Advanced CO_2
Booster Refrigeration System
Installation, Start-Up
and Operating Manual

MAY 2020

DISCLAIMER

This manual is designed to provide only general information. If you need advice about a particular product application or installation, you should consult your Hillphoenix Representative. The applicable specification sheets, data sheets, handbooks, and instructions for Hillphoenix products should be consulted for information about that product, including, without limitation, information regarding the design, installation, maintenance, care, warnings relating to, and proper uses of each Hillphoenix product.

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This volume is intended for use by Advansor Booster System Installation and Start-Up Refrigeration Technicians

Hillphoenix

Refrigeration Systems Division

ADVANSOR CO_2 BOOSTER SYSTEM INSTALLATION, START-UP, AND OPERATION

Version 4

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Section 1

Advansor CO_2 Booster Refrigeration Systems

1..A SCOPE OF SPECIFICATIONS

These specifications 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 Hillphoenix Advansor CO2 Booster Refrigeration System (hereafter referred to as Advansor) only. Failure to follow these specifications will void the manufacturer's warranty.

1..B GENERAL NOTICE

a. The Advansor system (equipment, devices, piping, insulation, etc.) shall be installed per the specifications contained in this "Advansor CO2 Booster Refrigeration System Installation, Start-Up, and Operating Manual," the Hillphoenix Refrigeration Schedule (Legend) and the system piping diagram and installation drawings (if provided).

b. Any changes that are not approved by Hillphoenix will void the warranty of the system.

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

1..C ADVANSOR SYSTEM BASICS

I.C.I INTRODUCTION

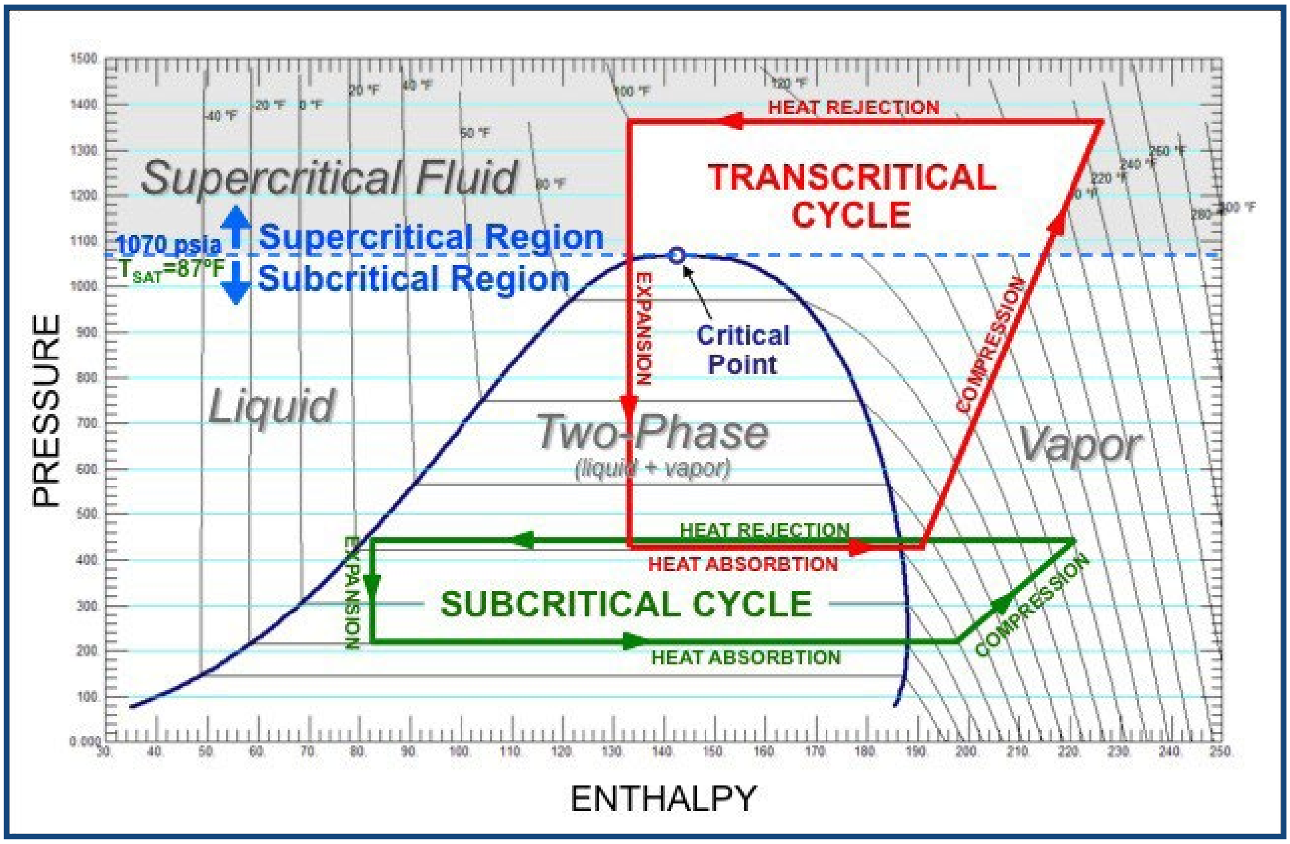
Advansor CO2 Booster Refrigeration Systems are the latest option in the Hillphoenix Second Nature product line that for the first time entirely utilize natural refrigerant. The Advansor system is the third type of CO2 system following the SNLT2 Secondary Coolant system and SNLTX2 Cascade system. Advansor systems, however, are not intended as a replacement to SNLT2, SNLTX2 systems, or any other type of system as each approach has unique characteristics that make them suitable for specific applications.

Advansor systems are considered Transcritical CO2 systems where the pressure of the CO2, depending on ambient conditions and other factors, may rise above the critical pressure of CO2. Operating pressures for these systems are higher than those in conventional direct-expansion systems. The components in the system and the entire system moreover, have been engineered to safely and efficiently handle those pressures. Typical operating pressures for Advansor systems are shown on page 28 of this manual.

1.C.II HOW THE SYSTEM WORKS

CO2 has a number of unique properties that make it ideal for use as a refrigerant in general and as refrigerant for booster systems in particular. The critical point of a substance is the point at which its liquid and vapor states cannot be distinguished. The critical point of CO2 for instance, is around 88 Fahrenheit and is lower than that of other refrigerants such as R-134a (214 ° F) and R-410a (162 ° F). Systems using these refrigerants operate in the subcritical region all of the time. Systems using only CO2 to reject heat to ambient temperatures, on the other hand, do not always operate in the subcritical region. That requires system designers to approach the heat transfer process somewhat differently than they would for more commonly used refrigerants.

As the critical point is approached, the gas and liquid phases of a substance advance toward one another, resulting in only one phase at the critical point: a homogeneous supercritical fluid. There is no distinction between the two phases above this point. Above the critical temperature no additional amount of pressure will cause liquid to form.



The critical point is important in understanding the operation of the CO2 booster system. With its use of compressors, the system works in some ways like any other direct expansion (DX) system but with a key difference. In a conventional DX system, the entire operation of the system takes place below the critical point, or in the subcritical region. Within this region, the refrigerant changes back and forth between only vapor and liquid. But as already pointed out, above the critical point another state is reached, that of a supercritical fluid and within that region no further state change such as condensation occurs.

The term “critical point” refers to when an indistinct physical state of a substance is reached. It does not in any way imply any difficulty in dealing with the substance. It simply means that at a temperature and pressure above the critical point there is no distinction between the liquid and vapor states of a substance. In fact, above the critical point, a substance is said to exist as a supercritical fluid in which no further state change can occur, only changes in density can take place

Certain aspects of the Advansor system will be familiar to anyone who knows how a traditional DX system works. Like those systems, the Advansor system has four main components that include compressors, evaporators, condensers, and expansion valves. Additionally, the system uses two types of specialized valves: a high-pressure control valve and a flash gas bypass valve.

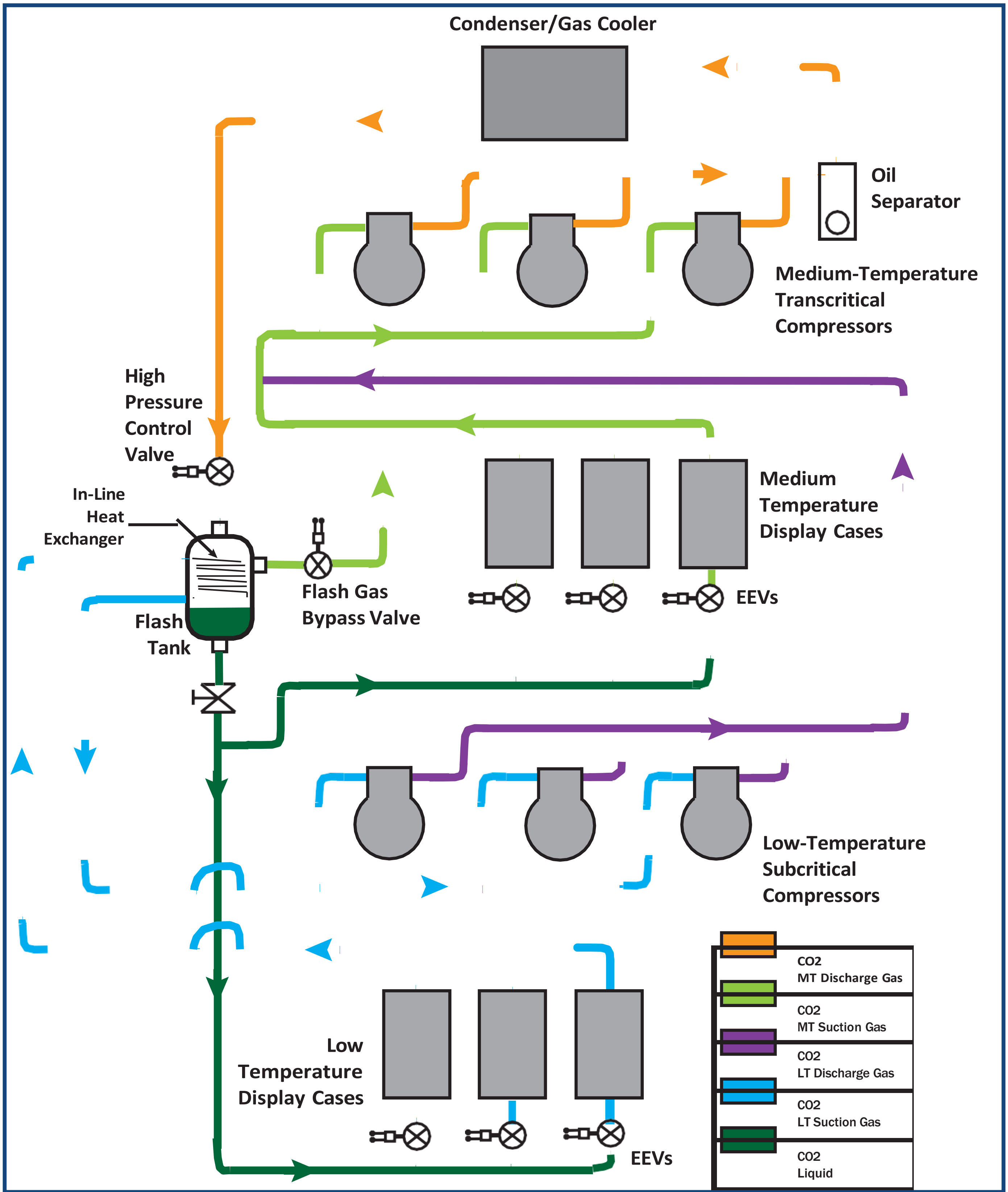
Another key difference from traditional systems is that functionally the system operates as what is known as a two-stage booster system with
the same refrigerant moving between the low and medium-temperature compressors. The low-temperature compressors discharge to the suction of the medium-temperature compressors. In other words, the medium-temp compressors serve as a booster to the low-temp compressors.

Suction gas from the low-temperature display case and freezer evaporators enters the low-temperature subcritical compressors at around 200 psig, well below the critical point for CO2. The low-temp discharge gas at about 400 psig, then combines with the medium-temp suction gas from the medium-temp display cases and walk-in cooler evaporators before entering the medium-temp transcritical compressors. The medium-temp discharge gas leaves the compressors, depending on ambient conditions, anywhere from 560 psig to as much as 1450 psig, which is above the critical point.

The medium-temperature compressors normally operate at pressures from 855 to 1290 psig depending upon ambient conditions.

Under warmer conditions in which the pressure rises above 1055 psig, the system enters the transcritical range. Under either condition, however, hot discharge gas from the medium-temp compressors feeds to a condenser/gas cooler where, as with any refrigeration system, the heat is rejected to the outside environment.

The page which follows depicts a simplified piping layout of an Advansor Booster System. Please take a few minutes to study this piping layout to gain an understanding of the locations of the various components and their locations relative to each other.



Simplified Diagram of the Advansor Booster System Piping

The sizing of the compressors on the low-temperature and medium-temperature stages of the system is carefully determined to provide optimal capacity control during partial load operation.

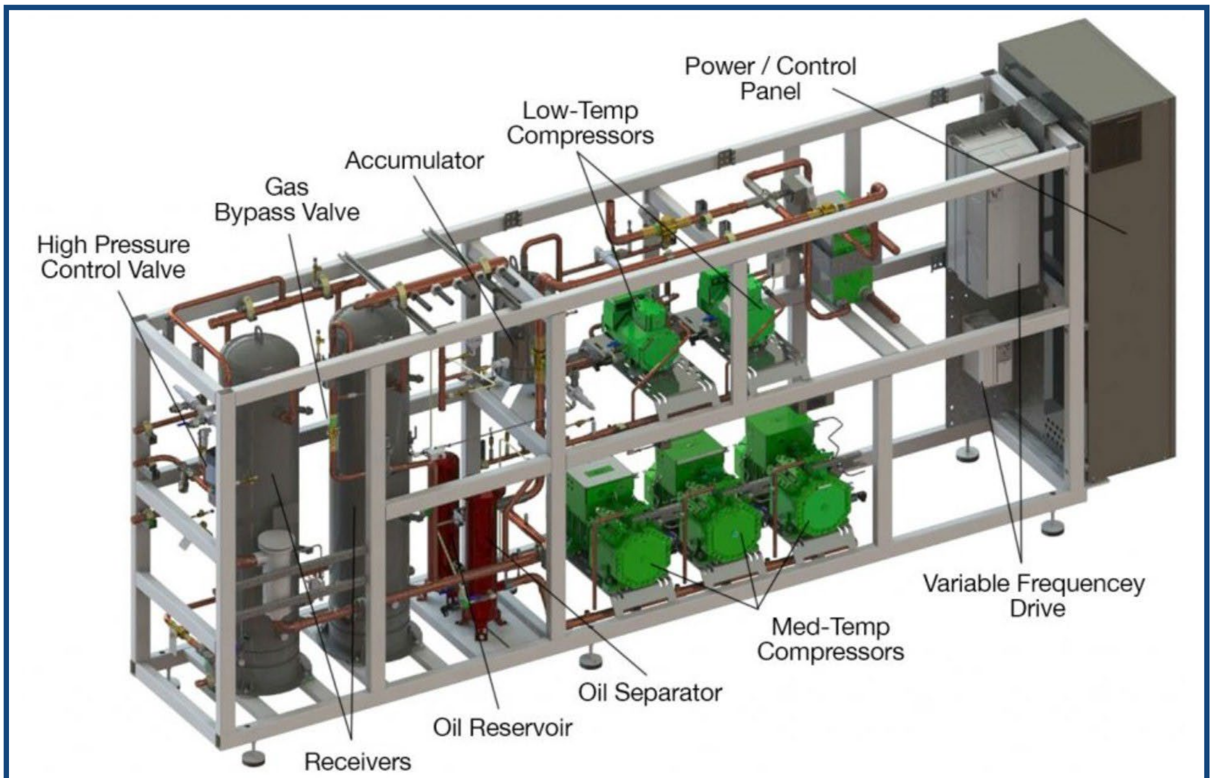
The condenser/gas cooler design is optimized to accomplish high-performance, even at high ambient temperatures when the system is operating in the transcritical range. (More about how these components work and their specific operation is described in greater detail in the next section.)

The CO2 leaving the condenser/gas cooler feeds to a high-pressure control valve that regulates the flow of CO2 into an intermediate pressure receiver, called a flash tank. The gas enters the valve at 560 to 1450 psig, depending on ambient conditions, and exits at approximately 540 psig. The valve is designed to work somewhat like a hold-back valve in order to maintain optimum pressure through the condenser/gas cooler for the most efficient operational performance of the system.

Liquid refrigerant is supplied to the medium and low-temperature evaporators controlled by conventional electronic expansion valves. Vapor from the flash tank is fed through the flash gas bypass valve back to the medium-temperature compressors. The flash gas bypass valve maintains a constant pressure in the flash tank.

Apart from some of the unique components just described, the system works in a similar way to other types of DX systems. The main differences are related to the two-stage design of the system and that all of the evaporators in the system are supplied with liquid from the same source. For most experienced technicians the system will not seem overly complicated.

I.C.III MAJOR SYSTEM COMPONENTS



Simplified Labeled Diagram of an Advansor Booster System Compressor Rack

Advansor CO2 systems use many components that are common to other types of DX systems as well as some that are specifically designed for the application. Like any other DX type of system, the Advansor system relies on the four principle components which include compressors, evaporators, condensers and expansion valves.

1.C.III.a CO2 Compressors

As with any other type of DX system, the CO2 booster system uses compressors to move the refrigerant in it. Unlike most other types of these systems, which are typically divided between medium temperature and low temperature applications, however, the Advansor system uses two sets of compressors in the same system.

The low-temperature "subcritical" compressors operate well below the critical point in much the same way CO2 compressors do in cascade systems. Like those compressors, the ones on the Advansor CO2 system receive suction gas from the low-temp evaporators. The suction gas enters the compressors at 183 psig and the discharge gas leaves them at 410 psig.
At the same time, the discharge from the low temperature compressors combines with gas from the medium-temp evaporators to become the suction gas for the medium-temp compressors.

The Advansor system can use either scroll or semi-hermetic reciprocating compressors for the low-temp portion of the system. These compressors sit on the top of the rack.

Only semi-hermetic reciprocating compressors can be used for medium-temperature portion of the system. These "transcritical" compressors sit on the bottom of the rack. As medium-temp compressors, they discharge at anywhere from 560 to 1450 psig, depending on the ambient conditions. When viewed on a pressure-enthalpy (P-h) chart on page 2, the action of the medium-temp compressors can be seen in the upper section (shaded upper area) of the chart around 385 psig when the gas enters the compressors. From there, again, depending on ambient conditions, the gas may reach to 1385 psig as it discharges from the compressors and enters the condenser/gas cooler. Of course for the gas to reach that range, the ambient conditions must exceed 80°F.

Each compressor is installed with some additional features including:

- Bolted to the frame on oil-resistant polymer mounts
- Equipped with service valves on the suction and discharge sides
- Individual oil switches and pressure switches are included on the discharge side
- Some CO2 compressors contain relief valves to ambient (see the compressor manufacturer's operating specifications for additional information)
- Crankcase heaters to warm the oil whenever the compressors are not running
- Variable frequency drives on the lead compressor for better capacity control

- Optional with the lead low-temperature compressor

- Standard on the lead medium-temperature compressor

1.C.III.b Oil Separator and Oil Requirements

The Advansor system uses the same oil management components system as those on conventional DX systems except that they are designed for the higher operating pressures needed for CO2. These include electronic oil level sensors, a separator, a reservoir, and a filter. Once the medium-temperature discharge gas leaves the medium-temp compressors, it passes through a highly efficient oil separator that uses coalescing filters to separate the oil from the refrigerant. The separator can be used with or without an external oil reservoir. Oil separators are a common component on DX systems of just about any type.

Only manufacturer-approved oil is permissible for use in the Advansor system.
For very small systems (i.e., 2x2 models), the oil separator is equipped with an oil reservoir at the bottom of the unit from which the oil is fed back to the compressors according to demand. On booster rack models with external reservoirs, the oil separator is equipped with a larger filter. The oil from these units is fed from the oil separator to the reservoir through a solenoid valve that opens when the oil reaches a preset level in the separator. From there, the oil is fed from the reservoir to the compressors.

1.C.III.c Condenser/gas cooler

This component usually works the same way a condenser does in a conventional DX system. At ambient conditions below 80°F, medium-temperature discharge gas enters the condenser/gas cooler and rejects heat to the outside air as it passes through the coils of the unit. The main difference between it and a conventional condenser is that when the ambient temperature rises above 80°F, the system begins operating in the transcritical range. This means that the discharge gas passing through the system does not undergo any further state change but instead remains a supercritical gas, or fluid as it is otherwise known. This last point is a key distinction. Under transcritical conditions, the discharge gas enters the condenser/gas cooler as a supercritical fluid and stays that way all the way through the condenser/gas cooler to the high pressure control valve. No condensing of the gas takes place as in a regular condenser. Below 80°F, however, the unit then works just like a condenser in a typical DX system.

In the same way that efficiency gains are made on the compressors through the use of variable speed drives, so too are the fans on the condenser/gas cooler controlled. Also, the condenser/gas cooler is equipped with a shut-off valve for maintenance or other needs.

I.C.III.d High-Pressure Control Valve

Like the condenser/gas cooler, the high-pressure control valve works under two modes of operation. It usually controls subcooling in the condenser/gas cooler when that unit operates as a condenser. Under conditions during which the condenser/gas cooler is working as a gas cooler (above 80°F ambient), the valve controls pressure in it.

The actuator in the valve can be accessed by removing three small bolts. The valve can then be operated manually with a hand magnet if necessary. Power to the valve is furnished from an uninterrupted power supply (UPS). The valve closes in case of a power failure.

I.C.III.e Flash Tank

The expanded gas from the high-pressure control valve flows into the flash tank. The flash tank is equipped with a flash gas bypass valve that maintains a set pressure in the tank. When opened, the valve bypasses excess vapor from the tank to the suction side of medium-temperature compressors.

I.C.IV OTHER SYSTEM COMPONENTS

I.C.IV.a Piping

One of the benefits of CO2 is its high volumetric capacity. This allows for smaller diameter piping to be used than would otherwise be needed for a HFC system of similar capacity. In fact, smaller diameters add to the overall advantages of the system since they decrease the refrigerant charge and handle higher pressures. Piping and elbows to and from the condenser/gas cooler should be carbon or stainless steel and should be installed to comply with appropriate standards. The piping is welded and must be coated with primer and varnish. During operation, the pipes can get hot (i.e., 250°F) and insulation is recommended anywhere they might be touched.

1.D CONTROL STRATEGY

Advansor systems in North America are installed with energy management system controllers specified by the customer. All U.S. made systems, however, use controls on the rack from Danfoss including one specifically for the condenser/gas cooler. The controller ensures the system's maxi mum performance by maintaining the optimal pressure in the gas cooler when regulation takes place in the transcritical range. This method of control provides optimum COP (coefficient of performance). Heat reclaim with a 0-10 volt signal is also available through this approach.

The Advansor system, as pointed out, usually operates in a similar manner to conventional DX systems during the subcritical mode of operation. But since the system is referred to as a transcritical booster system that operates from the subcritical to supercritical range of CO2, there are some significant differences from conventional systems. In order to understand those differences, particularly with respect to how the system is controlled, a simplified configuration of the system that does not include any additional features best illustrates how the system works. The numbers used for this discussion, for instance, are based in part on the system operating in the Hillphoenix lab where the condenser is sized for a five-degree temperature difference (TD). The TD for others systems will depend on the specific requirements of each specific installation. But regardless of those specifics, the control strategy for any Advansor system will change from one to another of three modes of operation (subcritical, transitional, or supercritical) depending on ambient temperature conditions.

1.D.I OPERATIONAL STAGES

1.D.I.a Subcritical Operation

While operating in CO2's subcritical temperature range the high side of the system is controlled by maintaining the liquid outlet temperature from the condenser/gas cooler through the use of two devices: the condenser fans (either variable or constant-speed) and a high-pressure control valve, or ICMT valve. On units with variable speed fan control, the condenser/gas cooler fan motors are wired in parallel so that they all operate at the same speed. The variable speed controlled fans in a sense operate as a single big fan, ramping up and down and cycling on and off together instead of individually.

Taking a condenser sized for a five degree TD (as noted above), both the condenser fans and the ICMT valve work together to maintain three degrees subcooling when ambient temperatures range from 41°F to 72°F. Operating in the subcritical mode, the condenser fans are controlled so that the saturated liquid temperature set point at the exit of the condenser is kept to five degrees above ambient (i.e., at an ambient temperature of 72°F, the saturated liquid temperature set point would be 77°F, and at 41°F ambient the saturated liquid temperature set point would be 46°F. The controller achieves three degree subcooled liquid by taking the saturated liquid temperature set point and calculating how much pressure is needed. The ICMT valve then modulates the refrigerant pressure to maintain the subcooled liquid by 3.6°F. Thermodynamically speaking, when the saturated liquid temperature set point is 77°F, its corresponding saturated pressure is 919 psig. In order to subcool CO2 three-degrees at 77°F, the saturation pressure at 80°F (77° + 3°) that needs to be achieved is 955 psig. The ICMT valve modulates the pressure of the refrigerant so that the CO2 liquid becomes subcooled at 77°F and 955 psig.

A detailed description of how to setup the system from a controls perspective is included in the next section of this manual.

When ambient temperatures are colder than 41°F, the fans in the condenser/gas cooler are generally not needed and will shut off. Natural convection extracts enough heat from the CO2 vapor to condense into a subcooled liquid. The amount of subcooling that occurs when ambient temperatures fall below 41°F is only controlled by the ICMT valve.

1.D.I.b Transitional Operation

When ambient temperatures are between 72° F and 83° F the saturated liquid temperature set point no longer floats to five degrees above ambient. In this range the condenser fan set point is fixed at 77° F. On systems equipped with variable speed controlled fans, the fans vary to maintain the set point in order to cool the CO2 gas as much as possible. Although the ICMT valve starts to use a different algorithm to achieve the three degrees of subcooling, it continues to operate as it does in the subcritical operation mode. Once the ambient temperature hits the condenser/gas cooler discharge saturated liquid set point of 77° F, the fans go full on (100% on variable speed controlled units and all on for non-variable speed controlled systems).

1.D.I.c Transcritical Operation

Above 83° F ambient, the system begins to operate in the transcritical range and the removal of latent heat that occurs in a conventional condenser no longer takes place. At this point the gas (now referred to as a supercritical fluid) cannot be converted to liquid, it can only be cooled. From 83°F and warmer, the system is unable to maintain the five degree above ambient setpoint and can only reduce its sensible heat content by running the fans at full speed.

The control module attached to the ICMT valve determines how to regulate the gas pressure depending on whether the system is in transcritical mode or subcritical mode. While in transcritical operation mode, the ICMT valve reduces the pressure of the supercritical CO2 fluid so that it returns to its subcritical state as a saturated liquid vapor mixture. From there the subcritical liquid vapor mixture reaches the flash tank. Through the flash gas bypass valve a portion of the vapor returns back to the inlet of the medium temp compressors thereby maintaining the flash tank operational pressure. Algorithms controlling the ICMT valve enable it to achieve an optimum COP (coefficient of performance) for the compressors during transcritical operation.

1.E.I DIRECT EXPANSION REFRIGERATION USING CO2

Under normal conditions the system works much like the way a typical DX system does. Once the CO2 refrigerant has accumulated in the flash tank as a liquid, the refrigeration process and control strategy hardly differs from any other kind of DX system. The liquid CO2 is distributed to both the medium and low temperature cases where their respective expansion valves control the refrigerant flow through the evaporator. As the liquid CO2 absorbs heat from the product, it changes phase to a superheated vapor. The vapor from the lines return to the low or medium temperature compressors, where the discharge CO2 is compressed to a pressure and temperature that is similar to the superheated vapor that returns from the medium temperature lines. This CO2 vapor is also mixed with the flash gas bypass CO2 vapor that is coming from the flash gas tank. All three of these vapor sources feed the medium temperature compressor suction line where the whole refrigeration process repeats itself.

1.E.I.a Compressor Control

Compressor control is for the most part, handled like any other type of multiple suction-group DX system. Compressor capacity control is accomplished through the controllers. These controllers work on suction pressure and are a standard means for controlling multiple suction groups in any refrigeration system. The controllers are capable of regulating variable speed for two compressors combined with one-step compressors of the same or different sizes, depending on the choice of coupling pattern.

1.F CO2 PROPERTIES AND HANDLING

Before handling Carbon Dioxide (CO2), the contractor should be familiar with the Material Safety Data Sheet (MSDS) and the materials physical properties. An MSDS for CO2 is available from any supplier of industrial gases or the Compressed Gas Association– see next page.

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 shows selected properties of CO2.

Carbon Dioxide has excellent thermodynamic properties which make
it ideally suited for use as a refrigerant. Table 2 below shows selected properties of CO2 at -20°F and +20°F. A detailed pressure-temperature chart for CO2 is also shown in Appendix A.

Table 1: Selected Properties of Carbon Dioxide

Molecular Weight	44.01
Boiling Point @ 1 atm.	-109.1°F (78.4°C)
Triple Point @ 60.4 psig	-69.8°F (-56.6°C)
Critical Pressure	1055 psig (73.8 barg)
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 CO2

Property	@-20°F (-28.9°C)	@+20°F(-6.7°C)
Saturation Pressure, Psig/ Barg	200.2/13.80	407.2/28.08
Liquid Density, Lb/Ft3	66.9	60.3
Vapor Density, Lb/Ft3	2.40	4.94
Heat of Vaporization, Btu/Lb	129.6	107.5

1.F.I 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 5000 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).

Operating temperatures for an Advansor system are similar to those of other types of DX systems. Typical operating pressures usually range from 870 to 1305 psig on the medium-temp discharge, and approximately 375 psig to 440 psig on medium-temp suction. The low-temp suction pressure operates at approximately 180 to 220 psig. Rapid depressurization of CO2 in liquid or liquid-vapor at pressures below the 60 psig triple point 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

1.F.II 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 (below).

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. Remove non-condensables, which may get charged into the system, by using an available access valve in the system to vent off CO2.

Table 3: Common Grades of CO2

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

Hillphoenix recommends using Instrument (Coleman) Grade CO2 which contains less than 0.01% non-condensable gases and moisture.

Table 4: Specifications of Instrument Grade CO2 impurities

Minimum Purity of CO2	99.99%
Nitrogen, N2	< 50 ppm
Oxygen, O2	< 20 ppm
Water, H2O	< 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 Instrument Grade is not recommended and should only be done in emergency situations.

Although 99.99% purity level (Instrument grade) CO2 is recommended, it is not necessarily required for the system to effectively operate. Using CO2 with purity levels less than that recommended by Hillphoenix is acceptable provided that the following precautions are taken:

a. Include a filter drier in the line as part of the charging process.

b. Thoroughly check for non-condensables, which may get charged into the system and have available a means for removing.

Use of Carbon Dioxide of a higher purity level than 99.99% is also acceptable though typically neither cost effective nor readily available in the quantities usually needed to charge an entire system. To ensure that refrigeration systems operate properly, it is necessary that the purity of the CO_2 (R-744) utilized in R-744 refrigeration systems meets certain standards. These standards are as specified below.

Table below is copied from AHRI Standard 700-2015, page 11, Table 1C

Carbon Dioxide Refrigerant (R-744) and its Allowable Levels of Contaminants		
	Reporting Units	**R-744**
Characteristics		
Sublimation Point[1]	°C at 101.3 kPa	-78.4
Sublimation PointRange	K	±0.3
VAPOR PHASE[2]		
Air and other non-condensables, Maximum	% by volume at 10°C below the critical temperature and measure non-condensable directly	1.5
LIQUID PHASE[3]		
Water, Maximum	ppm by weight	10
High Boiling Residue, Maximum	% by weight	0.0005
Particulates/Solids	Pass or Fail	Visually clean
Minimum Purity	% by weight	99.9
See the Notes for this table at the top of the next page.		

Notes:

1. Sublimation point, sublimation point range, although not required, are provided for informational purposed Refrigerant data compiled from Refprop 9.1.

2. Sample taken from vapor phase.

3. Sample vaporized from liquid phase.

Instrument Grade CO2 is widely available throughout North America by suppliers of industrial gases.

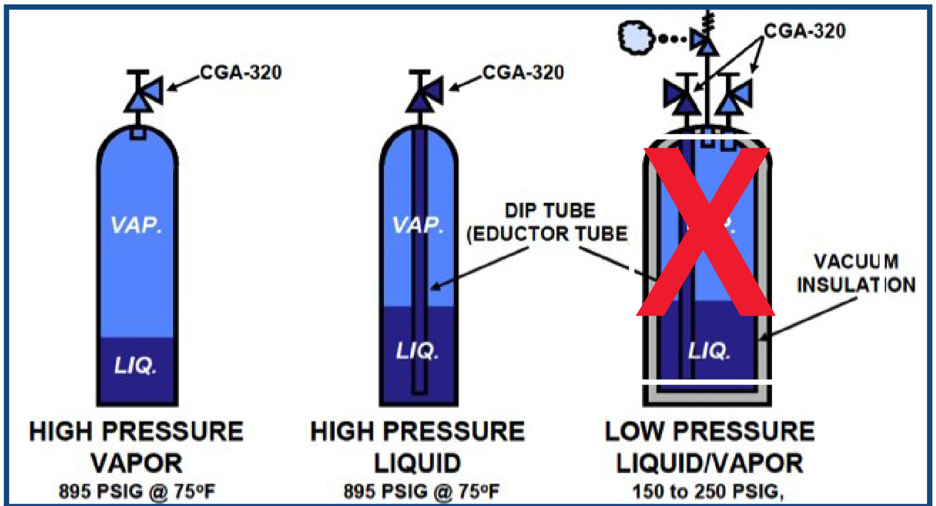
Air Liquide America L.P. 2700 Post Oak Blvd, Suite 1800 Houston, TX 77056 866-822-5638 www.airliquide.com	Praxair, Inc. 39 Old Ridgebury Rd. Danbury, CT 06810 203-837-2000 www.praxair.com	Linde Gas 6055 Rockside Woods Blvd. Independence, OH 44131 216-642-6600 www.us.lindegas.com

I. F.III CO2 CYLINDERS

CO2 is available in both liquid and vapor form and in a variety of cylinder sizes. The most common types and sizes of CO2 Cylinders are shown schematically in Figure 5 and are:

- High-Pressure Vapor Cylinder, 50 lbs of CO2
- High-Pressure Liquid Cylinder, 50 lbs of CO2
- Low-Pressure Liquid/Vapor Cylinder, 350 lbs of CO2

These types of cylinders are NOT APPLICABLE for use with transcritical CO_2 systems.



Different Types of CO2 Cylinders

Note: Low-Pressure Liquid/Vapor cylinders are not recommended for use with booster systems due to their lower pressure ratings.

High-pressure cylinders contain CO2 at a saturation pressure corresponding to the temperature of their surroundings. At a room temperature of 75 °F this corresponds to 895 psig. CO2 can be stored in high-pressure cylinders indefinitely.

Low-pressure cylinders contain CO2 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 CO2 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 CO2 pressure rises until the vent/relief valve opens, releasing vapor CO2. This causes a small amount of CO2 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.

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. Section 2.C.II (page 32) details the various equipment needed for both methods of charging and the different procedures that are required.

1.F.IV 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.

Wall-Mounted CO2 Sensor

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. Different examples of leak detectors which have been used successfully are shown bellow.

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. 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.

Important: CO_2 sensors should also not be mounted near sources of combustion including furnaces, gas heaters, and loading docks as higher levels of CO_2 can be present in these locations.

Examples of Carbon Dioxide Leak Detectors

Emerson Leak Detection System

NOTE

NOTES

Section 2

Advansor Installation, Start-Up, and Operating Procedures

The procedures covered in this manual should be followed along with the installation documentation and any other documentation supplied by the consulting engineers for the complete installation of the refrigeration system. The specific steps described here are only for the installation, testing, and initial start-up of an Advansor refrigeration system. Failure to follow these specifications may void the manufacturer's warranty.

2.A SYSTEM INSTALLATION

A.A ADVANSOR SYSTEM PIPING

Piping line sizes for any type of CO_2 system are generally one to two sizes smaller than those commonly used for HFC applications. The installation drawings for the specific job usually specify what lines sizes are required. However, if line sizes have not been provided or are missing, the Hillphoenix representative for the job should be contacted.

Always keep in mind that any deviation from the line sizes specified by Hillphoenix can result in improper operation of the system.

Liquid supply lines are sized to ensure a proper and evenly distributed pressure drop and velocity of the CO2 liquid. A minimum line size of 3/8" OD is used for both liquid and suction lines. Line sizes are specified by engineering drawings for the specific project and should be strictly adhered to. Changing 3/8" liquid lines to 1/2" size is not recommended as it increases the charge of CO2 required for proper system operation.

Suction return lines carrying vapor CO_2 and small amounts of oil in both horizontal and vertical configurations are sized to ensure the effective return of oil back to the compressors.

Any time that a suction line turns vertically upward, this is considered to be a vertical riser. Follow the line size specifications for vertical risers as stated on the refrigeration schedule or drawings.

2.A.A.a Field Installed Copper Piping Recommendations

Copper pipe is the recommended material for connecting the Advansor rack to evaporators. Any consideration of alternative piping materials should always be reviewed with the Hillphoenix representative for the job.

The Maximum Allowable Working Pressure (MAWP) on the suction side of the Advansor system is generally 220 psig for the low temp, and typically 428 psig for the medium temp. These pressures match the setting of the main Pressure Relief Valves installed on the system (refer to the factory-supplied piping diagram to confirm relief settings and locations). Relief valves set at a higher pressure than the main reliefs are additionally located in selected positions throughout the system to protect specific equipment against pressures higher than their ratings. Type L copper piping can be used on some pipe sizes, however Type K copper should be used on larger sizes. The tables on the previous page show specifications for Type L and Type K copper tubing based on the system design pressures for a maximum operating temperature of 100°F which is applicable for liquid and suction line applications on field installations.

2.A.I.a.i Mueller Streamline Copper Products

Refrigeration brazing is commonly performed at 900°F to 1300°F. **Take Note:** Temperatures in this range involve sufficient heat to anneal copper. Therefore, the working pressure ratings for all Streamline copper tube and wrot fittings should be based on performance in the annealed state—this is true whether referring to actual field brazing or to an annealing furnace. Following years of testing, the Mueller company is able to offer copper products rated for continuous up to **700 psi at 250°F**, as identified in the table provided below. All of these values have already been de-rated for brazing.

Product Line	Product Type	Diameters
Copper Tube	• Streamline Refrigeration Service Coils • Streamline Line Sets & Mini-Splits • Streamline ACR - Type L (Hard Lengths) • Streamline ACR - Type K (Hard Lengths)	⅛” to 1⅛” ⅛” to 1⅛” ⅛” to 1⅜” ⅛” to 2⅝”
Copper Fittings	• Streamline ACR - Wrot Solder - Joint Pressure	⅛” to 2⅝”

Refrigeration Systems With Pressures Higher Than 700 psi (250 °F)

In refrigeration applications such as transcritical CO2 systems where internal pressures can exceed 700 psi, piping manufactured using a Copper-Iron alloy such as C19400 becomes necessary.

The Mueller Streamline Company manufactures tube and fittings made from alloy C19400. This Streamilne XHP tube is made to meet the dimensional (OD), mechanical, cleanness, and eddy current testing requirements for the applicable specification of ASTM B280 (Seamless Copper Tube for …Refrigeration Field Service). Similarly, Streamline XHP fittings are made to meet the dimensional requirements and other applicable specifications of ASME B16.22 (Wrought Copper and Copper Alloy …Pressure Fittings).

- The higher pressure Streamline XHP line of ⅜” to 2 ⅛” tube and fittings products are third-party recognized by UL for refrigeration applications with continuous high operating pressures of up to **130 bar/1885 psi** at up to **120°C/250°F.**

- The Mueller Streamline Company also manufactures a lower pressure XHP line of ⅜” to 2 ⅛” tube made from alloy C19400 that has been recognized for use in lower pressure refrigeration applications with continuous operating pressures up to **90 bar/1305 psi** at up to **120°C/250°F.**

In any case, the specific local system operating pressures must be accounted for prior to the selection and installation of any piping.

Other Manufacturers of Copper-Iron Alloy Products

Another manufacturer of alloy C19400 copper products is the Wieland Copper Products company. Their high strength copper-iron alloy product is known as K-65. This K-65 copper piping product is available at a pressure rating of 120 bar (1740 psi), making it viable for use in transcritical R-744 systems. This piping may be used in the high or low side system piping. Please Note: K-65 piping is not approved for use in some areas. Thus it is advisable for refrigeration contractors to check and verify local code requirements.

2.A.I.a.i Other Important Notes Applicable to Piping and Brazing

Always be aware that R-744 (CO_2) systems operate at higher pressures than traditional DX systems. In addition, as with traditional DX refrigeration systems, short radius fittings are not recommended for piping installation. Long radius elbows are available from a number of different manufacturers. Always be certain to install only appropriate pressure-rated fittings.

All welded/brazed joints should be made up using 15% silver "Silphos" solder. Use 45% to 56% silver "Easy Flo" solder on sweat valves and other control devices. There is an additional, **essential** practice that is crucial to brazing refrigeration lines. Whenever pipe brazing operations are being performed, it is very important to flow dry nitrogen through the interior of the piping being joined. Consistently adhering to this practice will act to displace the oxygen inside the pipe, and prevent the formation of scale inside the pipe.

⚠ CAUTION **It is always important to ensure that the silver solder being used is pulled into the full depth of every joint (full penetration).**

2.A.I.a.ii Brazing

Joints in copper piping for CO_2 systems are brazed the same way as for conventional refrigeration systems. Nitrogen must be used to reduce oxidation of the piping during the brazing process.

2.A.I.a.iii 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 types of joints must be used, the following guidelines should be applied to ensure a leak-free joint.

2.A.I.a.iv Threaded Joint Sealants

Threaded joints applied to booster systems are required to only use approved thread sealants. A particular sealant approved for this use is Permabond MH052. PTFE tape may be used in combination with this material. When used, this tape should be wrapped around each joint. Use of any thread sealants other than this may result in improper system operation and leakage of CO_2. More information on this material may be obtained from the manufacturer:

2.A.I.a.i Sloping of Refrigeration Lines

All CO_2 piping (liquid supply and suction return lines) must be installed to slope or pitch downward towards the machine room in order to enable proper return of refrigeration oil. This is the same practice used for conventional DX systems with HFCs (example slope: 1" per 20 feet or greater).

2.A.I.a.vi Traps

Traps must be installed in all suction lines when transitioning to piping that runs vertically upward (risers) to assist with oil return. Typically, the riser pipe size should be one to two sizes **smaller** than the horizontal pipe size. Transition from the horizontal to the riser size may be made within the p-trap or outlet. Inverted or reverse traps are recommended although not required on booster system piping. All liquid line drops must come off of the side of the liquid header/liquid line.

2.A.I.a.vii Inverted Traps

With all risers, an inverted trap must be installed into the top of the main suction loop from the riser.

2.A.A.b Safety Relief Valves

Relief valves are used in locations where the maximum design pressure may be exceeded. Relief valves are either factory-installed, or must be field-installed as per the system piping schematic. When relief valves operate in gas, pipes or hoses can be used at the outlet to carry the discharged gas to the surroundings.

Relief valves used for CO_2 applications are designed for use on cryogenic systems and should not be replaced with relief devices typically installed on conventional refrigeration systems. Vapor relief valves mounted at the rack are piped to a common header from which a vent line must be field-installed to terminate outside the building, as required per local code. Liquid relief valves must also be vented to the outside.

The high-pressure side of the piping system should not be loaded beyond the acceptable maximum pressure. All due care must be taken to ensure that this maximum pressure not be exceeded owing to the effect of external heat sources in the ambient environment such as heating pipes and radiant heat from motors and other sources.

On all pipe sections that can be isolated when valves are closed, safety valves are installed to protect those areas. Fittings and accessories should be easily accessible and thus positioned to ensure safe operation as well as maintenance. The valves should also be situated so that the release of any pressure does not affect surrounding piping, components or material. All outlets from the vapor safety valves should be joined and connected to the outside through hoses or type “K” copper pipes.

Ultimately, the system is equipped with high-pressure switches that ensure that the compressors are cut-off before they can reach the maximum acceptable pressure and prior to blowing the safety valves on the high-pressure side.

Pressure switches on the system are electrically independent from the energy management system controls.

2.A.A.c Supports

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. Edges should be rounded to minimize cutting into the insulation. This will reduce possible stress concentrations and protect the insulation from damage.

A minimum air space of one inch (1”) should be provided between insulated lines to prevent condensation on the surface of the insulation.

Closed trenches (not open and accessible) should be used for underground piping. These should be designed so that the pipe can be installed without damage to the insulation.

Rigid clamps should not be used to directly supporting the piping as they conduct heat from the piping, are difficult to insulate, and will cause continuous condensation during system operation.

2.A.A.d Insulation

2.A.I.d.i General Guidelines

Insulation should generally be applied in accordance with local building codes, the consulting engineers’ and insulation manufacturer’s specifications.

The use of any insulation material other than those listed in this manual requires the written approval of Hillphoenix and the customer.

Piping system should always be insulated in order to reduce heat transfer between the fluid lines and the surrounding ambient air. Insulating the lines also prevents condensation or ice formation on the pipe surfaces and minimizes corrosion of the piping materials. When insulation requirements are determined, the following major factors should be considered::

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

The application temperature used in this manual is for a booster system with a low temperature CO_2 evaporating temperature of -15 to -20°F. For systems with significantly higher or lower evaporating temperatures, consult the insulation manufacturer about proper thickness recommendations.

Insulation sizing is determined based on either of two different ambient conditions:

- 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

Hillphoenix recommends the use of insulation sized/rated for “Normal Conditions” for typical indoor air-conditioned space, and insulation sized for “Severe-Conditions” for outdoor applications and non-conditioned spaces.

The normal condition is applicable for most indoor air-conditioned environments in North America. 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 stringent condition of “severe,” determining which of these to use depends on local ambient conditions and should be evaluated for each installation site. It is also important to consider that even in some air-conditioned environments, air at or near the ceiling or roof can be much hotter than elsewhere in the store and that evaluation of these conditions is extremely important for systems containing overhead piping.

The insulation thicknesses recommended in this section are designed to limit heat gain into the piping network, and, as a rule, are one size larger than those required 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.

All valves, controls, and fittings in contact with CO_2 should be insulated so as to allow easy removal for component servicing. Components should also be insulated to minimize air pockets or voids, which can, over time, collect moisture.

Running piping in non-air-conditioned spaces should be avoided wherever possible in order to minimize insulation thickness requirements and to reduce heat gain.

2.A.I.d.ii Insulation Materials

The recommended insulation materials for field-installed Advansor system piping are:

- Flexible Closed-Cell Elastomeric Foam
- Styrofoam
- Trymer

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

Styrofoam and Trymer insulating materials are also acceptable for use on field-installed piping. Both are 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 have a minimum required thickness and should be covered with an appropriate vapor-barrier (e.g. Saran) and jacketing material.

Recommended Thickness of Elastomeric and Rigid Insulation Materials

Pipe Size (OD)	Normal Conditions 85°F (29°C) Dry Bulb 70%RH, 0 fpm			Severe Conditions 90°F (32°C) Dry Bulb 80%RH, 0 fpm		
	Liquid	LT Suction Return	MT Suction Return	Liquid	LT Suction Return	MT Suction Return
3/8”	3/4”	3/4”	3/4”	1”	1-1/2”	1”
1/2”	3/4”	3/4”	3/4”	1”	1-1/2”	1”
5/8”	3/4”	1”	3/4”	1”	1-1/2”	1”
7/8”	3/4”	1”	3/4”	1”	1-1/2”	1”
1-1/8”	3/4”	1”	3/4”	1”	1-1/2”	1”
1-3/8”	N/A	1”	N/A	N/A	1-1/2”	N/A
1-5/8”	N/A	1”	N/A	N/A	1-1/2”	N/A
2-1/8”	N/A	1”	N/A	N/A	1-1/2”	N/A

Note: Additional thickness may be needed beyond the minimum requirements due to design and surrounding conditions.

2.A.A.e Under-Floor and Under-Ground Pipe Installations

Where piping overhead is not feasible, under-floor piping is permitted (though not recommended). Under-floor piping should be insulated inside of PVC piping or equivalent rigid pipe to prevent damage to the insulation material. The void between the insulation and the PVC pipe, where the insulated piping exits the PVC, should be filled with expanded polyurethane foam to prevent air from entering the pipe.

Hillphoenix **does not recommend** “direct burial” of insulated piping.

2.A.A.f Labeling Requirements

ll CO_2 piping, whether factory or field installed, should be labeled to indicate:

- Fluid type (i.e., Carbon Dioxide)
- Arrows indicating direction of flow

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

A.B .II ADVANSOR COMPONENTS

The major components of booster systems were introduced in the first section of this manual. In this section, the discussion of those components and their operation is examines them further.

Any technicians who are already familiar with standard refrigeration components and configurations will recognize many aspects of the Advansor system. The familiar components that were briefly described in the first section of this manual include the compressors, the pressure safety controls, direct expansion valves, the filter drier, the oil separator and filter and associated components.

2.A.B.a Compressors

On the Advansor compressor rack, the Low-Temperature (LT) compressors are located on the top, and the Medium-Temperature (MT) compressors are located on the bottom. Of course the size and the number of both LT and MT compressors depend upon the LT and MT loads, as well as the strategy for staging the running of compressors in response to current demand on the system.

2.A.B.b Compressor Operating Pressures

MT discharge pressure: Approximately: 480 to 520 psig

Receiver pressure: Approximately: 480 to 520 psig

MT suction pressure: Approximately: 348 to 406 psig

LT suction pressure: Approximately: 130 to 203 psig

A pressure gauge for each individual compressor is typically mounted nearby on the rack.

2.A.B.c High Pressure Control Valve

The Danfoss ICMTS is a motor-operated, high-pressure control valve designed to regulate the flow of transcritical gas or subcritical liquid flowing from the gas cooler in transcritical CO_2 systems. It exercises control over the temperature differential in the gas cooler/condenser during transcritical operation (when the gas cooler/condenser is operating as a gas cooler) and sub-cooling (when the gas cooler/condenser is operating as a condenser) during subcritical operation. The maximum working pressure for the ICMTS valve is 2030 psig (140 bar).

The actuator may be detached by removing three socket bolts. By means of a hand magnet, the valve can then be operated manually. The valve must be powered from a UPS and will shut down (close) under conditions of a complete power failure.

2.A.B.d Flash Gas By-Pass Valve

The Danfoss CCM flash gas-by-pass valve is situated between the flash tank/receiver and the suction to the MT compressors. Ball valves are mounted for shut-off before and after the CCM valve. The CCM valve is an electric stepper motor valve, maintaining a constantly adjusted pressure in the receiver. The maximum working pressure for the valve is 1291 psig.

In case of power failure, the valve will shut down (close) by means of a required UPS in the control panel.

2.A.B.e Oil System Components

The oil system for the CO_2 booster system refrigeration rack contains most of the normal oil system components, and is optimized by use of the following components:

- 200 ppm coalescing oil filter

- Oil level switches located on each compressor
- Solenoid valves on each compressor for oil return
- Oil separator with either an internal or external reservoir

2.A.II.e.i Oil Separator

The system is equipped with a highly efficient, mechanical oil separator with coalescing filters that prolong the lifetime of the compressors.

Filter cartridges should only be switched according to service instructions. Depending on the overall system design, the oil separator is equipped either with or without an external oil reservoir.

2.A.II.e.ii Filter Drier

The replaceable-core filter shell contains two high-water 48 inch capacity, cartridge cores, which must be installed upon start-up of the system. The filter drier may be removed by unbolting the top cover.

2.B INSTALLATION PROCEDURES

System Installation must be carried out in accordance with local code requirements.

As with any other types of rack systems, Advansor systems must be installed on a flat, level and stable surface capable of supporting the weight of the equipment. The rack may be mounted on a vibration isolation pad to prevent any vibrations from spreading to the rest of the building.

The rack should only be installed in properly ventilated, fire-protected, dedicated spaces. Such spaces should be ones that are not subject to excessive heat or cooling, as well as the risk of collision from other equipment or associates that may occur in non-dedicated spaces. Given those considerations, the system may be installed either indoors or outdoors. For outdoor installation, the system must be installed in an enclosure.

The installation site should also have available adequate lighting and working space in which to access and carry out service and maintenance tasks safely.

2.B.I. Piping Installation

2.B.I.a Condenser/Gas Cooler Piping

Gas cooler/condenser should utilize high pressure copper piping. Outdoor piping placed in locations where moisture may be present will have to be coated with primer and varnish. During operation, these pipes may become quite hot (100°), so insulation is recommended in areas where the piping may be touched.

All field piping to the condenser/gas cooler should be brazed together by a qualified refrigeration installer before final connections to it are made in order to avoid any opening of the system for excessive amounts of time

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2.B.I.b Evaporator Piping

Steps for connecting cases and walk-ins:

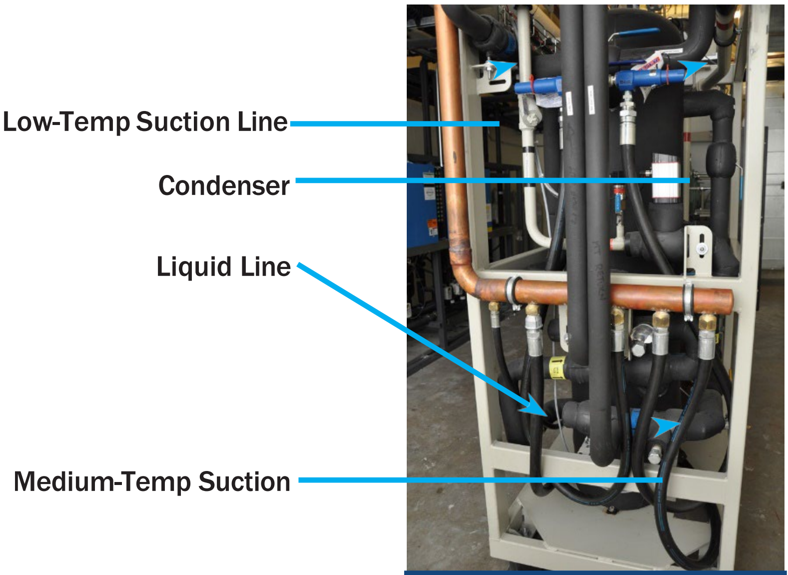
- Leak and pressure test to approximately 435 psig through the Flash Tank Outlet Service Valve for the low-temp and 653 psig for the medium-temp (once the piping has been completed between the rack and the evaporators) with the vessel isolated at the Hot Gas Injection Service Valves into the medium- and low-temp suctions. This should only be done with the Relief Safety Valves on the medium- and low-temp suction manifolds removed and the fittings plugged along with all of the electronic expansion valves closed to the low-temp side.
- Pressurize the low- and medium-temp suctions via the Access Valves on the respective suction manifolds. The low-temp Compressor Discharge and Service Valves should also be closed if needed. Release the nitrogen in the piping and reassemble the Relief Safety Valves on the medium-and low-temp suction manifolds.

Connection for the condenser suction and liquid lines are typically located at the receiver end of the rack. The liquid line is common for medium-temp and low-temp, and should be insulated.

2.B.II Electrical Connections

Advansor racks come from the factory with the control panel and all internal electrical connections pre-wired. As with any other system, a certified electrician must make all field connections.

Specific aspects of the electrical connections to take note of include the required electrical supply for the system, which depends on job site requirements, and cable and component markings.



Rack Piping Connections

2.C START-UP PROCEDURES

As with any other type of refrigeration system, the steps required to be performed prior to start-up and for starting up the Advansor Booster System are only to be performed by qualified refrigeration technicians. In performing these tasks, the goal is to achieve an accurate, complete installation of all mechanical and electrical components of the system.

The rack should only be installed in properly ventilated, fire-protected, dedicated spaces. Such spaces should be ones that are not subject to excessive heat or cooling, as well as the risk of collision from other equipment or associates that may occur in non-dedicated spaces. Given those considerations, the system may be installed either indoors or outdoors. For outdoor installation, the system must be installed in an enclosure.

The installation site should also have available adequate lighting and working space in which to access and carry out service and maintenance tasks safely.

In any case, detailed steps for the performance of both Pre-Start-Up and Start-Up are provide for your use in Appendix A on the pages listed below.

Pre-Startup Guide: Appendix A, page A-3.

Startup Guide: Appendix A, page A-9.

Appendix A: Advansor CO2 Booster Pre-Startup Guide and Startup Guide: These guides provide information pertaining to the mechanical and electrical systems, piping, valves and positioning, and system evacuation. Also included are electrical considerations, compressor oil charging, wiring verification, system charging, start-up of suction groups, as well as system operation verification and optimization. Auxiliary unit operational testing is also included.

Also provided at the end of Appendix A:

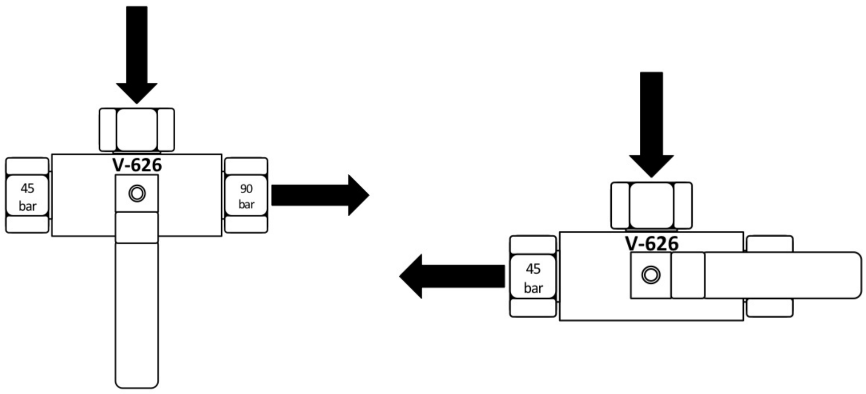
- Booster Validation Checklist
- Yearly Preventive Maintenance for the Hillphoenix Advansor Booster System
- Hillphoenix Pressure-Temperature Chart for R-744 (CO_2)

2.D SERVICE PROCEDURES

2.D.I Pump-Down to Receiver - for Standstill Purposes (i.e., Servicing)

- Close the **Flash Tank Outlet Service Valve** (main liquid supply isolation ball valve) feeding the store loads
  - Verify that the Hot Gas Injection Service Valve into the medium temp suction (manual by-pass valve) is Closed.

- If the CO_2 liquid at or below the highest site glass and the LT and MT compressors have pumped down and cycled off (i.e., suction pressure no longer rising):
  - Turn OFF compressor panel switches
  - Close the **Flash Gas Bypass Service Valve**
  - Close the **Flash Tank Inlet Service Valve**
  - Rotate the **Three-Way Valve** for the relief valves at the flash tank from the 45 bar position to the 90 bar position (diagram, below)
  - Close the **Oil Reservoir Vent Line Service Valve**



At this point, the CO_2 refrigeration system has been pumped-down and the receiver isolated from the rest of the system.

- If the CO2 liquid level rises above the highest site glass:
  - Immediately Close the **Flash Gas Bypass Service Valve**
  - Immediately Close the **Flash Tank Inlet Service Valve**
    Note: the MT compressors will go off-line on high discharge pressure
  - Turn OFF all MT and LT compressor switches
  - Close the Oil Vent Line Service Valve
  - Vent CO2 liquid from store piping system down to 290 psig
  - Vent MT suction line down to 290 psig
  - Vent LT suction line down to 203 psig
  - Shut down all circuits, Close all EEVs on all cases, coolers, freezers, etc., turn OFF all fans and all defrost heaters
  - Vent Condenser/Gas Cooler down to 870 psig
  - Monitor all store piping to ensure CO_2 pressures do not rise and vent if necessary

2.D.II Coming Out of Pump-Down - For Normal Operation

- Slowly open the Flash Gas Bypass Service Valve
- Open the Oil Vent Line Service Valve
- Continuously check the system pressure (LT suction, MT suction, MT discharge) and the receiver liquid level
- Open the Flash Tank Inlet Service Valve
- Slowly Open the Flash Tank Outlet Service Valve
- During active operation to the receiver, position the three-way valve (see diagram on previous page) so that the port connected to the 45 bar relief valve is opened to the receiver pressure.
- Turn on both the LT and the MT systems through the pack controller
- When both the LT and MT compressors are running, slowly Open the Flash Gas Bypass Service Valve

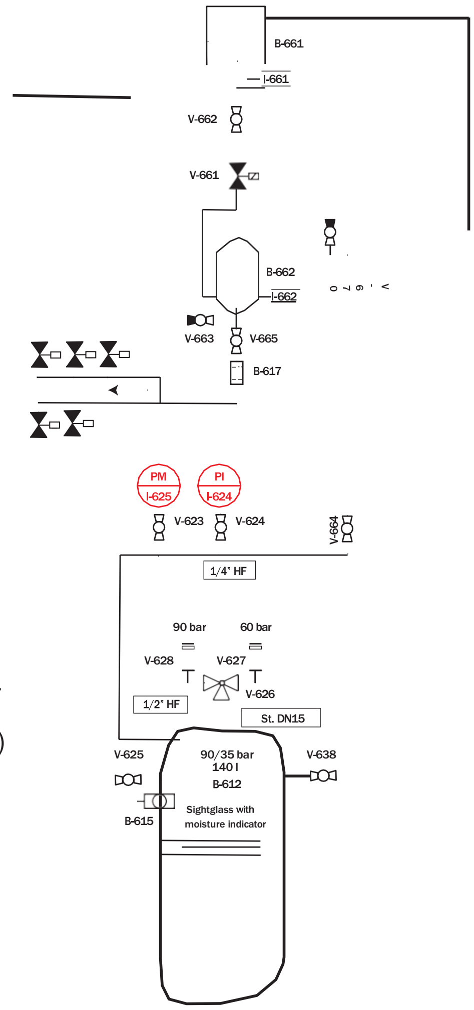
2.D.III Charging the System with CO_2 Vapor

- Make certain that all EEVs are Open
- Charge the system through the Receiver Access Valve until the pressure reaches 150 psig
- Charge the receiver with CO_2 liquid

2.D.IV Adding Oil to the System

- Leak test the system and make any repairs that are necessary
- Close the Main Oil Line Service Valve (located after the oil separator) in order to isolate the top of the reservoir and vent the pressure inside the reservoir to 75 psig of vapor pressure
- Close the Oil Line Service Valve (located after the oil reservoir)
- Connect a vacuum pump to the Oil Vent Line Access Valve, which is located on the vent line from the oil reservoir
- Triple-evacuate the system to ensure the removal of moisture and non-condensables. (This procedure is the same as for a DX HFC system.)
- Break the third vacuum with 150 psig of CO_2 vapor pressure. (This keeps dry ice from forming inside the system.)

- Using an oil hand pump, fill the oil reservoir with the compressor manufacturer approved oil through the Oil Reservoir Drain Valve (located downstream of the oil reservoir)
  - Be careful to ensure that no moisture is pumped in with the oil
  - Add oil until the level rises above the oil level sensor
- Once the reservoir is full of oil, make sure that the electronic oil level switch on each compressor is powered
- Pressurize the oil vent line by opening the Oil Vent Line Service Valve, which is located between the oil reservoir and the receiver
- Open the isolation valves around the oil reservoir
  - The Main Oil Line Service Valve (located after the oil separator_
  - the Oil Line Service Valve (located after the oil reservoir)
- Allow the oil level switches, once they have been powered, to call for oil and fill the compressors (as they would during normal operation)
- Check that when the proper oil level for the compressors has been reached, the oil level switches shut off and the crankcase heaters are energized



2.E MAINTENANCE PROCEDURES - ANNUAL AND PERIODIC

Any service performed on the system must be in accordance with local code requirement as well as the directions in this manual in order to maintain the safe and reliable operation of the system. Service should be only performed by authorized contractors, or customer-designated technicians. Hillphoenix strongly recommends that any technician working on the system have attended a Hillphoenix Learning Center training course for Advansor systems. See hillphoenixlc.com for more information.

In addition to the tools, components, parts and materials needed for service this section covers the procedures for:

- Checking the general condition of the system, including compressors, valves, pipes, insulation, heat exchanger, and receiver.
- Checking oil and refrigerant levels in compressors and reservoir
- Checking safety pressure switch and safety valves
- Checking instruments and gauges

- Changing oil filters
- Changing liquid filters
- Checking the system for the presence of moisture
- Extraction of oil samples to check for acid and water content
- Gas alarms for rooms and ventilation

Maintenance of the compressors, pressure vessels (receiver and oil reservoir), and piping systems should be conducted as specified by Hillphoenix and the component manufacturers. A log book should be kept with the system, to note:

- Any change (loss or additions) to the system's refrigerant charge
- Oil testing
- Problems with, and corrections/repairs mad to, the system

Service on the pipe system and vessels should be performed on a regular basis. Pressure-switches have to be checked every year and service on vessels equipped with safety valves should be carried out every other year. Safety valves on vessels and pipes should also be inspected every other year.

2.E.I Tools and Components Needed for Service

In general, these include:

- Hydraulic or vacuum pump for oil charging
- Hand magnet for the ICMT valve (HT valve)
- Tubes, fittings, and pressure gauges suitable for system's operating pressures, to secure the filter during fill of the system

2.E.I.a Parts and Materials Needed During Service

- Oil Filter (B-661): Temprite, 1 piece set, including O-rings
- Filter-Drier cartridge(s): Danfoss type 48-DM, 1 piece, including gasket
- R-744 (CO_2): Instrument grade (99.99% pure) or better
- Oil: refer to the compressor manufacturer's specification for the type and quantity of oil required
- Thread Sealant: Permabond MH052

- Paint for piping (steel) and for frames.
- Insulation material: Armaflex (cold/hot, appropriate for service conditions

2.E.II Service After Start-Up

Perform the following checks after start-up:

- Refrigerant charged to the proper level —add if necessary
- Oil in the compressors, separator(s), and reservoir charged to the proper level—add if necessary
- Oil is uncontaminated and clear—change oil and oil filter if necessary
- Pressure and temperature are within specifications:
    - MT: suction/pressure at 350 to 475 psig with 20 to 50 °F of superheat, high-pressure gas at approximately 230 °F
    - LT: suction/pressure at 189 to 363 psig with 20 to 50 °F of superheat, high-pressure gas at approximately 149 °F

2.E.III Service After 3 to 4 Weeks of Operation

- Change the oil separator(s) filter(s) if they exhibit a dirt loading of above 12 psid (0.9 bard) across the separator
- Add oil if necessary
- Check for pressure drop across the filter-drier and change filter if a pressure drop is found
- Check for leakage and tighten fittings, making repairs if leaks are found
- Add refrigerant if necessary
- Make any other adjustments and repairs that are necessary for the safe and efficient operation of the system

2.E.IV Ongoing Service Procedures

Following the start-up and initial service of the system, the annual and periodic procedures listed below should be performed.

2.E.IV.a Annual Service (or Otherwise if Noted)

Compressor Service	
Inspect each compressor prior to service. Investigate any unusual sounds or vibrations to determine the cause and repair or replace as necessary.	
Specific components to check include: Vibration isolation mounts Oil system Compressor oil levels Reservoir oil level Solenoid operation Insulation Flex tubes	Note the condition of, and steps taken in the log book: Check that the vibration isolation mounts are intact and investigate any wear that is apparent to determine and correct the cause Check the oil system, retightening any fittings that are loose Check compressors oil levels via sight glass (typically medium-temp) and sensors (medium and low-temp) Test all solenoids and switches Inspect insulation and repair any damage or deterioration Inspect and tighten any flex tubes as necessary
Collect an oil sample to submit for analysis.	Oil sample - see below

Receiver and Piping System Service	
Carefully inspect and repair any insulation for the receiver, piping, or piping system component that shows signs of damage or deterioration.	Examine the insulation for the receiver, piping and all components including valves, manometers, and safety valves for corrosion or any other condition requiring repair or replacement
Inspect the oil piping system on a regular basis -- at least 3 to 4 a year. Any stains, spills or other indications of leaks should be carefully examined and corrected.	Check that the oil piping system and fittings are tight and free of corrosion — tighten, repair and repaint as necessary Be sure to include all valves and solenoids when checking for operation and tightness
In the Log Book, note any spills or leaks found, and the actions taken to correct them.	

Condenser/Gas Cooler Service	
Inspect the condenser/gas cooler to make sure that the fans (and inverters) are operating properly and that any problems are corrected.	Confirm that the fans are operating and are turning in the correct direction. Check for dirt on the coils, and remove and clean as necessary.

Suction Line Filter-Drier	
Prior to service, check for any pressure drops across the filter-drier. Change the filter if a pressure drop of 5 psig is found.	Change the filter cartridge after any service has been performed, or every other year of operation.

Oil Separator Filter	
Check to see if the oil in the separator is clear, and verify that there is a pressure drop of no more than 10 psid across it.	Change the filter cartridge if the oil is unclear or discolored, or if the pressure drop ahead of the oil separator is too high.

Liquid Strainer	
Check for pressure loss and flash gas in the liquid line.	Change the filter if the pressure drop is too high (i.e., 5 psig or higher)

Oil Sample Collection	
Annually test the oil for the presence of water and acid content.	Take oil samples from either the oil separator or reservoir. Note that the sample may foam since the oil contains refrigerant, which expands when extracted.

Safety Equipment Inspection	
Inspect safety pressure switches for proper operation and replace if necessary.	Refer to local code requirements and regulations pertaining to the testing and replacement of safety valves.
Inspect safety valves and replace if necessary with new or unused valves.	Always use safety valves rated for the correct pressure.
Check machine room mounted (and any adjacent) leak detectors and confirm they are operating properly, Since any concentration of refrigerant around sensors increases their readings. Ensure that ventilation in the machine room (and anywhere lese sensors are located) is adequate and not obstructed. Inspect and ensure emergency stop and alarm functions are working.	Ensure entry and exit to and from the machine room is unobstructed and that all safety equipment is in working order.

Instruments and Pressure Gauges	
Check all pressure gauges to ensure they are reading accurately before and after pumping down the system.	Compare readings between pressure gauges and transmitters. Check that any temperature sensors are properly mounted and that they are correctly sending signals.

Electric System	
Perform a check of all level switches. Inspect cables and pipes. Check that the controller display is working correctly Check the Uninterruptable Power Supply (UPS)	Check all level switches for oil and CO_2 Visually inspect to verify proper working conditions

2.E.IV.b Every Other Year Service

Oil Separator Filter	
Change the separator filter.	Remove the oil separator top flange by loosening the screw bolts. Make certain to change the O-ring with the filter cartridge.

Suction Line Filter-Drier	
Check to see if the oil in the separator is clear and verify that there is a pressure drop of no more than 5 psig.	Filter type: 48-DM, 1 -2 pieces

Mechanical Parts	
Change the metal flex tubes on both the liquid and suction sides of the compressor Inspect and confirm operation of the oil system solenoid valves.	Change metal flex tubes whenever any signs of wear are noted Replace any solenoids as deemed necessary.
Check all mechanical parts and piping (particularly around compressor suction lines) for ice formation that could impact operation.	Carefully remove any ice that has formed and could potentially bend pipes and displace components.

NOTES

NOTE

NOTES

Appendix
A

Advansor Booster System

Pre-Start-Up Guide

&

Start-Up Guide

Advansor CO2 Booster Pre-Startup Guide

05/2022

PRIOR TO STARTUP

Mechanical and Electrical Systems

1. *Properly installed as per code and regulatory requirements*

Piping Installed

2. *Assembly of Carbon/Stainless Steel, or Wieland K65 and Muller Streamline XHP High Pressure Copper Iron Pipes to Gas Cooler*
   A. Steel connections are joined by means of TIG-welding
      i. Care must be taken to avoid slag inside the pipe during welding (see installation manual)
   B. Copper connections must be brazed using standard brazing methods
      i. 15% silver solder joining copper to copper
      ii. 45% silver solder joining copper to steel
   C. Assembly must be carried out by a certified welder in accordance with local code *Note: Contractors will be responsible for providing copper-to-steel transition fittings in the event steel piping is used for installation of the high side piping*
3. *Assembly of Pipes to Evaporators*
   A. MT suction piping needs to be installed using copper pipe rated to 650 psig [45 barg]
   B. LT suction piping needs to be installed using copper pipe rated to 435 psig [30 barg] for electric defrost systems and at least 650 psig [45 barg] for hot gas defrost systems
   C. All liquid lines must be rated to at least 650 psig [45 barg]
   D. Piping selected and mounted based on approved piping practices
4. *Pressure Testing with Nitrogen and Vented*
   A. The rack is pressure tested at the factory to 10% above the rated relief pressure for each section of the system prior to installing relief valves
   B. Field pressure test should be performed per local building codes or customer specifications (if supplied)
      Note: In the case of test pressures being above pressure relief valve ratings, pressure relief valves need to be removed and its mounting location sealed - replace relief valve after completion of pressure test
   C. Regardless of pressure testing method, the following <u>minimum</u> testing pressures shall be held for a minimum of 24 hours allowing for pressure variations due to ambient air temperature changes
      Note: Relief valves do not need to be removed for pressure tests below valve ratings
      i. LT Suction: 30 barg (435 psig) relief – test pressure=350 psig
      ii. MT Suction/Liquid: 45 barg (650 psig) relief – test pressure=525 psig
      iii. MT Suction/Liquid: 60 barg (870 psig) relief – test pressure=700 psig
      iv. MT Discharge: 120 barg (1740 psig) relief – test pressure=1400 psig
      v. MT Discharge: 130 barg (1885 psig) relief – test pressure-1500 psig

All Valves Checked for Evacuation Positioning

BEFORE EVACUATION PROCESS:

5. *Open All Service Valves On Compressors, Oil System Valves and All System Isolation Valves (Rack)*
   A. For electric valves on the rack, make sure to turn ON control circuit power, but keep compressor power OFF and crankcase heaters OFF
6. *Open Valves for Store/Circuit Piping Systems*
7. *Open High Pressure Regulating Valve*
   A. Remove head from high pressure valve
   B. Use provided magnet to turn clockwise to open valve 100%
8. *To Protect Transducers During Evacuation, Close Respective Isolation Valves*

System Triple Evacuation

USE THE FOLLOWING PROCESS WITH AN ELECTRONIC MICRON METER, OR IF CUSTOMER HAS VACUUM EVACUATION SPECIFICATION, FOLLOW IT.

9. *Evacuation Procedure*

   Note: Change oil in vacuum pump after every pull (use)

   A. 1st vacuum hold at 1500 microns for minimum of an hour
   B. Break to positive pressure (1 or 2 psi) with nitrogen

   Note: Change oil in vacuum pump after every pull (use)

   C. 2nd vacuum hold at 500 microns for minimum of an hour
   D. Break to positive pressure (1 or 2 psi) with CO_2 VAPOR
   E. Add oil to oil reservoir
      i. Use Bitzer BSE-85K for all systems with Bitzer MT Compressors (BSE-85K is approved for use with Copeland LT Scrolls)
      ii. Any other MT compressors types, consult Hillphoenix for approved options
      iii. Fill all oil reservoir(s) via the oil reservoir charging port(s) to the sight glass(es) with oil.

      ATTENTION: Additional oil will be needed on site to complete startup - contractor supplied

   Note: Change oil in vacuum pump after every pull (use)

   Note: Install filter drier core(s) and suction filter shell(s) as applicable

   F. 3rd vacuum to below 500 microns and must maintain for 24 hrs with no more than 100 micron increase with vacuum pump OFF and isolated
   G. REPEAT step 9.F (3rd vacuum step) until 24 hr test is completed successfully
      i. System vacuum testing must be verified with an electronic vacuum meter which should be placed at the furthest possible location from vacuum pump
      ii. Ensure that *ALL* portions of the system are under vacuum

   Note: For low pressure oil systems (filterless oil separator), add 7.5 liters of oil after oil level has initially filled half of the oil reservoir sight glass

10. *Gas Cooler Instrumentation Verification*
    A. All inputs and outputs on condenser/gas cooler installed and confirmed
    B. Outdoor air temperature sensor located in the airstream of the gas cooler
       i. Air cooled gas cooler: sensor needs to be installed in fully shaded airstream, even at low sun angles (morning and evening when sun is close to horizon).
       ii. Adiabatic gas cooler: sensor installed in between pad and coils, far enough away from pad and coils to avoid water and metal contact with sensor

C. Verify parameter list for condenser/gas cooler controller (parameters enterable *at gas cooler*)
    i. Common BAC parameters:
        1. Precool start parameter will depend on geographic climate of store (BAC defined in Carell Controller)
        2. Diff SP, or deadband, defines at what temp precool mode stops (found in Technician Screen (passcode "1703") should be set to 3 degrees below start setpoint)

D. Verify controller condenser/gas cooler parameters (parameters enterable *at controller*)
    i. Common Gas Cooler Setpoints {Emerson CPC E2 equivalent parameters}
        1. Approach Setpoint (Dropleg Temp – Air Over Coil Temp) – 10°R {AM2 eq:10ddf}
        2. Minimum Condenser Dropleg Setpoint – 46°F {AM3 eq:46df}
        3. Maximum Condenser Dropleg Setpoint – 80°F {AM4 eq:80df}
        4. Additional Emerson Condenser Application Setpoints:
            a. {C1 General: Condenser Min Capacity Setpoint = 0.00}
            b. {C2 Setpoints: TR (Throttling Range) Temperature = 25.00}
    ii. Units with BAC adiabatic coolers, 0-10V output needs to correlate with 100%-0% fan operation (or 10-0V with 0-100% fan operation). This fail-safe ensures fans ramp to 100% if signal is lost for any reason (wire short or board output failure). This logic is not industry wide, therefore, air gas coolers probably don't need to have this parameter switched.

E. Leaving gas pressure transducer located on the rack for high-pressure control

F. Leaving gas temperature probes (one for high pressure valve and one for fan control) mounted properly (horizontally at 5 and 7 o'clock and as close to coil outlet as possible) and well insulated (cork insulation tape) as close to an outlet header as possible on the gas cooler

    ATTENTION: These sensors must be installed correctly as shown in manual's diagram
    i. If multiple parallel coils, DO NOT mount probes on common pipe. Select one gas cooler coil and mount probe on its outlet

G. For Guntner Adiabatic Gas Coolers in Cold Ambient Locations, set the controller into LCMM (Low Capacity Motor Management) to allow the fans to cycle off individually as temperatures get lower.
    i. Press the white center button on the Guntner Controller and rotate till "Service" is highlighted
    ii. Press the white center button again and rotate to and select "Features"
    iii. "Fan Group 1" should be highlighted and selected
    iv. Highlight the "LCMM on" feature and press the white center button to select it to make it read "LCMM on" if it does not already indicate it is selected

Advansor CO2 Booster Startup Guide

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STARTUP

Electrical

1. *All circuit breakers and switches are OFF*
2. *UPS protected circuits plugged into proper UPS outlet labeled "Surge and Battery Backup"*
3. *Phase monitor restart to be set for 10 second delay*

Compressor Oil Charging

4. *Pressurize Entire System to 150psig (~10barg)*
   A. Break last successful vacuum and pressurize to 150psig [10barg] with CO2 VAPOR
   B. Compressor oil fill instructions **(ATTENTION: Additional oil will be needed on site to complete startup – contractor supplied)**
      i. Shut oil line feed from oil separator to oil reservoir and shut oil vent line between oil reservoir and CO2 flash tank
      ii. Using the access port at the bottom of the reservoir, add additional oil as required to sight glass level
      iii. Using the access port at the top of the reservoir, pressurize the oil reservoir to 300 psig [20 barg] with CO2 VAPOR
         1. Maintain 300 psig within the reservoir during oil fill process
      iv. Starting with MT #1 compressor, trace the oil fill line from the compressor to the oil solenoid block - make note of the compressor and solenoid order
      v. With the MT #1 compressor breaker OFF, activate the compressor control circuit in the controller (bypass ON - override Compressor Run Signal in the controller) and turn ON compressor control switch to force the oil solenoid to energize or activate electronic oil level controller
      vi. Check to ensure the oil fill solenoid on the block is energized - red indicator solenoid light should be lit when energized
         1. The oil fill solenoid will only stay energized for the duration of the cycle for Medium Temp oil fill cycle
            a. MT Oil Timer Setting: Every 60 seconds, ON for 30 seconds.
            Note: MT Oil Systems that are in the filterless (muffler) system: Every 60 seconds, on for 50 seconds.
         2. Filling the compressor with oil may require more than one cycle of the oil feed solenoid. Monitor oil level in the reservoir and add more oil if required.
      vii. Watch the oil level sensor on that compressor and continue filling the compressor with oil until the red indicator ring on the compressor oil level switch illuminates, indicating the compressor has proper oil level to operate
      viii. Check to ensure the oil fill solenoid for the MT #1 compressor is now de-energized
      ix. Repeat steps 4B.v through 4B.viii for each MT and LT compressor.
         1. The oil fill solenoid will only stay energized for the duration of the cycle for Low Temp oil fill cycle
            a. LT Oil Timer Setting: Every 60 seconds, ON for 5 seconds.

2. Filling the compressor with oil may require more than one cycle of the oil feed solenoid. Monitor oil level in the reservoir and add more oil if required.

x. If oil level controls are electronic types (OM4/OM5), verify oil level via sight glass on the oil control mounted on the compressor

xi. Once all the compressors are properly filled with oil and all oil fill solenoid's functionality have been confirmed, recharge oil reservoir to sight glass and open the oil line feed from the oil separator to the oil reservoir and open the oil vent line between the oil reservoir and CO2 flash tank

xii. Verify oil reservoir alarm by disconnecting electronic head from well sensor for each compressor

xiii. Verify MT and LT compressor oil alarms by closing compressor oil supply valve and seeing alarm and shut down logic execute in controller

Note: For oil systems that are in the filterless (muffler) system, if the oil level in the compressor sight glass is not halfway full:

1. Isolate the compressor lacking oil
2. Add oil directly through suction port of the compressor until oil sight glass is half full

Note: Muffler systems also have a timer external to the control logic that must be set to open the solenoid valve to feed the oil reservoir for 5 seconds every 60 seconds.

C. Energize crankcase heaters

Wiring Verification

5. EMS/Controller

A. Contact Hillphoenix Field Service if base operating program issues arise

6. All Sensors, Transducers, Valves, Vfds, Hpv, Fgbv Checked and Proofed

A. Verify and check all the parameters in the High Pressure Control Valve Controller and Actuator are correct

i. If a component that requires parameter input is not working properly and it is believed that parameter verification is required, contact Hillphoenix Field Service

B. Calibrate High Pressure Valve:

i. Disconnect the red lead wire on the valve actuator

ii. Take the actuator off of the valve, then use the supplied HPV magnet to manually run valve to fully close, and then fully open

iii. Put the actuator back on the valve and reconnect the red lead wire

iv. Wait until the valve closes to zero (this should be done at low pressure, while the system is pressurized to 150psig [10barg] CO2 vapor)

v. Take the actuator off of the valve again and ensure the valve is fully closed with the supplied HPV magnet

vi. Restore the actuator and wiring when calibration process is complete

C. Calibrate Flash Gas Bypass Valve

i. Disconnect power on the valve controller

ii. Reconnect power on the valve controller

Note: Removing and reapplying power on the valve controller should force the valve to a fully closed state, including the overdrive steps

        iii. If leak-by occurs, contact Hillphoenix Field Service for further troubleshooting steps

D. Verify Hot Gas Dump functions properly – situation where return superheat to compressors is too low
    i. Manually override solenoid ON via controller (verify correct relay energizes)
    ii. *Either* of the following two parameters will activate MT Hot Gas Dump:
        1. MT Suction Superheat
            Note:°R refers to a differential temperature calculation value, like superheat, not a probe measurable temperature from a thermometer, which is reported in °F.
            a. Cut-in Setpoint 25°R
            b. MT Cut-out Setpoint 29°R
        2. MT Suction Minimum Suction Pressure
            a. Cut-in Setpoint 270pisg (-4°F)
            b. Cut-out Setpoint 290pisg (0°F)
    iii. LT Hot Gas Dump only available on Hot Gas Defrost Systems:
        1. LT Suction Superheat
            Note:°R refers to a differential temperature calculation value, like superheat, not a probe measurable temperature from a thermometer, which is reported in °F.
            a. Cut-in Setpoint 14°R
            b. Cut-out Setpoint 19°R
        2. LT Suction Minimum Suction Pressure
            a. Cut-in Setpoint 170psig (-28°F)
            b. Cut-out Setpoint 180psig (-25°F)

E. Verify Liquid Injection functions properly – situation where return superheat to compressors is too high
    i. Manually override solenoid ON via controller (verify correct relay energizes)
    ii. *Both* of the following two parameters are needed to activate Liquid Injection:
        1. MT Suction Superheat
            Note:°R refers to a differential temperature calculation value, like superheat, not a probe measurable temperature from a thermometer, which is reported in °F.
            a. Cut-in Setpoint 55°R
            b. Cut-out Setpoint 45°R
        2. MT Discharge Temperature
            a. High Temperature Cut-in 250°F
            b. High Temperature Cut-out 240°F

F. Verify compressor VFD alarms
    i. Contact Hillphoenix Field Service if VFD drive issues arise

G. LT Discharge High Pressure Switches (Mechanical) should be set to 600psi with lowest differential pressure setting

H. LT Suction Low Pressure Switch (Mechanical - if equipped) should be set to 100psi

I. Verify LT/MT mechanical startup time delays are set to
    i. MT (5 sec)
    ii. LT (5 sec)

J. Verify High Discharge setpoints in controller are set to
    i. MT 120 Bar System (1500 psi) 130 Bar System (1575psi)
    ii. LT (575 psi)

7. *Evaporator Instrumentation Verification*
    A. Verify all circuit controls are complete, operational and coordinated correctly (ie – controls operate correct circuit)
    B. Verify all temperature probes are located and installed as per coil manufacturer's specifications
    C. Verify all circuit pressure transducers are correctly installed to prevent oil from accumulating in transducers (never install transducer pointed down)
    D. Verify that all circuit probes and transducers are communicating properly with both case controller and rack controller.
    E. Verify EEV pressure transducer readings to ensure that measured pressure values match to corresponding saturated evaporation temperatures
        i. Room Temperature Example: 75°F = 895psig
        ii. Operating Temperature Example: -20.0°F = 200 psig
    F. Verify temperature probes to ensure that measured temperature values match actual temperatures of the evaporators
        i. Ensure that probes and controller are wired and landed correctly by means of cold spray or warming by hand with verification of temperature input fluctuation reported by the controller.
    G. See Emerson XM unit Startup Manual for more detailed information
        i. See appendix

System Charging

8. *Prepare System for Liquid Charging*
    A. Manually override EEV valves closed via the rack controller
    Note: Prior to removing the EEV override, verify that the suction transducer in the case/coil is at suction pressure. If the transducer reads closer to liquid pressure the liquid and suction lines are most likely crossed.
    B. Open suction line ball valves on header
    C. Close liquid line ball valves at header
    D. Hot Gas Defrost Systems
        i. Close hot gas defrost ball valves on header
        ii. Override the hot defrost gas control valve in the open position until rack is operational
    E. Ensure all manual isolation valves are open
        i. Hot Gas Dump (injection) isolation valve open
        ii. Oil feed solenoid isolation valves open
        iii. Pressure transducer isolation valve open
        iv. Liquid injector isolation valve open
        v. Flash Gas Bypass Valve isolation valve open
    F. Close the Manual ¼" Flash Gas Bypass Ball Valve (around the FGBV)
    G. Verify Compressor crankcase heaters are ON
    H. Turn ON power to Gas Cooler, check rotation direction of fans on gas cooler/condenser
        i. With ON/OFF controlled fans: check startup sequence of the fans (recommend that header end fans are first ON last OFF)
        ii. For modulating fans, manually ramp fans to 0%, 25%, 50%, 100% to ensure proper control of all fans (make sure all fans run at appropriate levels)
        iii. Validate gas cooler alarm signal and functionality

I. Rack controller and related gas cooler controls should be in automatic mode and ready to operate
J. Turn ON power (breakers in control panel) to compressors so they are ready to operate
K. Ensure that CO2 gas detector and emergency ventilation system are functional
L. For safety precautions, remove compressor suction and discharge service valve caps (replace caps after startup is complete)

9. Begin Liquid Charging

A. Verify that the flash gas tank pressure relief valve is set to the lowest of the two relief valves for normal operation (the higher of the two should only be selected during pump down operation)
   i. Follow the diagram attached to the relief valves for proper positioning of the handle to match the correct open port
B. Add liquid CO2 to the system via the flash tank liquid access port
   i. Verify CO2 liquid level alarm clears after 1-2 CO2 bottles
C. Monitor Low Temp and Med Temp suction pressure of the system. Pressure should not bypass any circuits resulting in suction pressure rise. FGBV should be closed until approx. 490 psig [34 barg] is reached
   i. If either Low Temp or Med Temp suction pressure rises, determine source and correct before continuing to fill system
D. As pressure rises above flash tank pressure control setting (490-550 psig [34 – 38 barg]) the Flash Gas Bypass Valve (FGBV) will start to open and provide pressure to the Medium Temp suction. A compressor should start at this time to keep the pressure from rising
   i. Check compressor operation; if a VFD is supplied, check that the compressor operates as it should
   ii. Check and confirm that FGBV opens and operates correctly
      1. If FGBV valve does not modulate, keep vessel pressure low using the manual bypass ball valve until issue with FGBV is corrected
E. Check BOTH the low sight glass and electronic level sensor (same level physically on tank). If liquid is seen in the low sight glass but sensor has not lit RED, the level sensor needs to be evaluated
   i. A RED indicator light on a level sensor means liquid is present, no lights on sensor means no liquid detected at that level
F. Charge and maintain liquid CO2 level in receiver to first (bottom) sight glass level (ball will float in sight glass) until system is fully operational
G. Verify CO2 leak detector devices alarm properly

Suction Groups Startup

10. MT Suction Group

A. Turn on one MT circuit at a time (no more than 25% of all MT circuits) by allowing the EEVs to operate normally (take out the override from the earlier step, open ball valves to each case if applicable)
   Note: Prior to removing the EEV override, verify that the suction transducer in the case/coil is at suction pressure. If the transducer reads closer to liquid pressure the liquid and suction lines are most likely crossed.
   i. Caution must be observed to not bring circuits on too fast resulting in the suction pressure rising too high and discharging CO2

B. As MT suction pressure begins to rise from circuits exchanging heat, the controller will make the MT compressors cycle ON and OFF several times, gradually pulling the suction temperature down; compressors will continue cycling until enough load is available to keep them running

C. Do not overload suction group by activating too many circuits on at one time to try to keep compressor cycling down; cycling is natural for startup, back off turning on cases to allow suction temperature to recover if needed

D. Verify that circuit valves, fans, and superheats are properly working as circuits are brought online

E. Continue to monitor refrigerant level and add liquid CO_2 as necessary to maintain a minimum level in vessel (CO_2 should always be visible in the bottom sight glass)

F. Check oil system; level satisfied at compressor (level switches), and monitor sight glasses in compressors. Monitor and maintain Oil Reservoir level at sight glass during startup of all MT and LT circuits.

G. Check and confirm that the receiver pressure and condenser/gas cooler pressure regulate correctly

  i. During duration of startup, use pressure gauges or review trending graphs of tank pressure, gas cooler fan power (pid%), and HPV/FGBV % opening

  ii. Receiver pressure should not fluctuate much more than ±20psi around setpoint

  iii. Check Pressure-Temperature chart in (page 1) to verify that condensing pressure is appropriate based on ambient temperature and programmed approach setpoint

    1. "Approach": the difference in temperature from the coil entering air temp (precooled air on adiabatic units) to the condenser/gas cooler outlet CO_2 temp (dropleg)

H. Closely observe the compressor suction superheat temperature – make sure that no liquid returns from evaporator

  i. Suction temperature needs to have at least 14°R of superheat; reported probe temperature higher than saturated suction temperature from reported suction pressure transducer

     Note:°R refers to a differential temperature calculation value, like superheat, not a probe measurable temperature from a thermometer, which is reported in °F.

  ii. Suction temperature can be no less than 5F (318psig [22barg])

     Note: If either superheat or suction temperature is too low, the MT Hot Gas Dump valve needs to energize - verify that the HG Dump valve works properly

I. Repeat steps 10.A through 10.H for the next 25% of the MT circuits

J. Once 50% of the MT circuits are active, continue to LT suction group

11. LT Suction Group

A. Once 50% of the MT suction group has reached temperature and stabilized, begin the same procedure with the LT suction group

B. Turn ON one circuit at a time (no more than a group of 25% of all LT circuits) by allowing the EEVs to operate normally (take out override from earlier step and open ball valves to each case if applicable)

   Note: Prior to removing the EEV override, verify that the suction transducer in the case/coil is at suction pressure. If the transducer reads closer to liquid pressure the liquid and suction lines are most likely crossed.

C. Verify correct circuit operation, including fan starting.

D. Check and confirm that each compressor starts one at a time

E. Make sure that LT compressors are supplied with oil, and there is enough oil in the oil reservoir (RED oil indicator lights ON means level SATISFIED).
    i. In systems where there are digital scrolls configured on the Low Temp portion of the rack, maintain proper oil level in compressors and verify OMB system is functioning properly
F. Allow temperature in first circuit to pull down and stabilize
G. Do not overload suction group by activating too many cases on at one time to try to keep compressor cycling down; cycling is natural for startup, back off turning on cases to allow suction temperature to recover if needed
H. Verify that case valves, fans, and superheats are properly working as cases are brought online
I. Continue to monitor refrigerant level and add liquid CO_2 as necessary to maintain a minimum level in vessel (CO_2 should always be visible in the bottom sight glass)
J. Closely observe the compressor suction temperature – make sure that no liquid returns from evaporator,
    i. Suction temperature needs to have at least 36°R of superheat; reported probe temperature higher than saturated suction temperature from reported suction pressure transducer
    Note:°R refers to a differential temperature calculation value, like superheat, not a probe measurable temperature from a thermometer, which is reported in °F.
K. Repeat steps 11.B through 11.J for the next 25% of the LT circuits
L. Return to the MT Suction Group and repeat step 10.H until all MT circuits are active
M. Repeat LT Suction Group step 11.K until all LT circuits are active

System Operation Verification and Optimization

12. Rack and Case Verification (recommend min of 12 hrs after completed startup)

A. Watch compressor cycle counts and ensure that excessive short cycling is not occurring - recommend no more than 6 cycles per hour (cycle count recommendation for fully loaded system after startup is completed)
B. Run cases/circuits through defrosts
    i. Verify defrost programming, set points, times, etc. match customer's/manufacturer's recommendations and that insulation/wiring is not in contact with defrost heaters
    ii. Hot Gas defrost – Set Defrost valve to maintain 550psig with a 33 bar flash tank (approx. 75 psi diff) and check the following to ensure proper operation and adjust as necessary.
        1. Electronic pressure switch settings (Wika) – Hot Gas Differential Valve bypass solenoid control set at 39 bar.
        2. Override Hot Gas Defrost valve OFF (unplug if necessary)
            a. Put each circuit into defrost one at a time and test that all valves work properly.
                i. Place circuit in defrost
                ii. Wait until circuit hot gas valve opens
                iii. Slowly open hot gas ball valve to make sure the suction stop is working properly and has shut, preventing discharge gas from entering the suction header

iv. Leave all valves open for that circuit

3. Once all circuits have been tested, remove Hot Gas Defrost valve override (plug in if necessary)
   a. Test each hot gas circuit for full operation.
4. Make sure the LT head pressure does not trip while performing a defrost test on the circuit located closest to the rack as well as the smallest hot gas defrost circuit
5. Make sure the defrost termination probe is mounted in the correct location and that it approaches the case specified defrost temperature during defrost to ensure there is enough heat to effectively defrost the circuit located farthest from the rack as well as the largest hot gas defrost circuits
6. If the hot gas defrost system is not defrosting as expected, contact a Hillphoenix Field Service Engineer before making adjustments

C. After system is stable and has operated for at least 12 hours, perform a power- loss/auto-restart test
   i. Follow the Simulated Electrical Power Loss Test procedure at end of this guide. The procedure should be executed top to bottom and is intended to first test various scenarios of power loss to the parts of the system, then to simulate an entire store power loss. Testing scenarios independently and verifying the achievement of expected results helps trouble shoot issues that could arise based on power failures. The last steps of the table simulate a complete power loss to all parts of the system.

D. Two days to one week after the system is fully operational, change filters (oil filter, Suction Filter-Drier/Liquid Filter as applicable) and clean "Y" strainer on gas cooler return line and main liquid supply line (also as applicable)
   i. Ensure that as much startup debris is out of system as possible
   ii. Include the cleaning of filters and strainers on the scheduled preventative maintenance of the system

E. Two weeks after the system is fully operational, if pressure drops are measureable and higher than expected, change filters. If pressure drops are not measureable, change filters (oil filter, Suction Filter-Drier/Liquid Filter as applicable)

F. Three weeks after the system is fully operational, if pressure drops are measureable and higher than expected, change filters. If pressure drops are not measureable, change filters (oil filter, Suction Filter-Drier/Liquid Filter as applicable)

Auxiliary Unit Operational Test

13. Auxiliary Unit

A. Verify that power comes from generator switch panel
B. Lower the high pressure switch on main rack for the liquid solenoid valve for auxiliary unit
C. Verify charge and operation

Simulated Electrical Power Loss Test

Action	Expected Results
Simulate Case power loss (but Rack and Controller still powered)	
*Turn off all breakers to Low Temperature circuits. * Keep breakers off till future step	Associated case power loss liquid line solenoids de-energize and evaporators pump out. Fans will shut OFF. Compressors will shut down on low suction pressure.
*Turn off all breakers to Medium Temp circuits. * Keep breakers off till future step	Associated case power loss liquid line solenoids de-energize and evaporators pump out. Fans will shut OFF. Compressors will shut down on low suction pressure. (Compressor will cycle to hold flash tank pressure)
Simulate Case power loss and Rack power loss (but Controller still powered)	
*Disconnect wire from Terminal 1 (not power terminals 25/26) on Danfoss 326A controller (or similar point on other controllers). *Reconnect wire	ICMTS (high pressure valve) and CCM (flash tank bypass valve) close to 0%.
*Auxiliary unit (if present) bypassed to ON to test operation.	Auxiliary unit starts. Need to validate sufficient refrigeration charge and set point for mechanical pressure control.
Simulate Rack power loss (but Cases and Controller still powered) – Case Controller *Electronic* Safety	
*Locate and activate single input point in main controller that forces ALL case EEVs closed (forcing OPEN N.C. or CLOSE N.O. inputs via software or hardware). *After bypassing control inputs, the breakers for all MT circuits and LT circuits are to be turned back ON.	Because of no signal from controller: All EEV's close to 0% All Fans in cases and evaps to stay OFF.
Simulate Rack power loss (but Cases and Controller still powered) – Case Controller *Mechanical* Safety	
*Remove PMR (Phase Monitor Relay) to simulate a phase loss to the 600V	Because Phase Monitor Relay failure at rack: All EEV's close to 0% Compressors will shut OFF or be unavailable.
Simulate Rack power, Case power and Controller power restored	
*Return the case override from previous step to normal operating position. *Replace Relay. *Return Rack to Normal operation for at least 30 minutes. (turn ON all breakers)	Everything will restart.
Simulate Rack power, Case power and Controller power loss and recovery	
*Complete shutdown of electrical to Mechanical room and cases for 30 minutes (monitor suction pressures). Turn OFF circuit breakers Turn OFF rack control breakers Turn OFF Rack main power	Refrigeration system shutdown.
*Turn power back on.	Everything restarts automatically.

Quick Summary Booster Validation List

- [ ] 1. HPV valve settings validated in Danfoss ICMTS actuator
- [ ] 2. HPV/CCM controller settings validated 326a/iPro/781
- [ ] 3. Co2 Liquid level alarm
    - Verify prior to start up and during charging to clear alarm- Light ON after 1 or to Liquid bottles added
- [ ] 4. Oil reservoir alarm Verify prior to start up – Remove HB sensor electronic from well sensor
- [ ] 5. Oil separator solenoid operation prior to start up by cycling RO in EMS & once light comes ON the HB sensor after system running. (Close Outlet ball valve from Separator to reservoir until HB sensor light comes on in which to then verify the Solenoid operates)
- [ ] 6. Compressor Oil Failure operation to shut off and alarm (Prior to start up or after)
    - All MT Compressors
    - All LT Compressors
    - Validate Oil Solenoids for each compressor operate when calling for oil (Trace oil lines to solenoids)
    - Prior to S/U - Remove HB sensor electronic from well sensor/close compressor ball valve - monitor operation for Oil Fail
  - After- DO above or close oil valve off to monitor operation for Oil Fail
- [ ] 7. Validate Hot Gas Valve opens when called for LOW SH or if enabled low load
- [ ] 8. Validate Liquid injection operates when calling High Superheat or High Discharge Temp
- [ ] 9. Validate VFD alarm for any compressor VFD on system
- [ ] 10. Validate Gas Cooler alarming currently Luvata only until BAC alarming enabled or option is purchased
- [ ] 11. Validate high-pressure mechanical controls & compressor Safety circuits for each compressor in LT & MT suction groups. When each alarm opens/trips compressor must shut off.
    - Mechanical High Discharge for LT (600psi) and MT (1490psi)
    - Verify case shutdown enabled during this check
- [ ] 12. LT & MT Time delays set in main electrical panel
    - LT 10 Sec
    - MT 10 sec
- [ ] 13. Case shutdown validated to shut off case groupings as per load sequences – See NEW appendix for thorough validation
- [ ] 14. Phase loss check to alarm
    - Validate the 326a iPro is off (POR relay) Shutdown with CCM and HPV O%
    - Case shutdown enabled at this time
- [ ] 15. Low Suction for MT (Currently 300psi) & LT groups (Currently 140Psi)
- [ ] 16. Co2 leak detector alarms

Yearly Preventive Maintenance for the Hillphoenix Advansor Booster System

- Measure the pressure differential of the system's Oil Separator/Filter; change the Oil Separator/Filter when the pressure differential is 13 psig or greater. Annual filter changes are recommended to maintain optimum system performance.
- Measure the pressure differential across the Suction Filter/Drier. If the pressure drop exceeds 5 psid, change the Suction Filter/Drier core.
- Measure the pressure differential across the liquid Y-strainer and/or liquid filter-drier, it should be less than 10 psid.
- Check the temperature of all of the compressor cylinder heads. If the temperature reading between cylinder heads differs by 30 °F or more, pull the high-reading compressor cylinder head for inspection.
- Clean all of the case honeycombs to ensure they are free of any debris.
- Inspect and clean the condenser/gas cooler coils.
  - Refer to the BAC manual for instruction for pad cleaning and unit maintenance.
- Verify that the leak detector is operating properly, and that the entire system, including evaporators and gas coolers, is leak-free.
- Verify the operation of all pressure transducers using a separate, calibrated gauge.
- Recalibrate the HPV to zero (see the start-up procedure for proper instructions).
- Check the system for non-condensable gases.
- Verify the proper operation of all safety controls.
- Check the the oil levels at all of the compressors and in the oil reservoirs.
- Inspect around the compressor for oil leaks or oil residue. Also check for signs of oil leakage around the oil management system.
- Check for proper operation of the liquid injection and hot gas dump valves (see the start-up procedure for instruction on how to do this).
- Refer to the case and evaporator manufacturers' manuals for cleaning and maintenance recommendations.
- Visually inspect all wires, contactors, and circuit breakers for signs of degradation, and to ensure that no wires or conduits are rubbing against refrigerant lines.
- Check the VFD (Variable Frequency Drive) for proper operation, including the cooling fan, cleaning of the heat sink, etc. Consult the VFD manufacturer's manual for additional recommendations.

Hill PHOENIX Pressure-Temperature Chart for CO2

Temp °F	CO2 (R-744) Pressure psi(g)	CO2 (R-744) Pressure bar(g)	Temp °C
-39	134.2	9.3	-39.4
-38	137.2	9.5	-38.9
-37	140.3	9.7	-38.3
-36	143.5	9.9	-37.8
-35	146.7	10.1	-37.2
-34	149.9	10.3	-36.7
-33	153.2	10.6	-36.1
-32	156.5	10.8	-35.6
-31	159.9	11.0	-35.0
-30	163.3	11.3	-34.4
-29	166.8	11.5	-33.9
-28	170.3	11.7	-33.3
-27	173.9	12.0	-32.8
-26	177.5	12.2	-32.2
-25	181.2	12.5	-31.7
-24	185.0	12.8	-31.1
-23	188.7	13.0	-30.6
-22	192.6	13.3	-30.0
-21	196.5	13.5	-29.4
-20	200.4	13.8	-28.9
-19	204.4	14.1	-28.3
-18	208.5	14.4	-27.8
-17	212.6	14.7	-27.2
-16	216.7	14.9	-26.7
-15	221.0	15.2	-26.1
-14	225.2	15.5	-25.6
-13	229.6	15.8	-25.0
-12	234.0	16.1	-24.4
-11	238.4	16.4	-23.9
-10	242.9	16.7	-23.3
-9	247.5	17.1	-22.8
-8	252.1	17.4	-22.2
-7	256.8	17.7	-21.7
-6	261.5	18.0	-21.1
-5	266.3	18.4	-20.6
-4	271.2	18.7	-20.0
-3	276.1	19.0	-19.4
-2	281.1	19.4	-18.9
-1	286.1	19.7	-18.3
0	291.2	20.1	-17.8
1	296.4	20.4	-17.2
2	301.7	20.8	-16.7
3	307.0	21.2	-16.1
4	312.3	21.5	-15.6
5	317.8	21.9	-15.0
6	323.2	22.3	-14.4
7	328.8	22.7	-13.9
8	334.4	23.1	-13.3
9	340.1	23.5	-12.8
10	345.9	23.8	-12.2
11	351.7	24.3	-11.7
12	357.6	24.7	-11.1
13	363.6	25.1	-10.6
14	369.7	25.5	-10.0
15	375.8	25.9	-9.4
16	382.0	26.3	-8.9
17	388.2	26.8	-8.3
18	394.5	27.2	-7.8
19	400.9	27.6	-7.2
20	407.4	28.1	-6.7
21	414.0	28.5	-6.1
22	420.6	29.0	-5.6
23	427.3	29.5	-5.0
24	434.0	29.9	-4.4
25	440.9	30.4	-3.9
26	447.8	30.9	-3.3
27	454.8	31.4	-2.8
28	461.9	31.8	-2.2
29	469.0	32.3	-1.7
30	476.3	32.8	-1.1
31	483.6	33.3	-0.6
32	491.0	33.9	0.0
33	498.5	34.4	0.6
34	506.0	34.9	1.1
35	513.6	35.4	1.7
36	521.4	35.9	2.2
37	529.2	36.5	2.8
38	537.1	37.0	3.3
39	545.0	37.6	3.9
40	553.1	38.1	4.4
41	561.2	38.7	5.0
42	569.5	39.3	5.6
43	577.8	39.8	6.1
44	586.2	40.4	6.7
45	594.7	41.0	7.2
46	603.2	41.6	7.8

Low Temp Suction, Typical (-25 °F to -15 °F)

Medium Temp Suction, Typical (15 °F to 25 °F)

Hill PHOENIX Pressure-Temperature Chart for CO2

Temp °F	CO2 (R-744) Pressure psi(g)	CO2 (R-744) Pressure bar(g)	Temp °C
47	611.9	42.2	8.3
48	620.7	42.8	8.9
49	629.5	43.4	9.4
50	638.5	44.0	10.0
51	647.5	44.6	10.6
52	656.7	45.3	11.1
53	665.9	45.9	11.7
54	675.2	46.6	12.2
55	684.6	47.2	12.8
56	694.2	47.9	13.3
57	703.8	48.5	13.9
58	713.5	49.2	14.4
59	723.3	49.9	15.0
60	733.3	50.6	15.6
61	743.3	51.2	16.1
62	753.4	51.9	16.7
63	763.6	52.7	17.2
64	774.0	53.4	17.8
65	784.4	54.1	18.3
66	795.0	54.8	18.9
67	805.7	55.5	19.4
68	816.4	56.3	20.0
69	827.3	57.0	20.6
70	838.3	57.8	21.1
71	849.4	58.6	21.7
72	860.7	59.3	22.2
73	872.0	60.1	22.8
74	883.5	60.9	23.3
75	895.1	61.7	23.9
76	906.9	62.5	24.4
77	918.7	63.3	25.0
78	930.7	64.2	25.6
79	942.8	65.0	26.1
80	955.1	65.9	26.7
81	967.5	66.7	27.2
82	980.0	67.6	27.8
83	992.7	68.4	28.3
84	1005.6	69.3	28.9
85	1018.6	70.2	29.4
86	1031.8	71.1	30.0
87	1045.1	72.1	30.6
87.8	1055.5	72.8	31

*All data from NIST Refprop 8.0 [Barometric Press=14.50377psi]

The following chart is specifically for the *approximation* of correlated temperatures and pressures in a CO2 gas cooler operating above the CO2 critical point temperature and pressure.
Again, these values are *guidelines* and will vary based on system configuration and system controller selection.

Temp °F	Gas Cooler CO2 psi(g)	Gas Cooler CO2 bar(g)	Temp °C
87	1125.5	77.6	30.6
88	1143.2	78.8	31.1
89	1161.2	80.1	31.7
90	1179.3	81.3	32.2
91	1197.5	82.6	32.8
92	1215.9	83.9	33.3
93	1234.3	85.1	33.9
94	1252.9	86.4	34.4
95	1271.5	87.7	35.0
96	1290.2	89.0	35.6
97	1308.9	90.3	36.1
98	1327.6	91.6	36.7
99	1346.1	92.8	37.2
100	1364.6	94.1	37.8
101	1382.9	95.4	38.3
102	1401.0	96.6	38.9
103	1418.8	97.9	39.4
104	1437.4	99.1	40.0
104+	1437.4	99.1	40.0+

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