 psig) – this will prevent moist air from entering the piping and condensing on cold surfaces inside.

    7. After the work on the system is complete, the piping should be evacuated, the vacuum should be broken with CO2 vapor, and the piping should be pressurized with vapor to 200 psig. The isolation valves may then be safely opened to the connecting piping.

4. Turning Off the CO_2 System: Occasionally it may be required to stop the entire CO_2 system in order to perform regular or preventive maintenance on the secondary or primary systems. The CO_2 system (secondary system) should always be shut down prior to turning off the primary (HFC) system in order to prevent loss of CO_2 through the relief valves. The order of events to properly turn off the lower cascade is:

   a. Pumpdown Rack by turning off CO_2 pumps using switch on control panel. Fans will remain running during this pumpdown period and CO_2 refrigerant will be moved to the CO_2 receiver.
   b. The Primary system may be used to keep the CO_2 pressure within acceptable limits during maintenance on the CO_2 system. Best performance of the primary system may be obtained by using only one condenser-evaporator while the CO_2 system is off.
   c. If the primary system must also be turned off, turn on the Auxiliary Condensing Unit (ACU), if equipped.
   d. If both the secondary and primary systems are turned off for a long period of time (several hours) and no ACU is equipped, the release of some CO_2 from the Pressure Regulating Relief Valve may occur and is part of the normal system operation. If this occurs, it may be necessary to add CO_2 to the system during or after the restart of the lower-cascade.

5. Turning On the CO_2 System after Shutdown: After the required maintenance has been performed and the primary system is operating or has been re-started, the secondary should be re-started using the procedures outlined previously in the sections "Starting the CO_2 Pump" and "Starting the Evaporator Circuits".

6. Low-Temperature Evaporator Troubleshooting:

Refrigeration: If Low-Temperature Evaporators are not refrigerating properly, check for the following parameters:

- Field-installed isolation valve is closed
- Solenoid valve at evaporator is not receiving signal to open
- Solenoid coil has failed

Defrost: If Low-Temperature Evaporators are experiencing difficulty defrosting, check the following parameters:

- The solenoid valve is not closing due to lack of closure signal or blockage of the seat with debris
- The case is piped backwards such that the supply and return pipes have been reversed (note that the solenoid valves used will not hold backpressure and will open if outlet pressure is higher than inlet pressure)
- The case is piped correctly, but the solenoid valve is piped backwards

Appendix 1 – Pressure-Temperature Chart for CO2

R-744 (CO_2) PRESSURE-TEMPERATURE CHART

Temp. °F	Pres. PSIG	Temp. °F	Pres. PSIG	Temp. °F	Pres. PSIG	Temp. °F	Pres. PSIG	Temp. °F	Pres. PSIG
-50	103.4	-20	200.2	10	345.7	40	552.9	70	838.1
-49	106.0	-19	204.2	11	351.5	41	561.0	71	849.3
-48	108.6	-18	208.3	12	357.4	42	569.3	72	860.5
-47	111.2	-17	212.4	13	363.4	43	577.6	73	871.8
-46	113.9	-16	216.5	14	369.5	44	586.0	74	883.3
-45	116.6	-15	220.8	15	375.6	45	594.5	75	894.9
-44	119.4	-14	225.0	16	381.8	46	603.1	76	906.7
-43	122.3	-13	229.4	17	388.0	47	611.7	77	918.5
-42	125.1	-12	233.8	18	394.3	48	620.5	78	930.5
-41	128.0	-11	238.2	19	400.7	49	629.3	79	942.6
-40	131.0	-10	242.7	20	407.2	50	638.3	80	954.9
-39	134.0	-9	247.3	21	413.8	51	647.3	81	967.3
-38	137.0	-8	251.9	22	420.4	52	656.5	82	979.8
-37	140.1	-7	256.6	23	427.1	53	665.7	83	992.5
-36	143.3	-6	261.3	24	433.8	54	675.0	84	1005
-35	146.5	-5	266.1	25	440.7	55	684.5	85	1018
-34	149.7	-4	271.0	26	447.6	56	694.0	86	1032
-33	153.0	-3	275.9	27	454.6	57	703.6	87	1045
-32	156.3	-2	280.9	28	461.7	58	713.3		
-31	159.7	-1	285.9	29	468.8	59	723.1		
-30	163.1	0	291.0	30	476.1	60	733.1		
-29	166.6	1	296.2	31	483.4	61	743.1		
-28	170.1	2	301.5	32	490.8	62	753.2		
-27	173.7	3	306.8	33	498.3	63	763.4		
-26	177.3	4	312.1	34	505.8	64	773.8		
-25	181.0	5	317.6	35	513.4	65	784.2		
-24	184.8	6	323.1	36	521.2	66	794.8		
-23	188.5	7	328.6	37	529.0	67	805.5		
-22	192.4	8	334.2	38	536.9	68	816.2		
-21	196.3	9	339.9	39	544.8	69	827.1		

Appendix 2 – Pressure-Temperature Chart for Common Refrigerants

Hill PHOENIX Pressure-Temperature Chart for Commercial Refrigeration

Temp. °F	REFRIGERANT						
	R-507 (AZ-50)	R-404A (HP-62)	R-410A (AZ-20)	R-22 (Freon)	R-407A (Klea)	R-744 (CO_2)	R-717 (NH_3)
-50	0.9	*0.1"*	4.9	*6.1"*	*9.0"*	103.4	*14.3"*
-49	1.3	0.3	5.4	*5.4"*	*8.4"*	105.9	*13.8"*
-48	1.7	0.7	5.9	*4.8"*	*7.7"*	108.6	*13.3"*
-47	2.1	1.2	6.5	*4.1"*	*7.1"*	111.2	*12.8"*
-46	2.6	1.6	7.0	*3.4"*	*6.4"*	113.9	*12.3"*
-45	3.0	2.0	7.6	*2.7"*	*5.7"*	116.6	*11.7"*
-44	3.5	2.4	8.2	*1.9"*	*5.0"*	119.4	*11.2"*
-43	3.9	2.9	8.8	*1.2"*	*4.3"*	122.3	*10.6"*
-42	4.4	3.4	9.4	*0.4"*	*3.5"*	125.1	*10.0"*
-41	4.9	3.8	10.0	0.2	-1.4	128.0	*9.4"*
-40	5.4	4.3	10.7	0.6	-1.0	131.0	*8.8"*
-39	5.9	4.8	11.3	1.0	-0.6	134.0	*8.1"*
-38	6.4	5.3	12.0	1.4	-0.2	137.0	*7.5"*
-37	7.0	5.8	12.6	1.8	0.2	140.1	*6.8"*
-36	7.5	6.3	13.3	2.2	0.6	143.3	*6.1"*
-35	8.0	6.8	14.0	2.6	1.0	146.5	*5.4"*
-34	8.6	7.4	14.7	3.1	1.4	149.7	*4.7"*
-33	9.2	7.9	15.4	3.5	1.9	153.0	*4.0"*
-32	9.8	8.5	16.2	4.0	2.3	156.3	*3.2"*
-31	10.3	9.0	16.9	4.4	2.8	159.7	*2.4"*
-30	10.9	9.6	17.7	4.9	3.3	163.1	*1.6"*
-29	11.6	10.2	18.5	5.4	3.7	166.6	*0.8"*
-28	12.2	10.8	19.3	5.9	4.2	170.1	0.0
-27	12.8	11.4	20.1	6.4	4.7	173.7	0.4
-26	13.5	12.0	20.9	6.9	5.2	177.3	0.8
-25	14.1	12.7	21.8	7.4	5.7	181.0	1.3
-24	14.8	13.3	22.6	8.0	6.3	184.8	1.7
-23	15.5	14.0	23.5	8.5	6.8	188.5	2.2
-22	16.2	14.6	24.4	9.1	7.4	192.4	2.6
-21	16.9	15.3	25.3	9.6	7.9	196.3	3.1
-20	17.6	16.0	26.2	10.2	8.5	200.2	3.6
-19	18.3	16.7	27.1	10.8	9.1	204.2	4.1
-18	19.1	17.4	28.1	11.4	9.7	208.3	4.6
-17	19.8	18.2	29.0	12.0	10.3	212.4	5.1
-16	20.6	18.9	30.0	12.6	10.9	216.5	5.6
-15	21.4	19.7	31.0	13.2	11.5	220.8	6.2
-14	22.2	20.4	32.0	13.9	12.2	225.0	6.7
-13	23.0	21.2	33.1	14.5	12.8	229.4	7.3
-12	23.8	22.0	34.1	15.2	13.5	233.7	7.8
-11	24.6	22.8	35.2	15.8	14.2	238.2	8.4
-10	25.5	23.6	36.3	16.5	14.9	242.7	9.0
-9	26.4	24.5	37.4	17.2	15.6	247.3	9.6
-8	27.2	25.3	38.5	17.9	16.3	251.9	10.3
-7	28.1	26.2	39.7	18.7	17.0	256.6	10.9
-6	29.0	27.0	40.8	19.4	17.8	261.3	11.5
-5	30.0	27.9	42.0	20.1	18.5	266.1	12.2
-4	30.9	28.8	43.2	20.9	19.3	271.0	12.9
-3	31.9	29.8	44.4	21.6	20.1	275.9	13.6
-2	32.8	30.7	45.7	22.4	20.9	280.9	14.3
-1	33.8	31.6	46.9	23.2	21.7	285.9	15.0
0	34.8	32.6	48.2	24.0	22.5	291.0	15.7
1	35.8	33.6	49.5	24.8	23.3	296.2	16.4
2	36.8	34.6	50.8	25.7	24.2	301.5	17.2
3	37.9	35.6	52.2	26.5	25.1	306.8	18.0
4	38.9	36.6	53.5	27.4	26.0	312.1	18.8
5	40.0	37.7	54.9	28.3	26.9	317.6	19.6
6	41.1	38.7	56.3	29.1	27.8	323.0	20.4
7	42.2	39.8	57.8	30.0	28.7	328.6	21.2
8	43.3	40.9	59.2	31.0	29.7	334.2	22.0
9	44.5	42.0	60.7	31.9	30.6	339.9	22.9
10	45.7	43.1	62.2	32.8	31.6	345.7	23.8
11	46.8	44.3	63.7	33.8	32.6	351.5	24.7
12	48.0	45.4	65.2	34.8	33.6	357.4	25.6
13	49.2	46.6	66.8	35.8	34.6	363.4	26.5
14	50.5	47.8	68.4	36.8	35.7	369.5	27.5
15	51.7	49.0	70.0	37.8	36.7	375.6	28.4
16	53.0	50.2	71.6	38.8	37.8	381.8	29.4

Temp. °F	REFRIGERANT						
	R-507 (AZ-50)	R-404A (HP-62)	R-410A (AZ-20)	R-22 (Freon)	R-407A (Klea)	R-744 (CO_2)	R-717 (NH_3)
17	54.3	51.5	73.2	39.9	38.9	388.0	30.4
18	55.6	52.7	74.9	40.9	40.0	394.3	31.4
19	56.9	54.0	76.6	42.0	41.2	400.7	32.4
20	58.2	55.3	78.4	43.1	42.3	407.2	33.5
21	59.6	56.6	80.1	44.2	43.5	413.8	34.6
22	61.0	58.0	81.9	45.3	44.7	420.4	35.6
23	62.3	59.3	83.7	46.5	45.9	427.1	36.8
24	63.8	60.7	85.5	47.6	47.1	433.8	37.9
25	65.2	62.1	87.4	48.8	48.3	440.7	39.0
26	66.7	63.5	89.2	50.0	49.6	447.6	40.2
27	68.1	64.9	91.1	51.2	50.9	454.6	41.4
28	69.6	66.4	93.1	52.4	52.2	461.7	42.6
29	71.1	67.8	95.0	53.7	53.5	468.8	43.8
30	72.7	69.3	97.0	55.0	54.8	476.1	45.0
31	74.2	70.8	99.0	56.2	56.2	483.4	46.3
32	75.8	72.4	101.0	57.5	57.6	490.8	47.6
33	77.4	73.9	103.1	58.8	59.0	498.3	48.9
34	79.0	75.5	105.2	60.2	60.4	505.8	50.2
35	80.7	77.1	107.3	61.5	61.8	513.4	51.6
36	82.3	78.7	109.5	62.9	63.3	521.2	52.9
37	84.0	80.3	111.6	64.3	64.8	529.0	54.3
38	85.7	82.0	113.9	65.7	66.3	536.9	55.7
39	87.4	83.7	116.1	67.1	67.8	544.8	57.2
40	89.2	85.4	118.3	68.6	69.4	552.9	58.6
41	90.9	87.1	120.6	70.0	70.9	561.0	60.1
42	92.7	88.8	123.0	71.5	72.5	569.3	61.6
43	94.5	90.6	125.3	73.0	74.1	577.6	63.1
44	96.4	92.4	127.7	74.5	75.8	586.0	64.7
45	98.2	94.2	130.1	76.1	77.4	594.5	66.3
46	100.1	96.0	132.6	77.6	79.1	603.0	67.9
47	102.0	97.9	135.0	79.2	80.8	611.7	69.5
48	104.0	99.8	137.5	80.8	82.5	620.5	71.1
49	105.9	101.7	140.1	82.4	84.3	629.3	72.8
50	107.9	105.3	143.2	84.1	104.2	638.3	74.5
51	109.9	107.2	145.8	85.7	106.2	647.3	76.2
52	111.9	109.2	148.4	87.4	108.2	656.5	78.0
53	114.0	111.2	151.1	89.1	110.2	665.7	79.8
54	116.1	113.3	153.8	90.8	112.3	675.0	81.6
55	118.2	115.3	156.5	92.6	114.4	684.4	83.4
56	120.3	117.4	159.3	94.3	116.5	694.0	85.2
57	122.5	119.5	162.1	96.1	118.6	703.6	87.1
58	124.6	121.7	164.9	97.9	120.8	713.3	89.0
59	126.8	123.8	167.8	99.8	123.0	723.1	91.0
60	129.1	126.0	170.7	101.6	125.2	733.1	92.9
61	131.3	128.2	173.7	103.5	127.4	743.1	94.9
62	133.6	130.4	176.6	105.4	129.7	753.2	96.9
63	135.9	132.7	179.7	107.3	132.0	763.4	99.0
64	138.3	135.0	182.7	109.3	134.3	773.8	101.1
65	140.6	137.3	185.8	111.2	136.6	784.2	103.2
66	143.0	139.7	188.9	113.2	139.0	794.8	105.3
67	145.4	142.0	192.1	115.2	141.4	805.5	107.5
68	147.9	144.4	195.3	117.3	143.9	816.2	109.7
69	150.3	146.9	198.5	119.3	146.3	827.1	111.9
70	152.8	149.3	201.8	121.4	148.8	838.1	114.1
71	155.4	151.8	205.1	123.5	151.3	849.2	116.4
72	157.9	154.3	208.4	125.7	153.9	860.5	118.7
73	160.5	156.8	211.8	127.8	156.4	871.8	121.1
74	163.1	159.4	215.2	130.0	159.1	883.3	123.5
75	165.8	162.0	218.7	132.2	161.7	894.9	125.9
76	168.5	164.6	222.2	134.5	164.3	906.7	128.3
77	171.2	167.3	225.7	136.7	167.0	918.5	130.8
78	173.9	169.9	229.3	139.0	169.8	930.5	133.3
79	176.7	172.7	232.9	141.3	172.5	942.6	135.9
80	179.5	175.4	236.5	143.6	175.3	954.9	138.4
81	182.3	178.2	240.2	146.0	178.1	967.3	141.0
82	185.1	181.0	244.0	148.4	181.0	979.8	143.7
83	188.0	183.8	247.7	150.8	183.8	992.5	146.4

Temp. °F	REFRIGERANT						
	R-507 (AZ-50)	R-404A (HP-62)	R-410A (AZ-20)	R-22 (Freon)	R-407A (Klea)	R-744 (CO_2)	R-717 (NH_3)
84	190.9	186.6	251.6	153.2	186.7	1005	149.1
85	193.9	189.5	255.4	155.7	189.7	1018	151.8
86	196.9	192.5	259.3	158.2	192.6	1032	154.6
87	199.9	195.4	263.3	160.7	195.6	1045	157.4
88	202.9	198.4	267.3	163.2	198.7	ABOVE CRITICAL POINT	160.3
89	206.0	201.4	271.3	165.8	201.7		163.1
90	209.1	204.5	275.4	168.4	204.8		166.1
91	212.3	207.5	279.5	171.0	208.0		169.0
92	215.4	210.7	283.6	173.7	211.1		172.0
93	218.6	213.8	287.8	176.4	214.3		175.0
94	221.9	217.0	292.1	179.1	217.6		178.1
95	225.2	220.2	296.4	181.8	220.8		181.2
96	228.5	223.4	300.7	184.6	224.1		184.4
97	231.8	226.7	305.1	187.4	227.4		187.5
98	235.2	230.0	309.5	190.2	230.8		190.8
99	238.6	233.4	314.0	193.0	234.2		194.0
100	242.1	236.8	318.5	195.9	237.6		197.3
101	245.6	240.2	323.1	198.8	241.1		200.6
102	249.1	243.6	327.7	201.8	244.6		204.0
103	252.6	247.1	332.4	204.7	248.2		207.4
104	256.2	250.6	337.1	207.7	251.7		210.9
105	259.9	254.2	341.9	210.8	255.3		214.4
106	263.5	257.8	346.7	213.8	259.0		217.9
107	267.2	261.4	351.5	216.9	262.7		221.5
108	271.0	265.1	356.5	220.0	266.4		225.1
109	274.8	268.8	361.4	223.2	270.1		228.8
110	278.6	272.5	366.4	226.4	273.9		232.5
111	282.4	276.3	371.5	229.6	277.8		236.2
112	286.3	280.1	376.6	232.8	281.6		240.0
113	290.3	284.0	381.8	236.1	285.5		243.9
114	294.2	287.9	387.0	239.4	289.5		247.7
115	298.3	291.8	392.3	242.8	293.5		251.6
116	302.3	295.8	397.6	246.1	297.5		255.6
117	306.4	299.8	403.0	249.5	301.5		259.6
118	310.5	303.8	408.4	253.0	305.6		263.7
119	314.7	307.9	413.9	256.4	309.8		267.8
120	318.9	312.0	419.4	260.0	314.0		271.9
121	323.2	316.2	425.0	263.5	318.2		276.1
122	327.5	320.4	430.6	267.1	322.4		280.3
123	331.8	324.7	436.4	270.7	326.7		284.6
124	336.2	329.0	442.1	274.3	331.1		288.9
125	340.7	333.3	447.9	278.0	335.4		293.3
126	345.1	337.7	453.8	281.7	339.9		297.7
127	349.7	342.1	459.8	285.4	344.3		302.2
128	354.2	346.6	465.7	289.2	348.8		306.7
129	358.8	351.1	471.8	293.0	353.4		311.2
130	363.5	355.6	477.9	296.9	357.9		315.8
131	368.2	360.2	484.1	300.8	362.6		320.5
132	372.9	364.9	490.3	304.7	367.2		325.2
133	377.7	369.6	496.6	308.6	371.9		330.0
134	382.6	374.3	503.0	312.6	376.7		334.8
135	387.5	379.1	509.4	316.7	381.5		339.6
136	392.4	383.9	515.9	320.7	386.3		344.5
137	397.4	388.8	522.5	324.8	391.2		349.5
138	402.4	393.7	529.1	329.0	396.2		354.5
139	407.5	398.7	535.8	333.2	401.1		359.6
140	412.7	403.7	542.5	337.4	406.2		364.7
141	417.9	408.8	549.3	341.6	411.2		369.8
142	423.1	413.9	556.2	345.9	416.3		375.0
143	428.4	419.1	563.2	350.3	421.5		380.3
144	433.8	424.3	570.2	354.6	426.7		385.6
145	439.2	429.6	577.3	359.0	431.9		391.0
146	444.7	434.9	584.5	363.5	437.2		396.4
147	450.2	440.3	591.7	368.0	442.6		401.9
148	455.8	445.7	599.0	372.5	448.0		407.4
149	461.5	451.2	606.4	377.1	453.4		413.0
150	467.2	456.8	613.9	381.7	458.9		418.7

BOLD VALUES = psig, *ITALIC VALUES = VACUUM (Inches of Mercury)*, RED VALUES = BUBBLE POINT (Liquid), BLUE VALUES = DEW POINT (Vapor)

Note: All data from NIST Refprop 7.0

SECOND NATURE™