

Natural Refrigerant Training Summit

Building a Sustainable Workforce

Top 10 differences between HFC & CO2 (R-744)

Alain Mongrain

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NORTH AMERICAN
Sustainable
Refrigeration
Council



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Natural Refrigerant Training Summit

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Who We Are

A 501c3 nonprofit working to create a sustainable future for supermarket refrigeration by removing barriers to natural refrigerant adoption.




160+
member
companies



55K+
food retail
locations



Goals

-  Build a sustainable technician workforce
-  Increase funding for natural refrigerant equipment
-  Improve technology options, education, and awareness

What are Natural Refrigerants?

CO₂

R744
Carbon Dioxide

C₃H₈

R290
Propane

NH₃

R717
Ammonia

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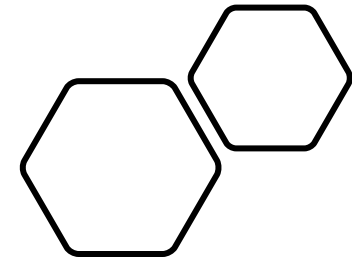
Top 10 Differences Between CO₂ and HFC Systems

NASRC – Natural Refrigerant Training Summit
Pittsburgh, PA

March 19-21, 2023

Alain Mongrain





Agenda:

- 1. CO₂ as a Refrigerant**
- 2. Safety and Handling**
- 3. Top 10 Difference Between HFC & CO₂ Systems**
- 4. CO₂ Unit Walk Around**

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CO₂ (R-744) as a Refrigerant

R-744 vs HCFC/HFC

	R-744	HFC / HCFC	Impact on R-744 Systems
Global Warming Potential	1	1300 to 4000	Future Proof
Ozone Depleting Potential	0	0 for HFC / High for HCFC	Future Proof
Saturation Pressures	Higher	Lower	Additional Safety Design
Operating Pressures	Higher	Lower	Specialized Components
Standstill Pressures (Power Outages)	Higher Rapid Pressure Rise	Lower	Relief Valves/Tanks/etc.. Pressure Relief Venting
Inert Gas	Yes	Yes	Copper may be used
Flammability	A1	A1	Not Flammable
Toxicity	No	No	Asphyxiate in High Concentrations
Odor	None	None	Leak Detection Required
Volumetric Mass Flow	Higher	Lower	Smaller Tubes & Compressors
Heat Transfer	Higher	Lower	Better Thermal Efficiency
High Ambient Performance	Lower	Higher	System Design to Compensate
Low Ambient Performance	Good	Good	Subcritical Cascade Favorable
Cost per Pound	Low	Higher	Economical
Complexity of Systems	Higher	Lower	Higher First Cost, Training & Experience
Adoption	Low	Higher	Higher First Cost
Legislation / Regulations	Low	Higher	Long-Term Viability

- R-744 Provides Many Benefits Over HFC Options

Basic Properties of R744 with R404A Refrigerants Commonly used in the Retail Sector

Refrigerant	R744 (CO ₂)	R404A
Temperature at atmospheric pressure	-109.3°F (-78.5°C) Temp of dry ice	-50.8°F (-46°C) (Saturation temp.)
Critical temperature	87.8°F (31°C)	161.6°F (72°C)
Critical pressure	1056psig	503psig
Triple point pressure	61 psi	0.28.9 Hg
Pressure at a saturated temperature of 20°C	815psig	144psig
Global warming potential	1	3922



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CO₂ (R-744) - Refrigerant Safety & Handling

PPE – Personal Protective Equipment



Hazards

Odourless, Tasteless

Toxicity levels (greater than most HFCs)

Heavier than air (asphyxiation concerns)

Higher pressures (compared to HFCs)

Low temperature exposures (frost-bite)

High temperature exposures (burns)



Toxicity Levels

ppm of CO ₂	Effects
370	- atmosphere concentration
5,000	- max. 8-hour limit exposure
15,000	- max. 10-minute limit exposure
30,000	- discomfort, breathing concerns, headache, dizziness, may have a taste
100,000	- loss of consciousness, death
300,000	- <i>quick death!</i>

5000 ppm = 0.5% concentration



Temperature Exposure



Boiling Temperature of CO₂

-78.5 °C (-109.3 °F)



- As with all refrigerants frostbite and burns are a concern
- Due to the extreme cold temperatures of CO₂, extra precautions are required



Liquid CO₂

- Liquid CO₂ “trapped” either in the system or in an airtight container may create a dangerous pressure situation
- A small increase in temperature will cause a large rise in pressure as the liquid tries to expanded into a vapour
- Always avoid a “Hydrostatic Condition”
- This is done by;
 - ensuring valves are open
 - where necessary, remove CO₂
 - relief valves are installed



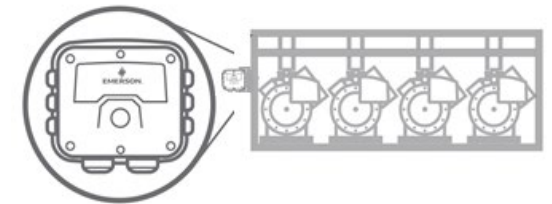
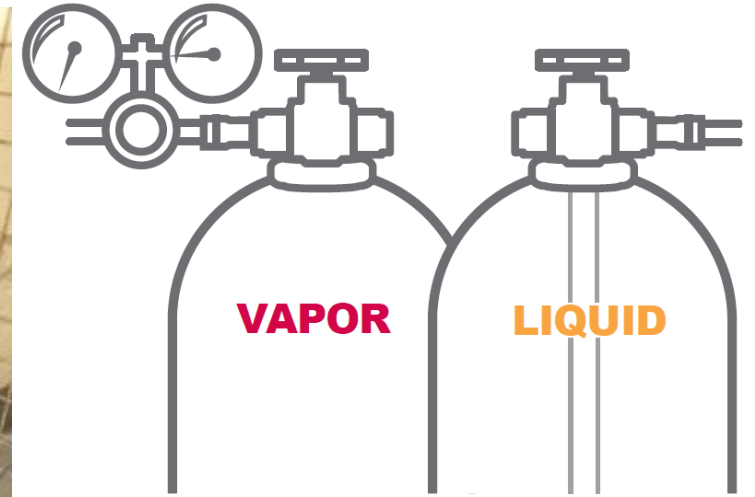
Potential, force of hydrostatic conditions due to liquid overfill and no relief valve

R744 (CO₂) Cylinder



Dip Tube Line Designating Liquid Tank

Grade 4 = 99.99% Pure



Cylinder standstill pressures are rated to 1800 psi at 68°F (20°C)

Cylinder Adapters

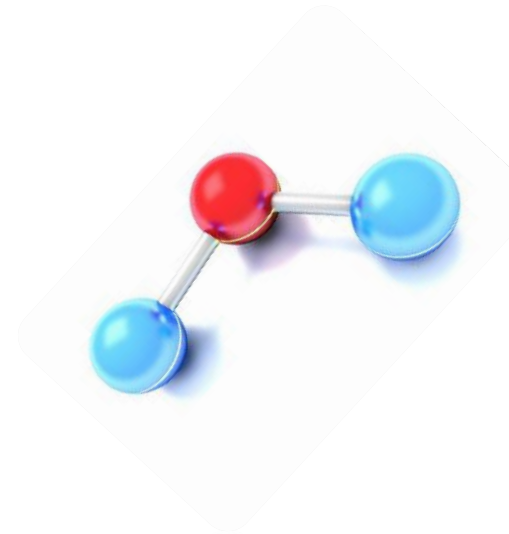
Service connector/adaptor is a CGA 320



Refrigerant Grade (Quality)

The difference is moisture content

- SFC (with helium) (99.999%) <1ppm
- SFC (without helium) (99.999%) <1ppm
- Research (99.999%) <0.5 ppm
- **Refrigeration Grade, Coleman, Anaerobic (99.99)% <10 ppm**
- Bone dry, Commercial (99.8 %) (liquid)



TOP 10 DIFFERENCES BETWEEN CO₂ AND HFC SYSTEM DESIGNS

KEY DESIGN CONSIDERATIONS OF CO₂ TRANSCRITICAL BOOSTER SYSTEMS COMPARED TO TRADITIONAL HFC SYSTEMS

CO₂ transcritical booster (TCB) refrigeration systems have proven to be safe, reliable and efficient in tens of thousands of installations around the globe.



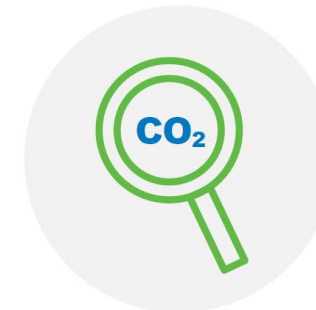
To meet sustainability targets, installations of CO₂ TCB systems are expected to rise significantly over the coming years in U.S. food retail markets.



Compared to systems based on legacy hydrofluorocarbon (HFC) refrigerants, CO₂ (refrigerant name R-744) TCB systems have unique characteristics that require specific mitigation strategies and design considerations.

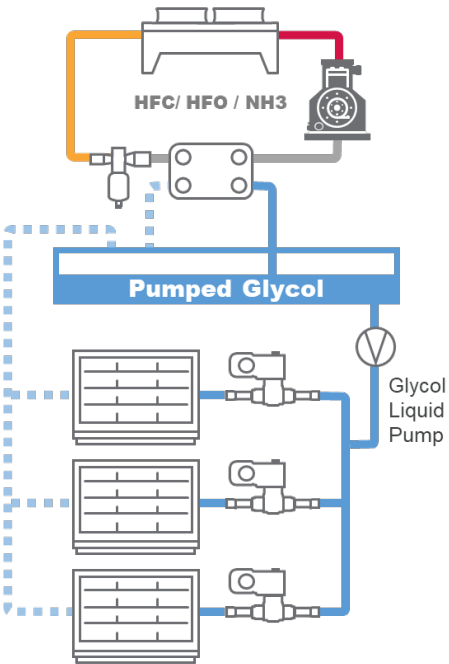


Original equipment manufacturers (OEMs), contractors and end users should begin familiarizing themselves with the key design differences and operating principles between CO₂ TCB and traditional HFC systems.

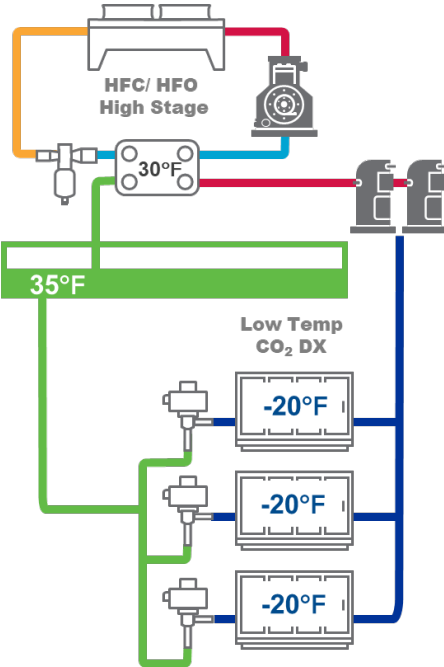
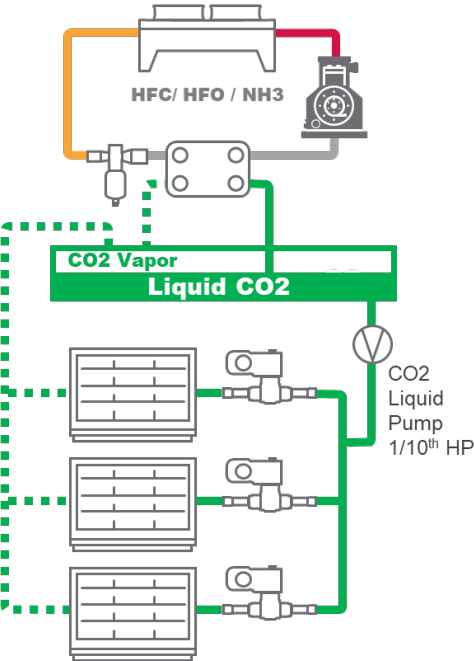


Types of CO₂ Systems

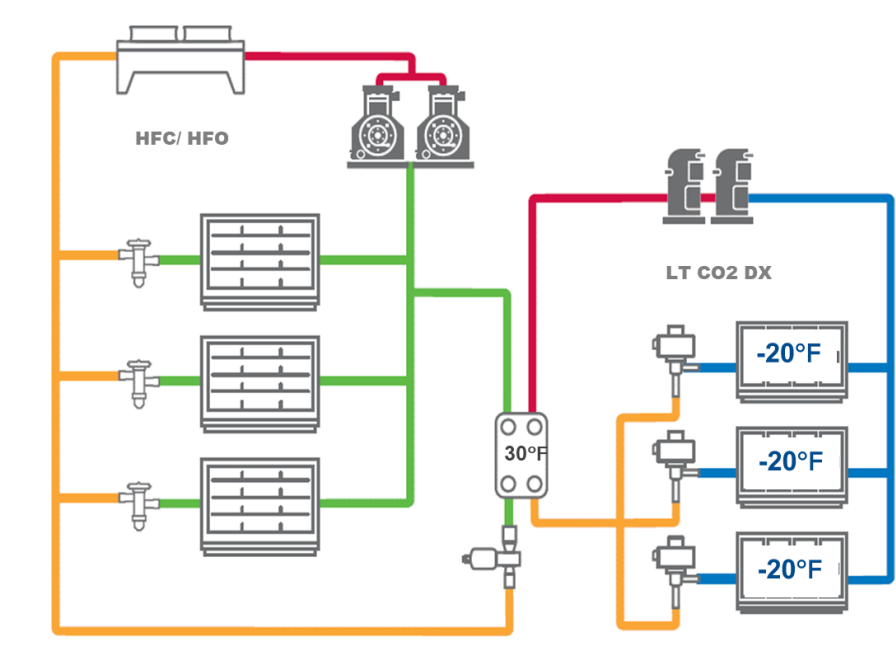
Pumped Secondary



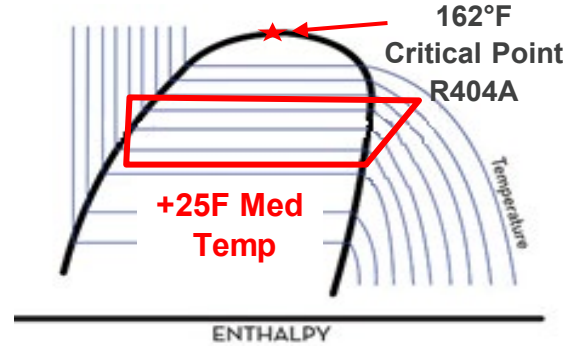
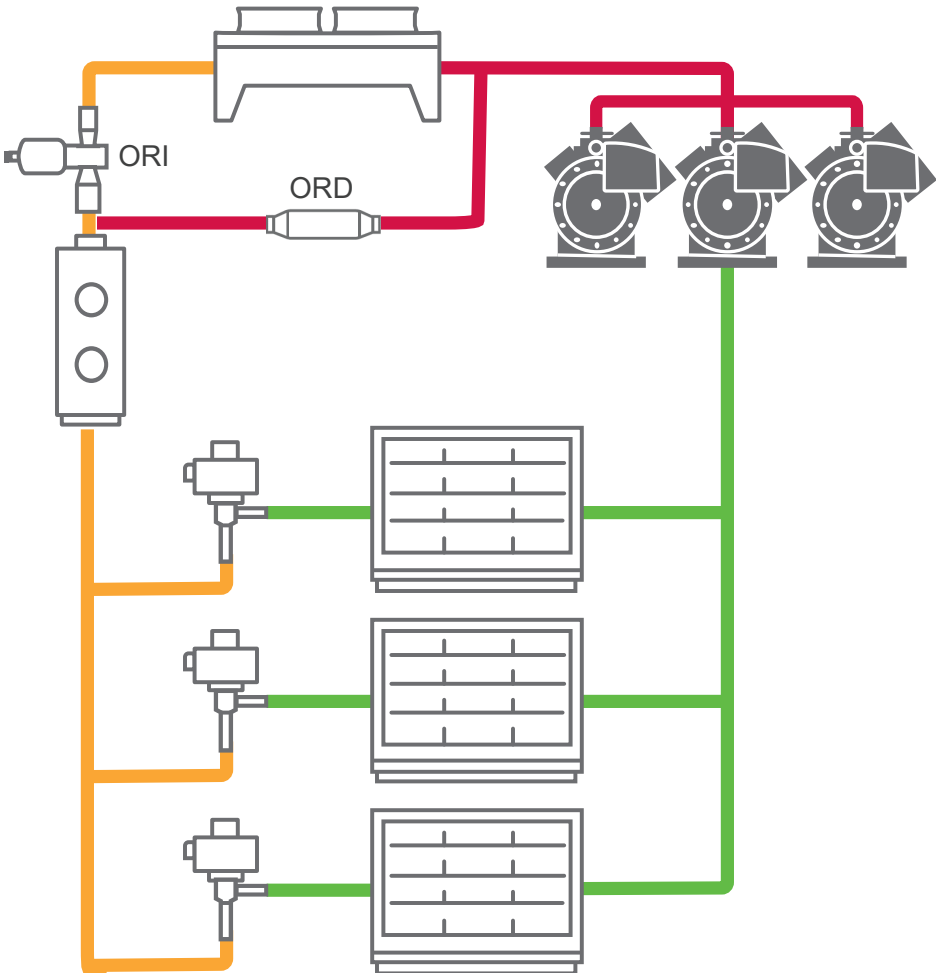
Simple Cascade



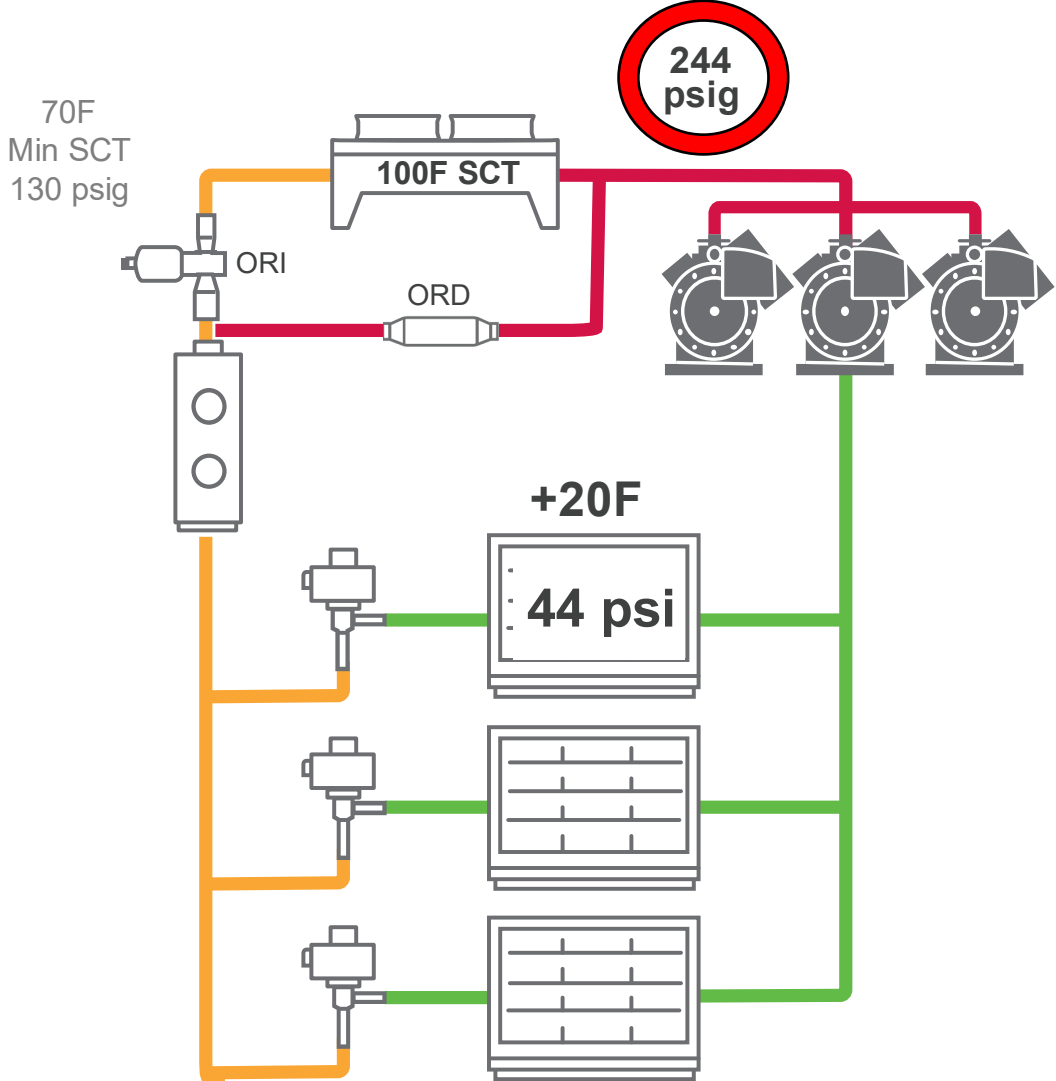
Retail Cascade



R448A With Head Pressure Controls System

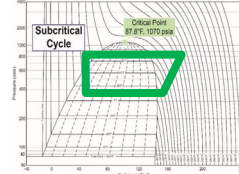
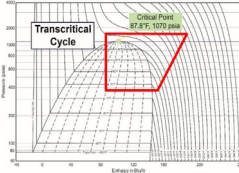
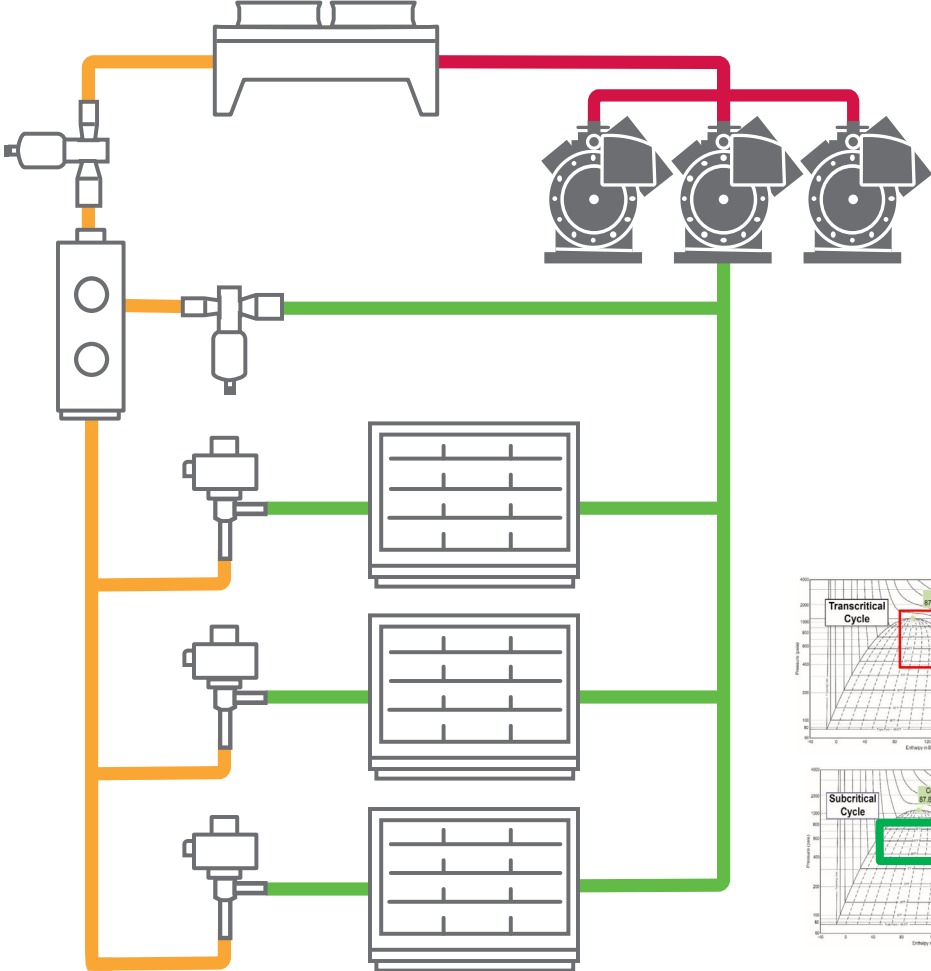


R448A With Head Pressure Controls



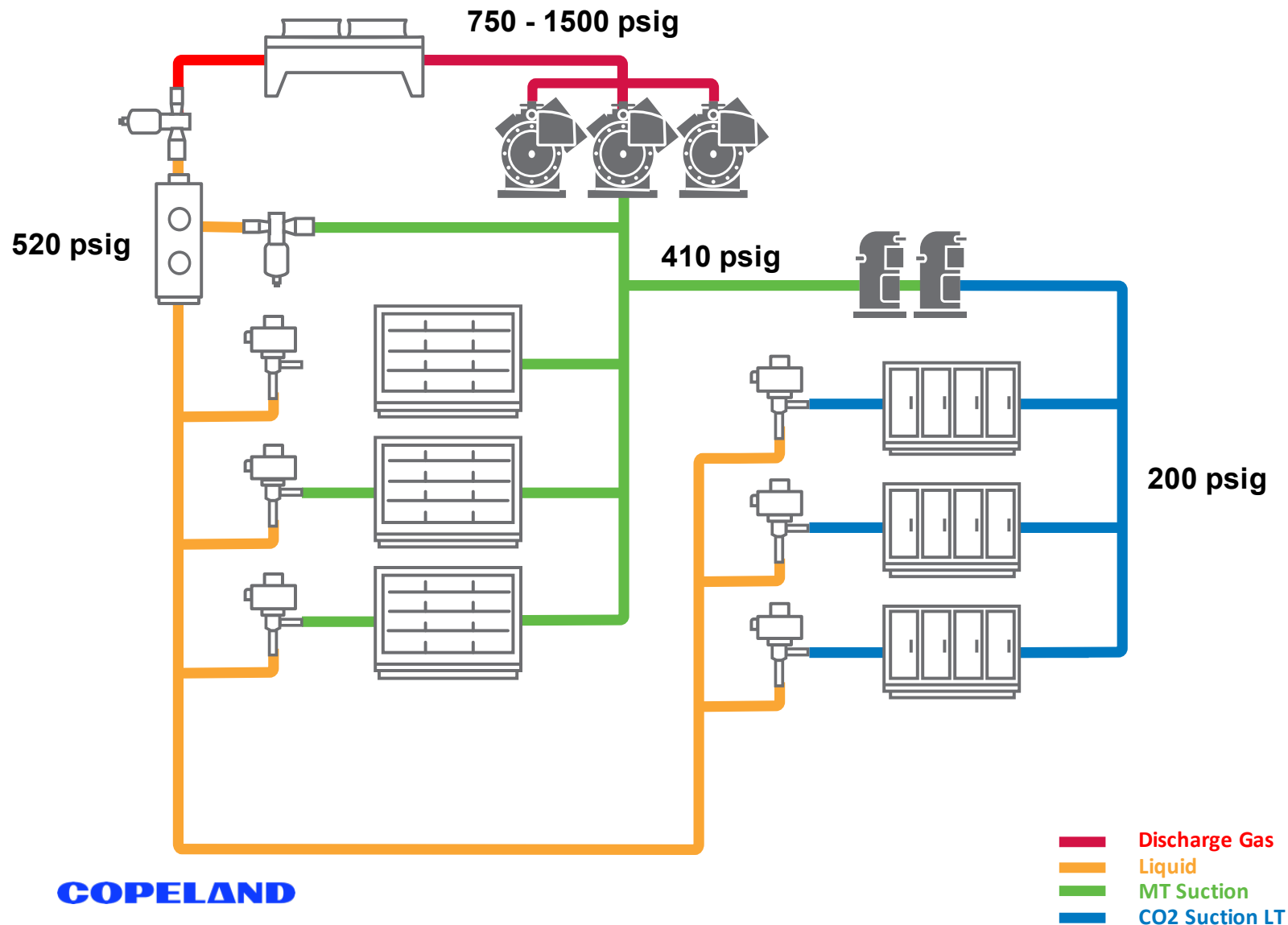
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Medium Temp CO₂ Transcritical Systems



Types of CO₂ Systems

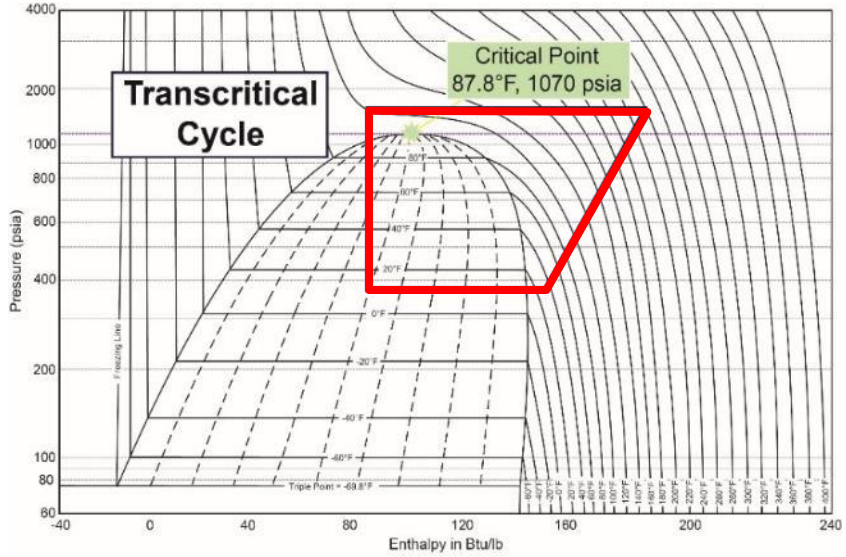
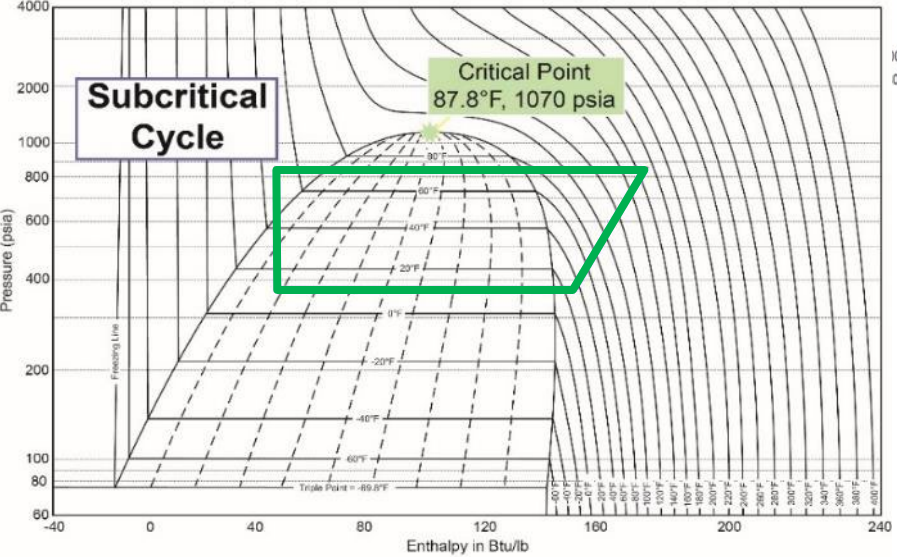
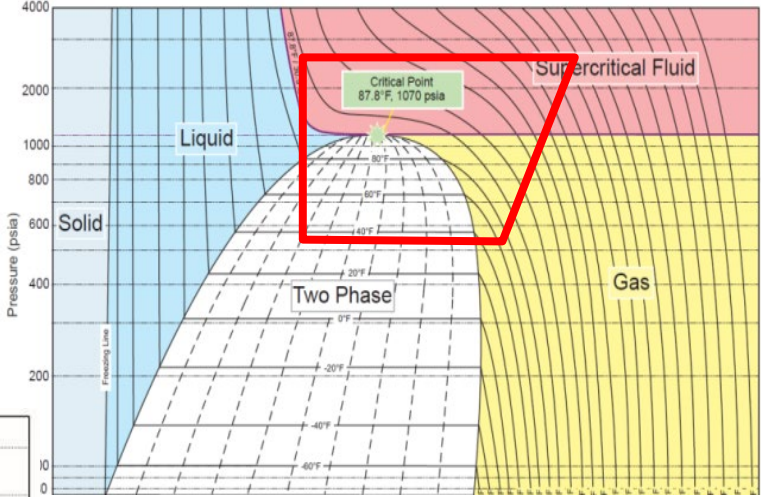
CO₂ Transcritical Booster (TCB)



10 Major Difference VS HFC

1. Booster Design
2. Gas Cooler (TC) / Condenser (SC)
3. Higher Discharge Pressure vs HFC
4. Low Critical Point CO₂
5. High Pressure Valve Bypass Valve
6. Flash Tank / Receiver
7. Reliance on Controls
8. High Triple Point
9. Standstill Pressure
10. Safeties and Pressure Relief Valves

Pressure-Enthalpy Diagram, CO₂



Transcritical Systems Can “Transition” from Subcritical to Supercritical

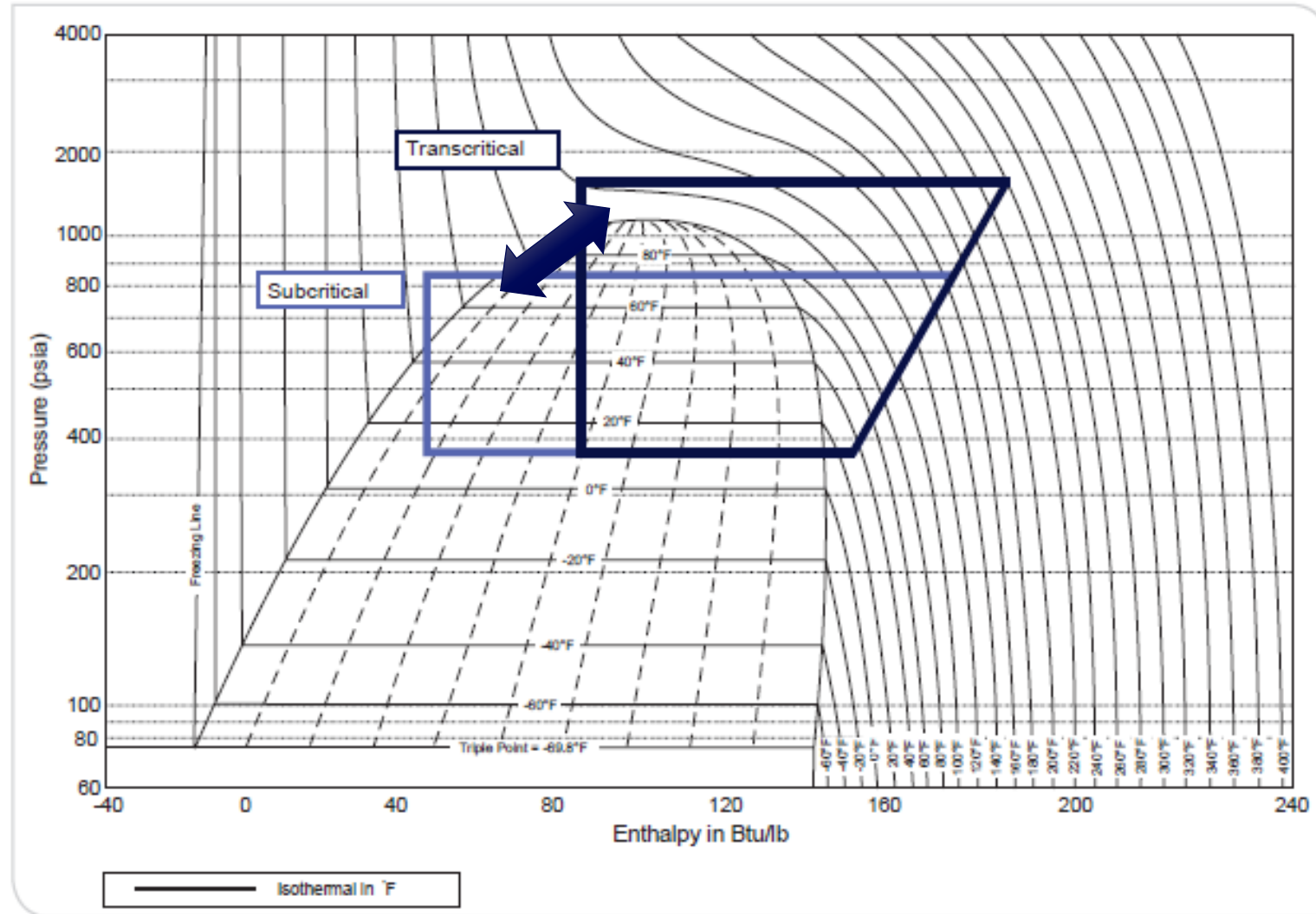


Figure 6. R744 pressure enthalpy chart showing subcritical and transcritical systems

<https://www.youtube.com/watch?v=RmaJVxafesU>



Thermodynamics - Explaining the Critical Point

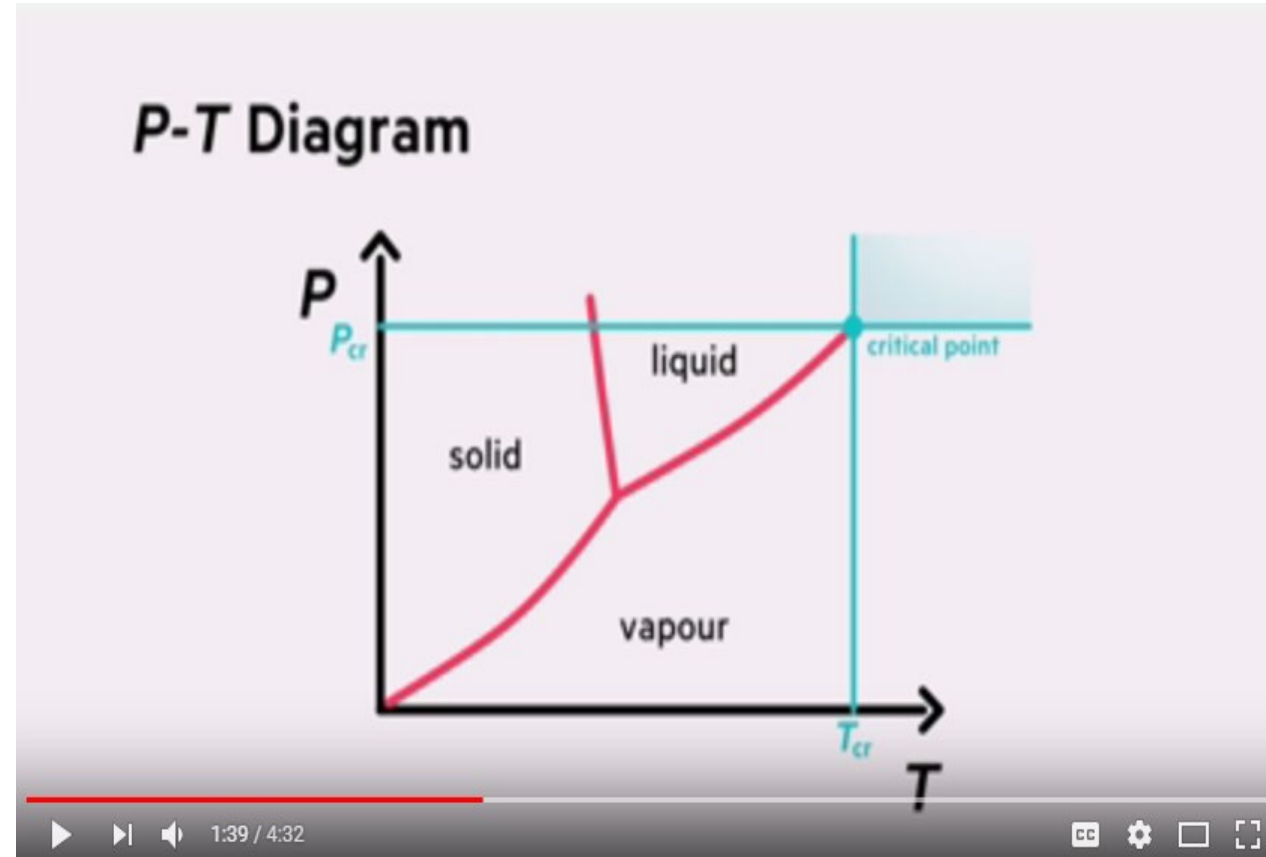


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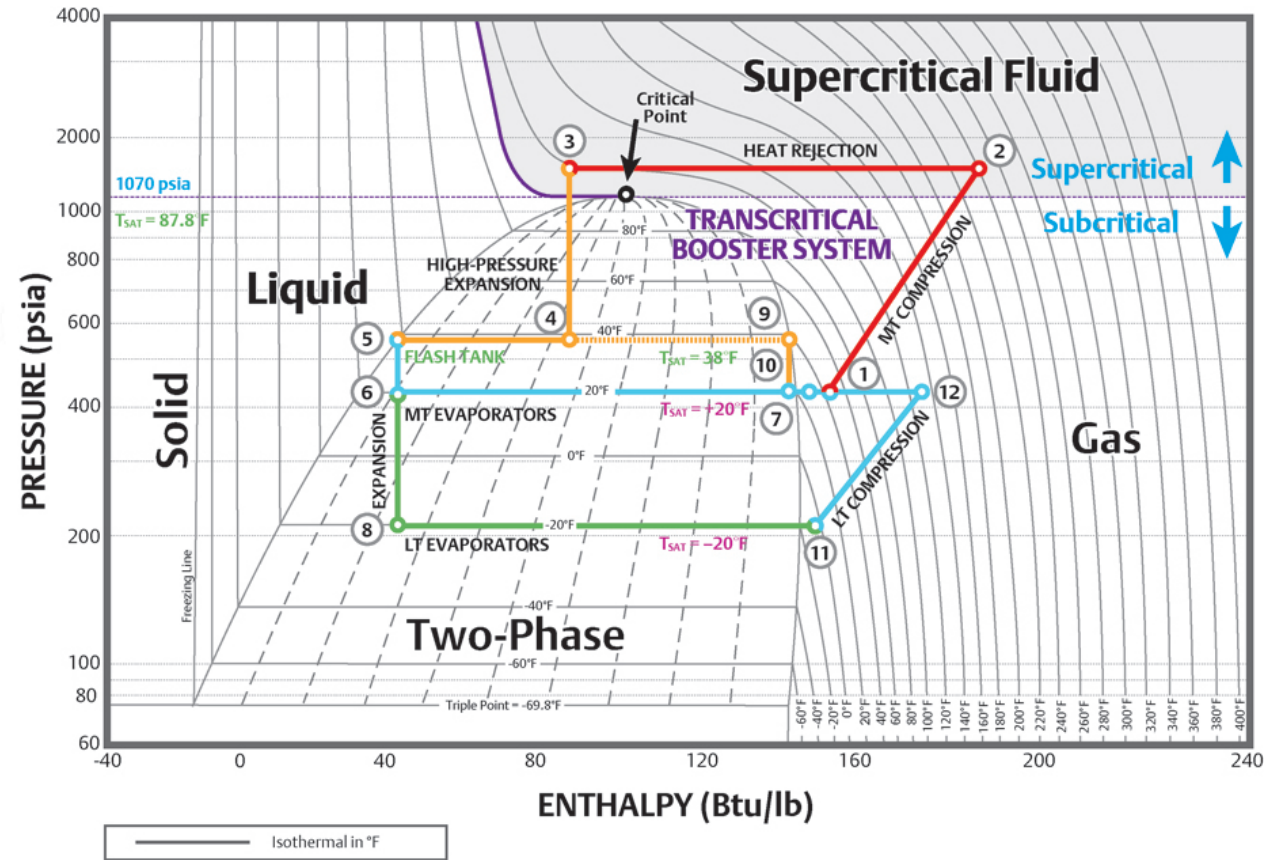
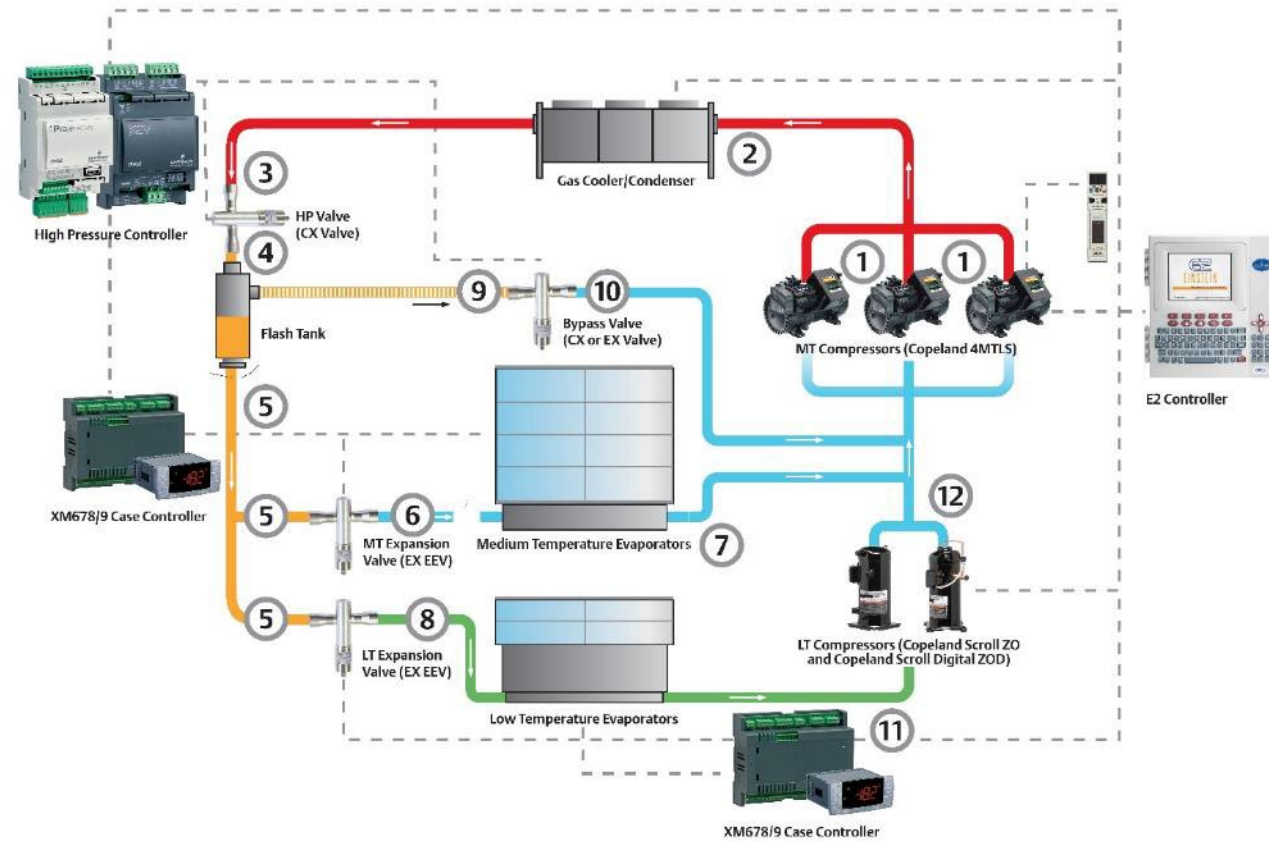
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Transcritical CO₂ Booster System - Animation



Design Differences

Between HFC and CO₂

Transcritical

Compressor

Compressors of same Capacity

Discus 4DH



Copeland[™]
brand products

CO2 4MTLS15



Copeland[™]
brand products

Stator Cover

Discus 4DH

005-1832-00



12 bolts

CO2 4MTLS15

505-1218-00



27 bolts

Head Covers

Discus 4DH

002-0433-00



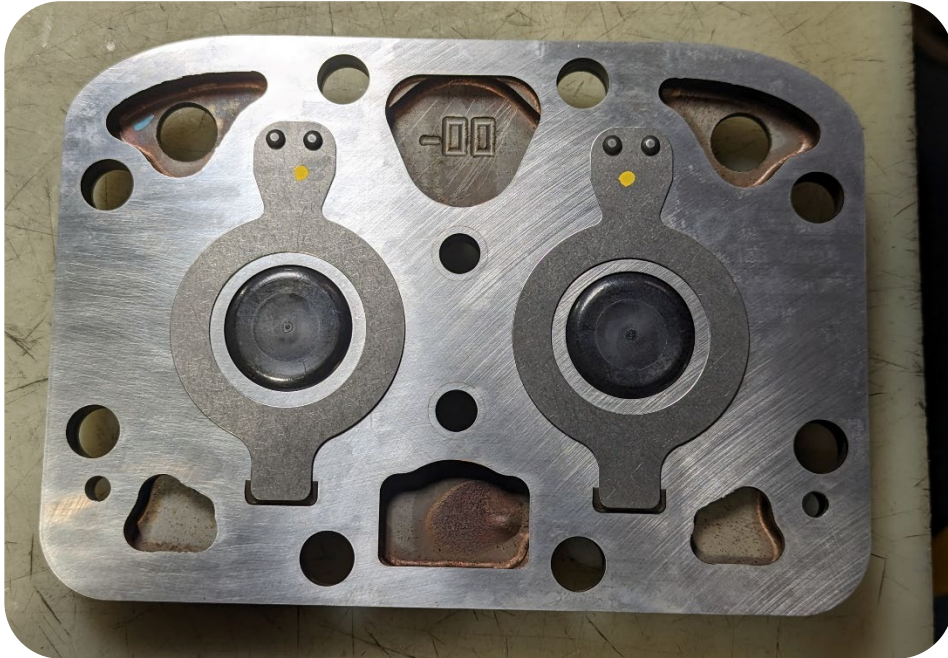
CO2 4MTLS15

002-0439-00



Valve Plates

Discus - 4DH



503-2032-00

CO2 - 4MTLS15



503-1075-00

Note: Discus "puck" design vs. traditional Reed

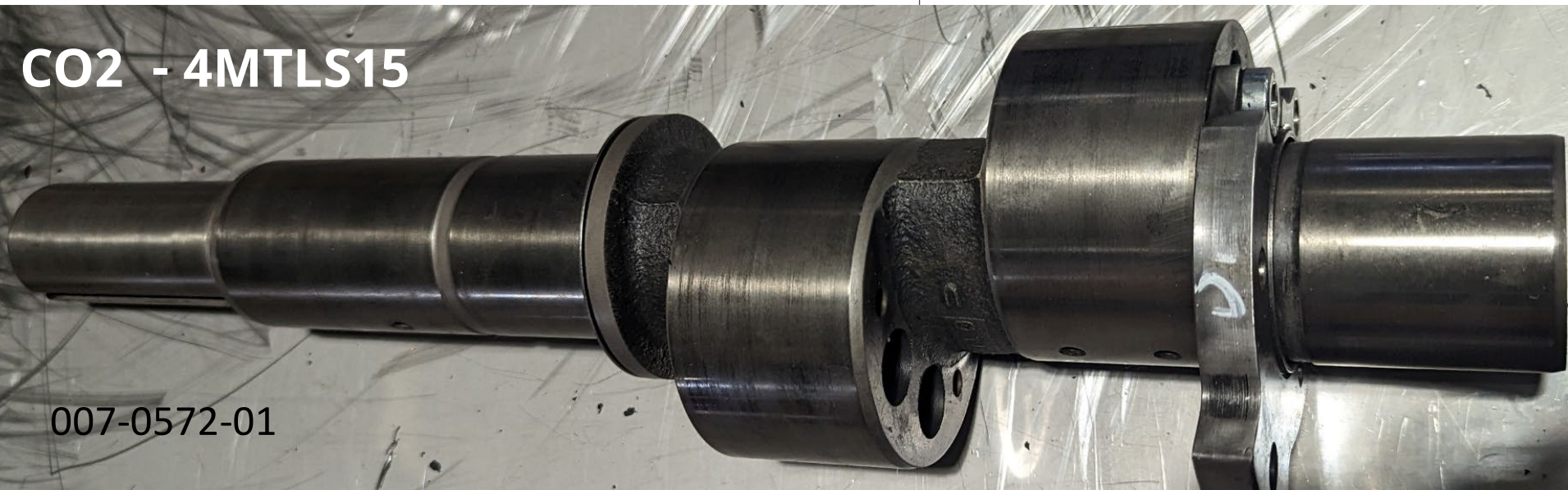
Crankshaft

Discus - 4DH



007-0556-00

CO2 - 4MTLS15



007-0572-01

Connecting Rods

Discus - 4DH

Discus
Large Diameter 47mm
Small Diameter 19mm



CO2 - 4MTLS15

CO2
Large Diameter 82mm
Small Diameter 25mm



DU Bearings pressed
in each hole

Wrist Pins

Discus - 4DH

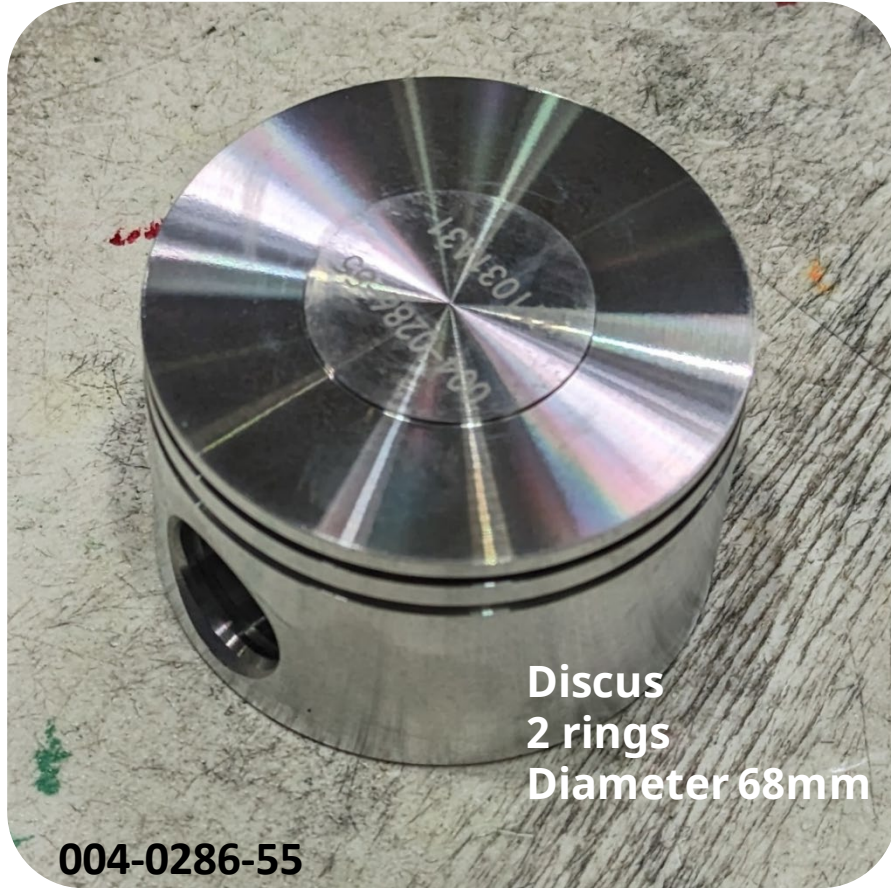


CO2 - 4MTLS15



Pistons

Discus - 4DH



Discus
2 rings
Diameter 68mm

004-0286-55

CO2 - 4MTLS15

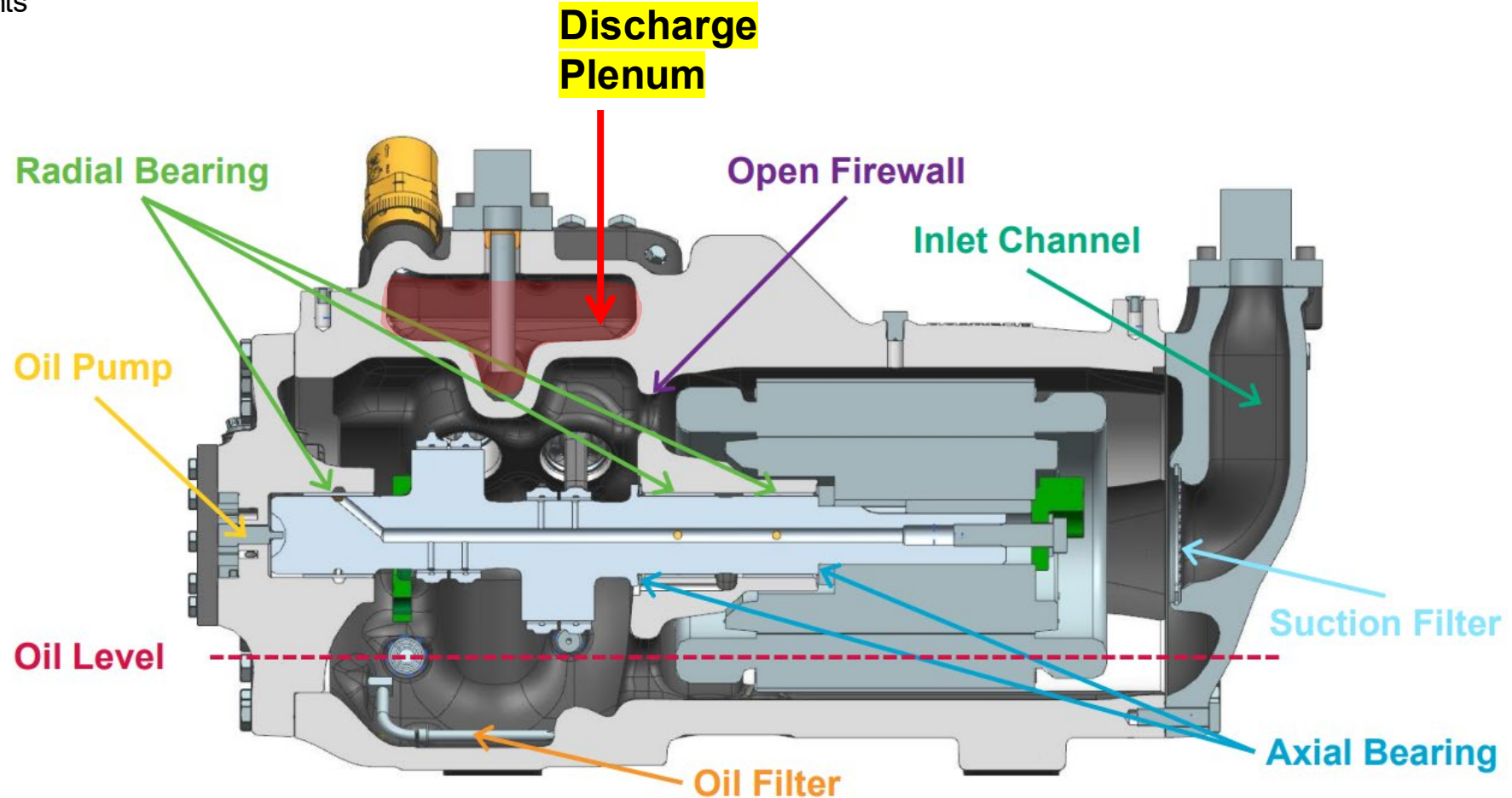


CO2
3 rings
Diameter 47mm
45% Smaller

004-0475-01

4MTLS20/22/28 Cutaway & Highlighted Attributes

Largest 3 Displacements



Recommend Oil Pressure for Semi-hermetic Compressor Between **9 and 60 lbs** of net oil pressure.
Oil pumps do not trip until they get **below a 9-pound differential** from oil pump to crankcase.
The oil pumps will **bypass at 60 lbs** of oil net pressure.

2

GAS COOLER

The gas cooler (aka condenser), typically located on the roof, is integral to a CO₂ TCB system's design.

- Must be sized to handle the system's total heat of rejection from MT compressors at an installation location's design conditions
- Typically designed with variable speed fan motor control
- Can include adiabatic cooling pads to improve system efficiencies in warm ambient climates



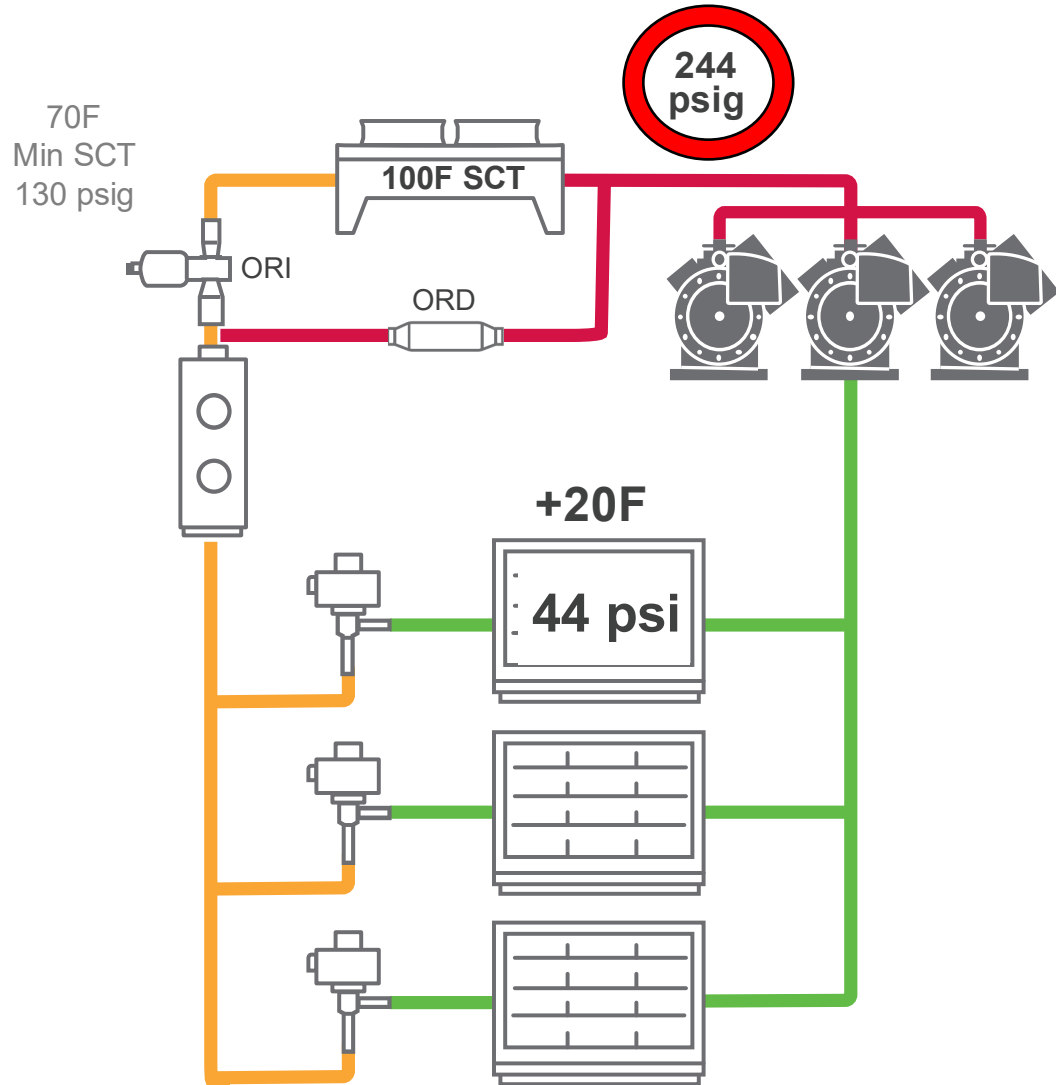
GAS COOLER/CONDENSER



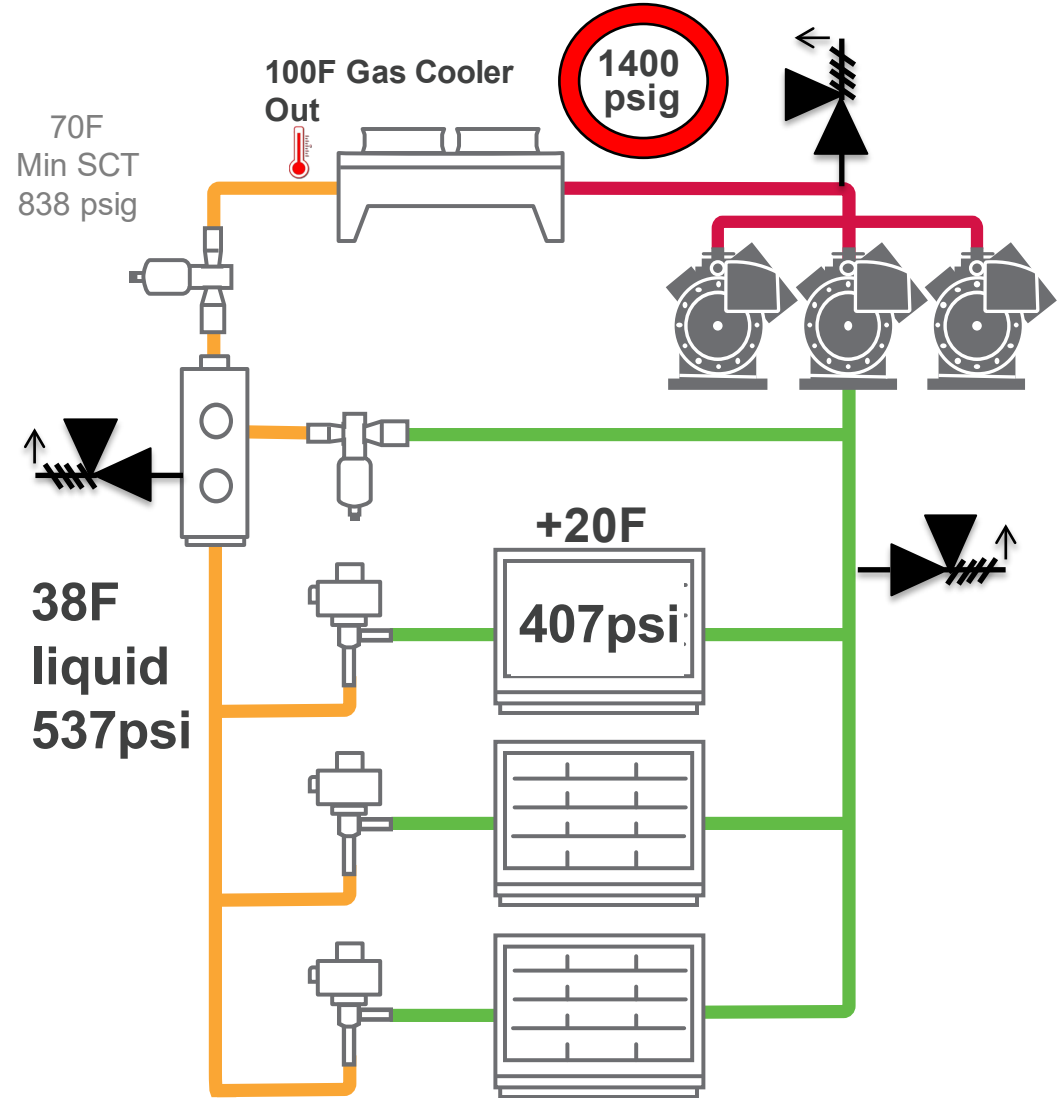
Gas Cooler (Training Unit)



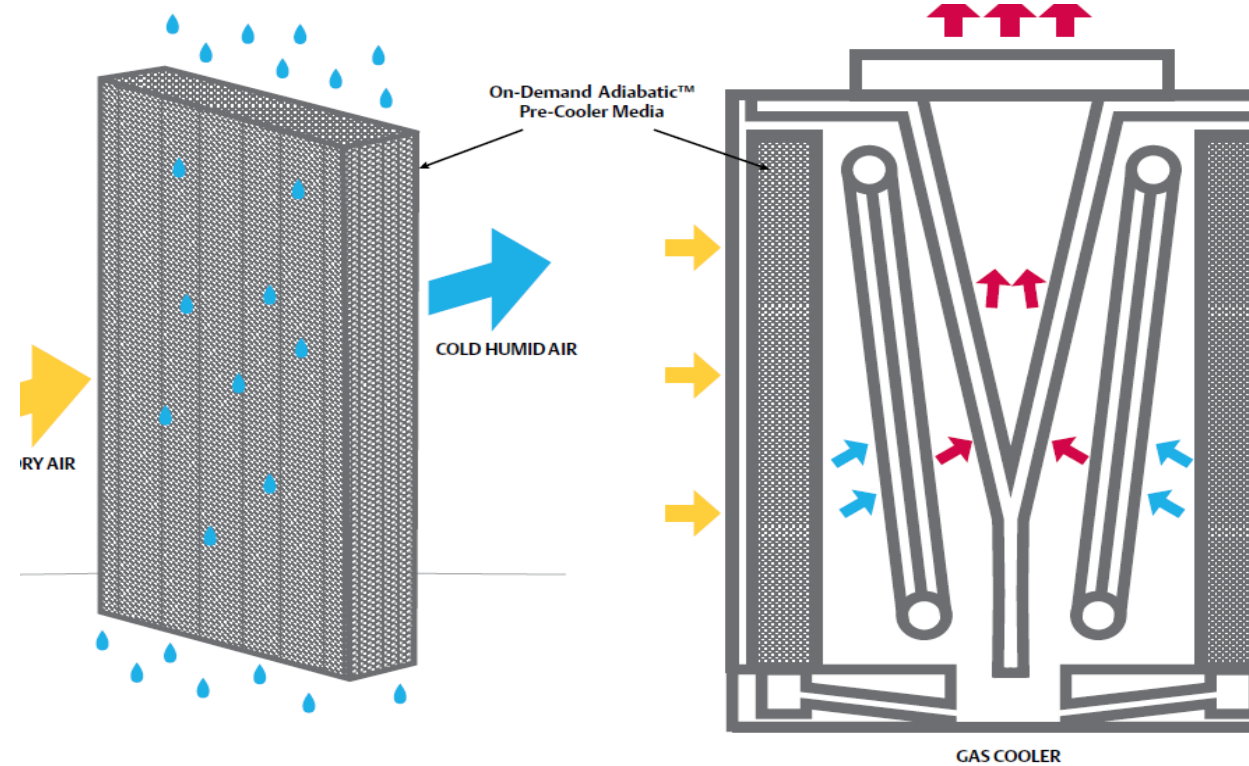
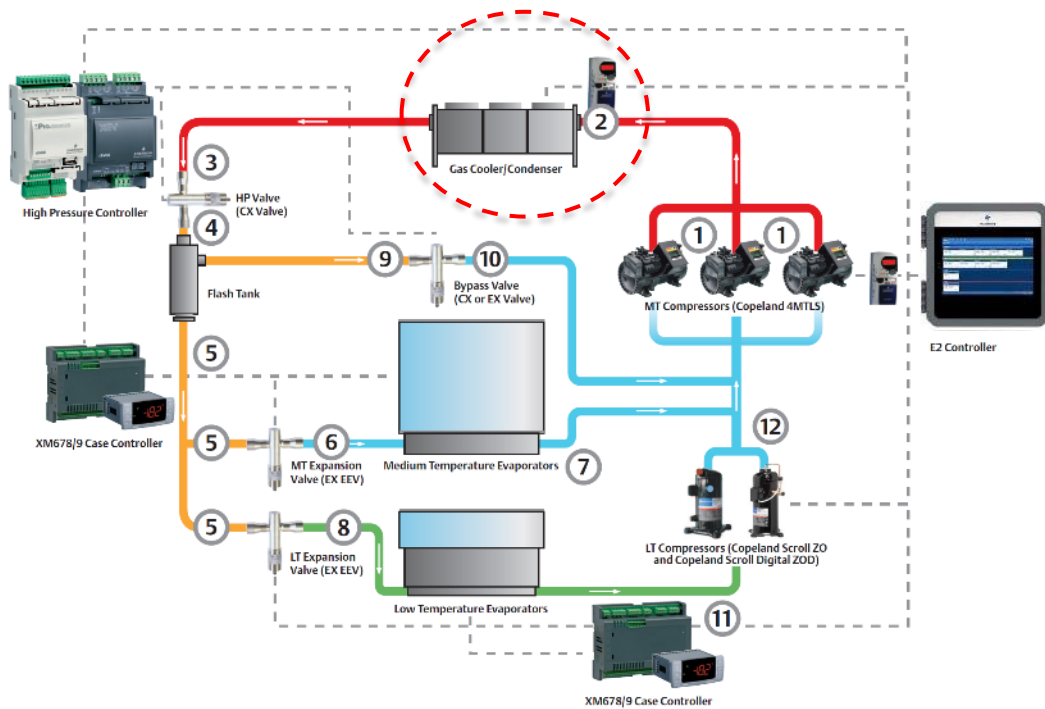
R448A With Head Pressure Controls



Medium Temp CO₂ Transcritical Systems



CO₂ Transcritical Booster System Condenser / Gas Cooler



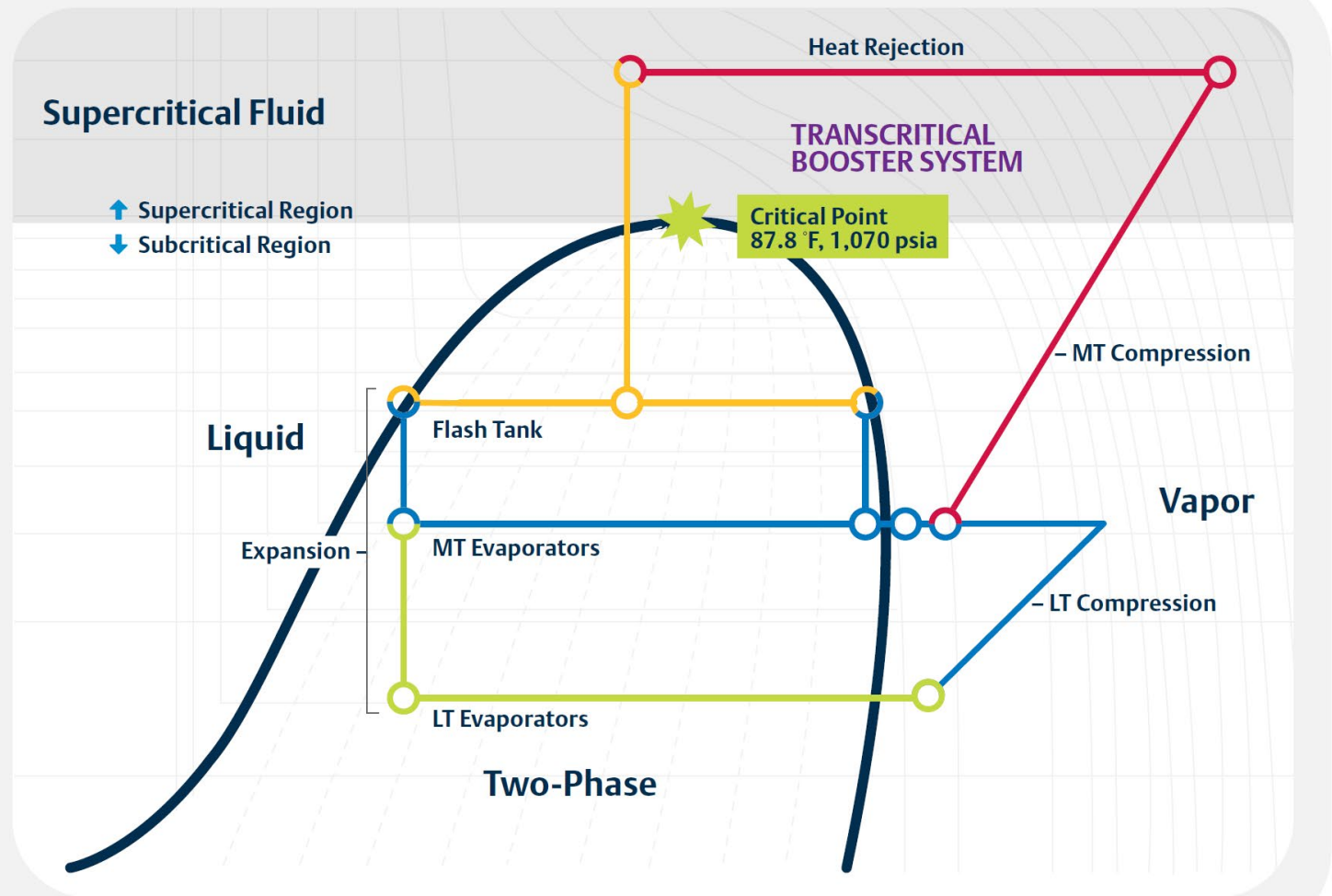
Zone	Hot Dry 2B	Max Temp	35F Bin	40F Bin	45F Bin	50F Bin	55F Bin	60F Bin	65F Bin	70F Bin	75F Bin	80F Bin	85F Bin	90F Bin	95F Bin	100F Bin	105F Bin	110F Bin	115F Bin	Total Hours	
Non Adiabatic	PHOENIX SKY HARBOR INTL AP	111.92	14	127	345	560	710	787	739	722	746	735	780	831	671	526	350	117	0	8760	
Adiabatic	PHOENIX SKY HARBOR INTL AP	76.88863	14	127	346	728	1621	1956	1885	1696	387	0	0	0	0	0	0	0	0	8760	
			Subcritical operation								Transcritical operation										
Percentage of total year spent at ambient BIN group																					
	Non Adiabatic	%	0.16	1.45	3.94	6.39	8.11	8.98	8.44	8.24	8.52	8.39	8.90	9.49	7.66	6.00	4.00	1.34	0.00		
	Adiabatic	%	0.16	1.45	3.95	8.31	18.50	22.33	21.52	19.36	4.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
	Non Adiabatic	4004 %				65 up	6100	69.63 %			75-85	2261	25.81 %		90-105	2378	27.15			%	
	Adiabatic	8373 %				65 up	3968	45.30 %			75-85	387	4.42 %		90-105	0	0.00			%44	

3

HIGH OPERATING PRESSURES

CO₂ TCB system operating pressures are significantly higher than traditional HFC systems (i.e., those using R-404A or R-410A).

- Pressures can **exceed 1,400 psi** when MT compressors discharge into the gas cooler on a hot summer day (e.g., 100 °F).
- MT discharge lines must be constructed with stainless steel or special ferrous alloy copper to handle these pressures.



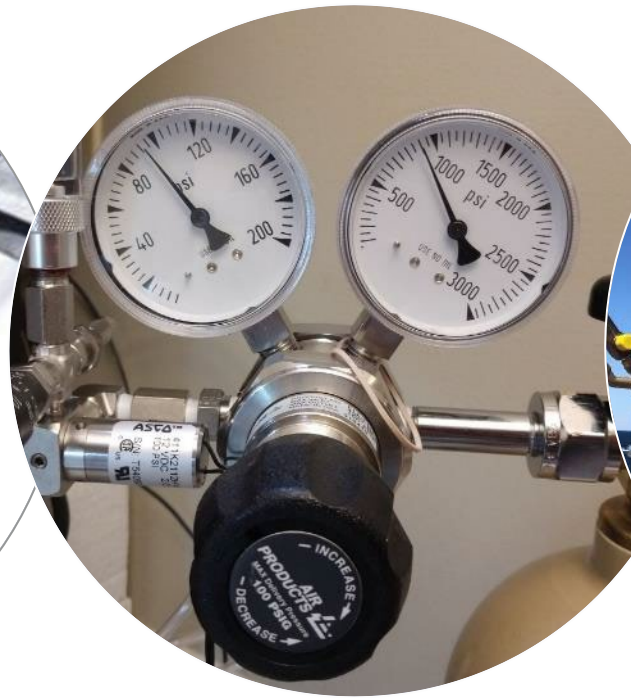
High Pressure Safety Mitigation



MT Compressor are rated for Minimum 1740 psig operating



High Pressure rated Piping For Discharge & other Sections



Pressure-test with dry nitrogen and evacuate.



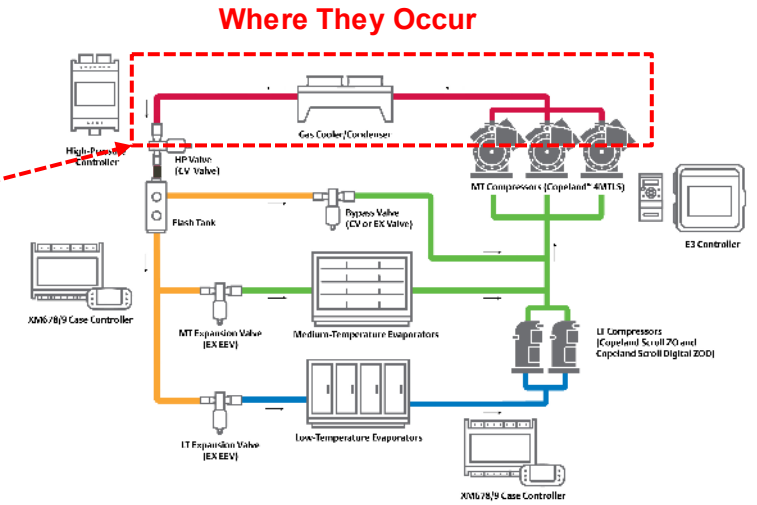
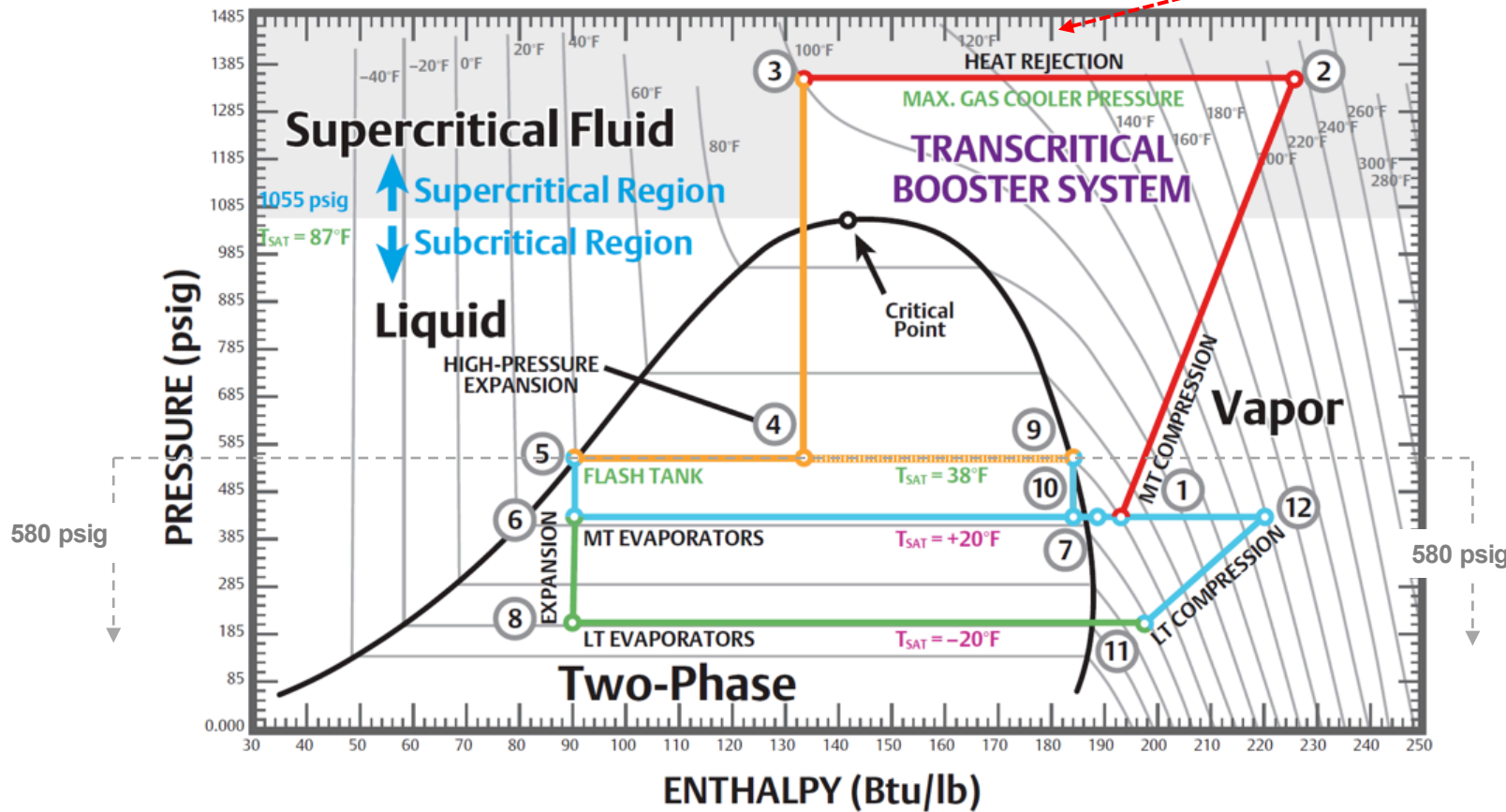
Verify if pressure-relief valves are installed in accordance with local building codes.

Must read all manuals/instructions provided by manufacturers and consult all applicable safety materials.

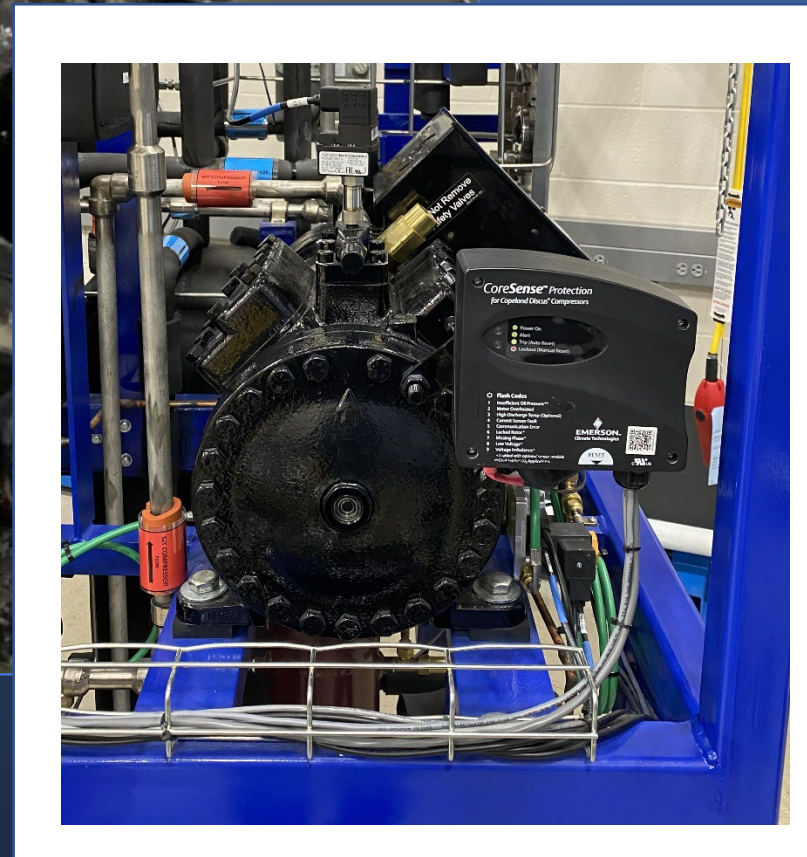
Differences: R-744 vs. HFC

- High Operating Pressures

- Safety awareness



Discharge Line



Copeland 4MTLS40KE-FSC-C00

Oil Separator



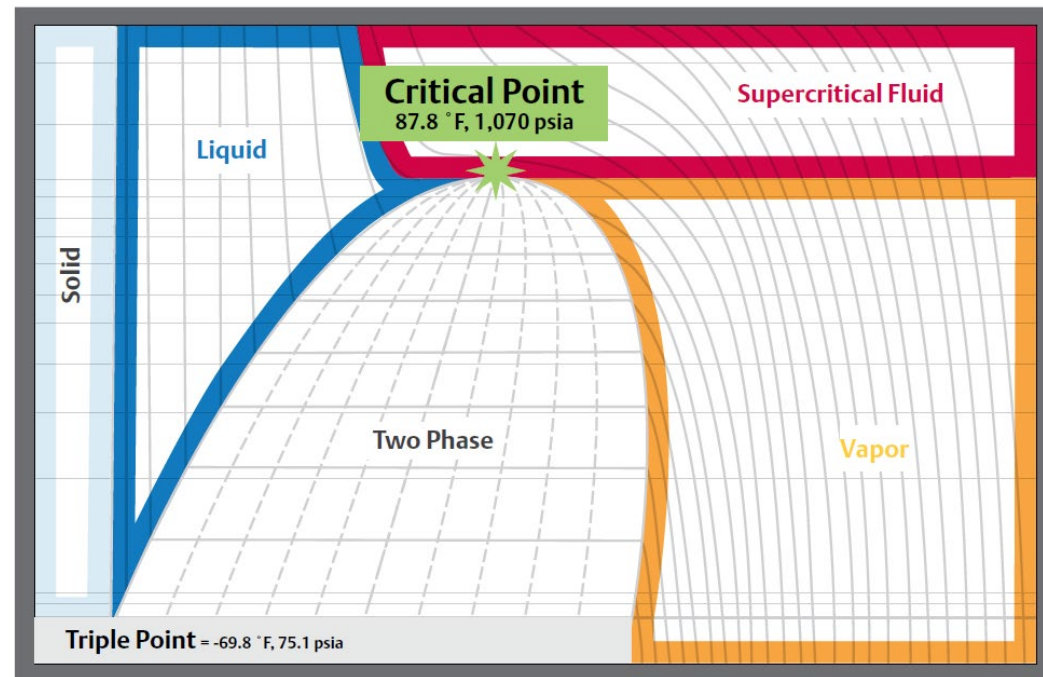
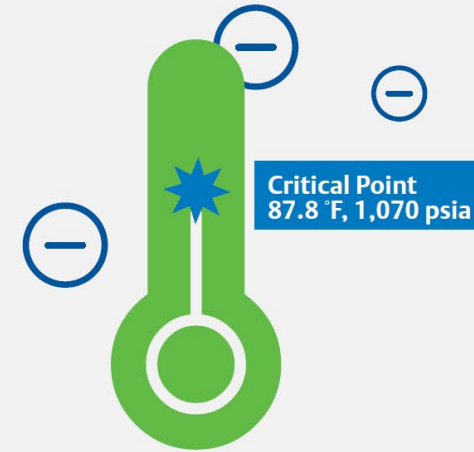
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LOW CRITICAL POINT OF 87.8 °F

R-744 has a critical point of **87.8 °F**, which is relatively low from a refrigeration perspective.

When the ambient temperature rises above approximately **75 °F**, system conditions cause the refrigerant to exit the gas cooler as a *supercritical* fluid (at or above **87.8 °F**) and run in *transcritical* mode, where its pressure and temperature relationships can rise and fall independently.

R-744 is at saturation when liquid and vapor coexist below the critical point. When the system operates below 87.8 °F, it is referred to as *subcritical* mode.

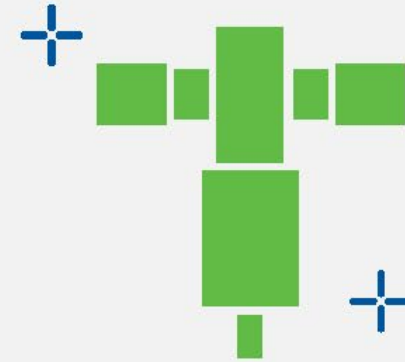


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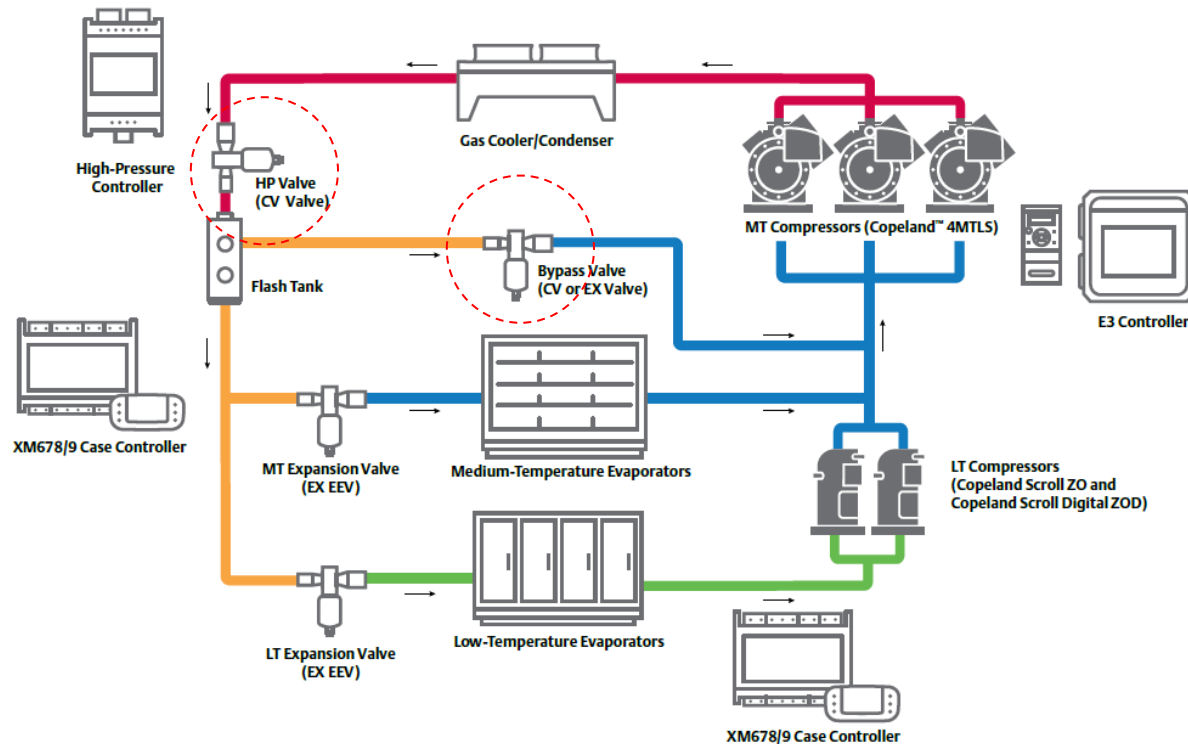
HIGH-PRESSURE VALVE & BYPASS VALVE

As R-744 exits the gas cooler, its pressures must be reduced before being reintroduced to the refrigeration circuits.

A high-pressure valve (HPV) reduces the refrigerant to around **550 psi** and transfers it to a receiver (aka flash tank) that separates vapor from liquid



HIGH-PRESSURE VALVE

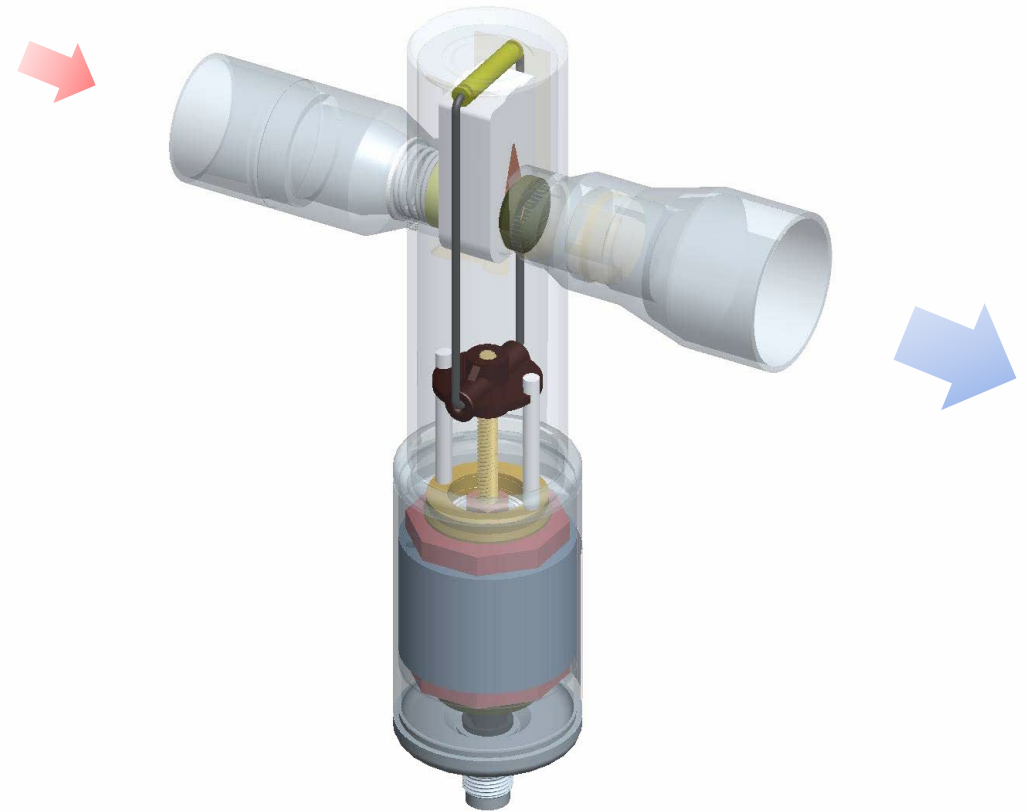


EX4 - 8 Electrical Control Valves 60 Bar (870 psig)

The EX4 / EX5 / EX6 / EX7 / EX8 are stepper motor driven valves for precise control of refrigerant mass flow in refrigeration systems with HFC's and CO₂ in subcritical applications.

Features:

- Multifunctional
 - Suction gas throttling
 - Hot gas bypass
 - Expansion valve
- Short opening/closing time
- Linear and precise flow control over a wide range, 10 to 100%



To Top of
Flash Tank



HPV



BGV

CO₂ High Pressure Controller

Inputs

1. Gas Cooler Out Pressure
2. Gas Cooler Out Temp.
3. Flash Tank Pressure
4. Capacity Demand Input

Subcritical Operation

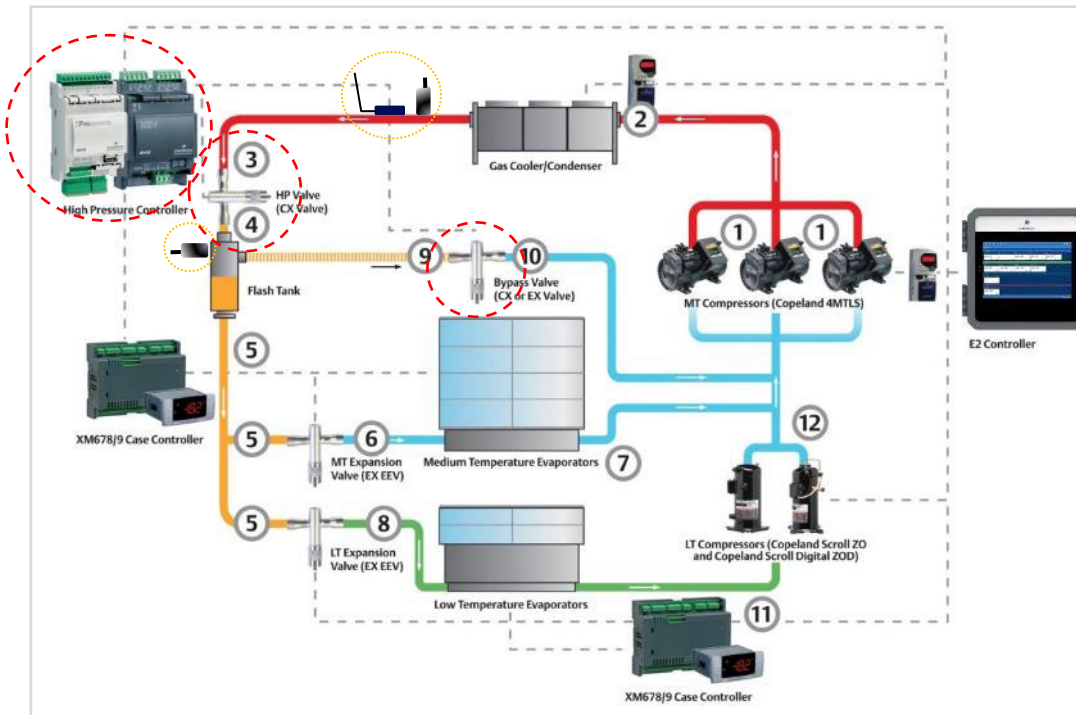
- Maintains Subcooling In Condenser

Transcritical Operation

- Ignores Subcooling Control & Controls Gas Cooler Pressure

Transient Operation

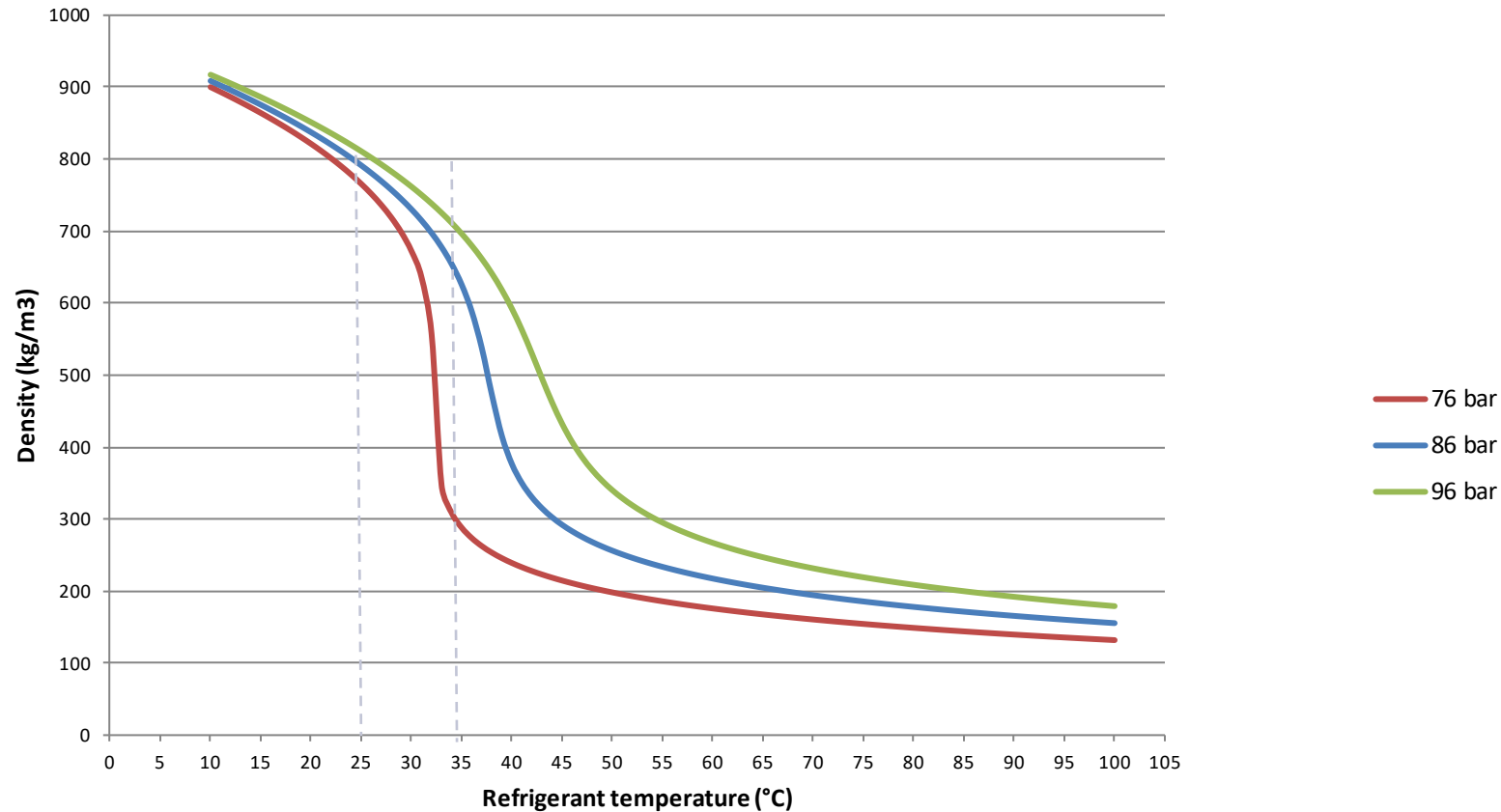
- Avoids Hard Switch In Either Sub or Transcritical To Evade Effects of Rapid CO₂ Density Change



High Pressure Valve (HPV) & Bypass Valve (BPV)

- The Control Point In Both The Valves Is Flash Tank Pressure
- If Pressure Is > Set Point, The HPV Throttle & BPV Opens
- If Pressure Is < Set Point. The HPV Opens & BPV Throttles

CO₂ Density (kg/m³)



The design of the gas cooler pressure regulating valve is very sensitive, as the refrigerant density changes rapidly between 25 and 35°C.(77F & 95F) The proper selection of the expansion valve therefore requires checking different operating points.

CEPTEK



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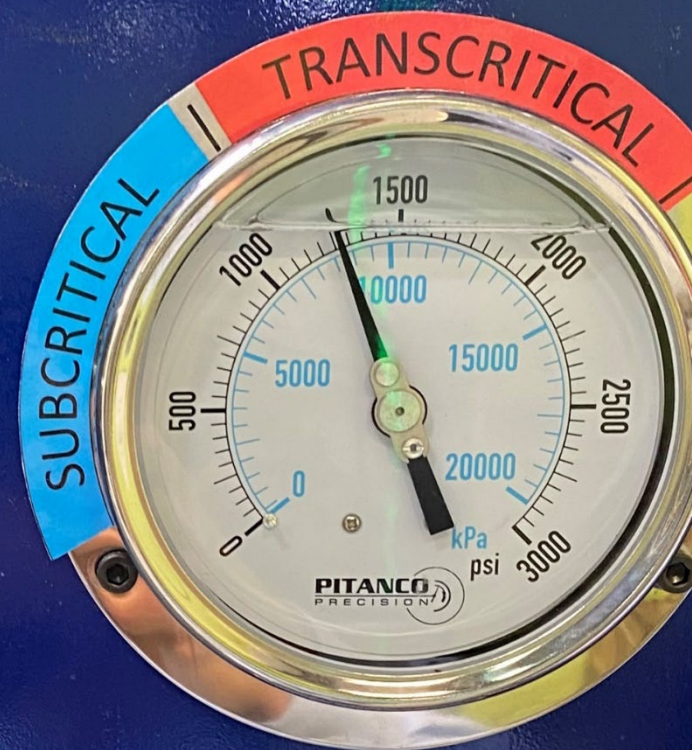
RX

↑ Name	CTRL VAL OUT	CTRL VAL STPT	T CTRL VAL OUT	T CTRL VAL STPT	CONTROL METHOD
GAS COOLER			101.52 °F		Temperature

IPRO HP Controller

↑ Name	P1 PRES-OUTLET	VALVE 1 OUTPUT	P2 PRES-RECEIVE	VALVE 2 OUTPUT	T1 TEMP	T2 TEMP
iPro CO2	1250.08 PSI	34 %	489.79 PSI	84 %	100.9 °F	100.9 °F

Receiver Pressure



HIGH PRESSURE
DISCHARGE - MT

Software User Interface Can Be Customized To User Preference



Software interface header for 'iPro CO2 HPV' showing 'Online' status and navigation tabs: Status, General, HPV Param, BGV Param, Inputs, Outputs, IO Config, OverrideCMD, Alarms Outs, Alarm Clg, Valve Clg, Cal Feature, Alarms, Input/Output Status, Generic Alarms.

T1 TEMP	75.0 °F
HPV Mode	Subcritical
SETPOINT	5.00
CONTROL VALUE	7.0
P1 PRES-OUTLET	983.50 PSI
VALVE 1 OUTPUT	20 %
BGV SETPOINT	440.00 PSI
P2 PRES-RECEIVE	440.91 PSI
VALVE 2 OUTPUT	23 %
ENABLE	ON



Great Screen For Troubleshooting

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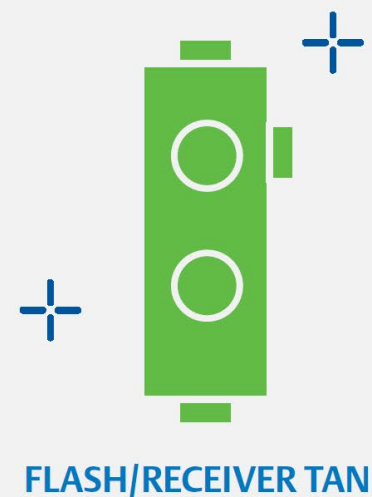


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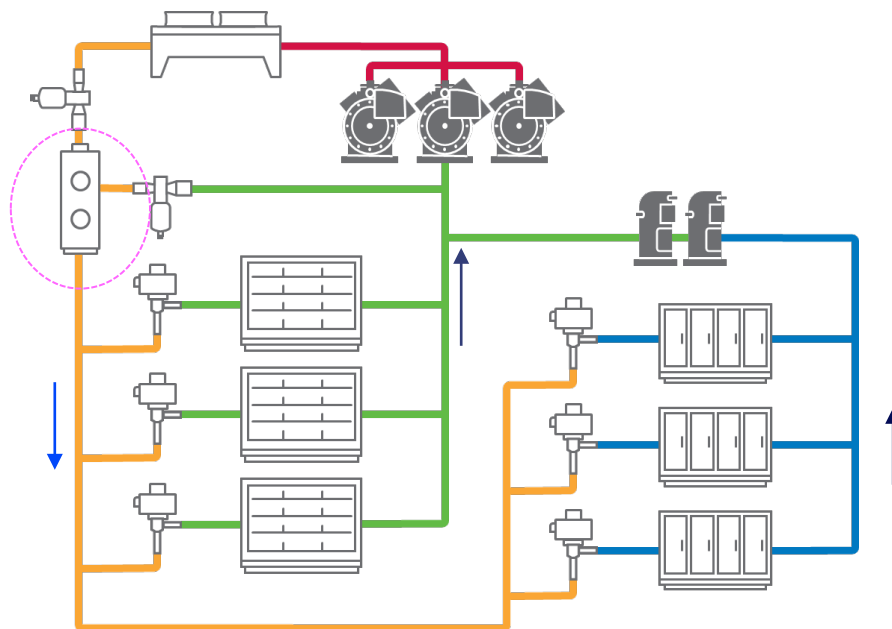
FLASH TANK AND/OR RECEIVER

The flash tank receives a mixture of vapor and liquid refrigerant at around **40 °F** equivalent saturation, with vapor rising to the top and liquid settling at the bottom.

- Liquid is circulated through insulated lines that feed the MT and LT cases (as low as **-20 °F**) — all of which are equipped with an electronic expansion valve (EEV).
- To help relieve flash tank pressures, vapor is fed to a bypass line through a bypass gas valve (BGV) located at the upper right of the tank.

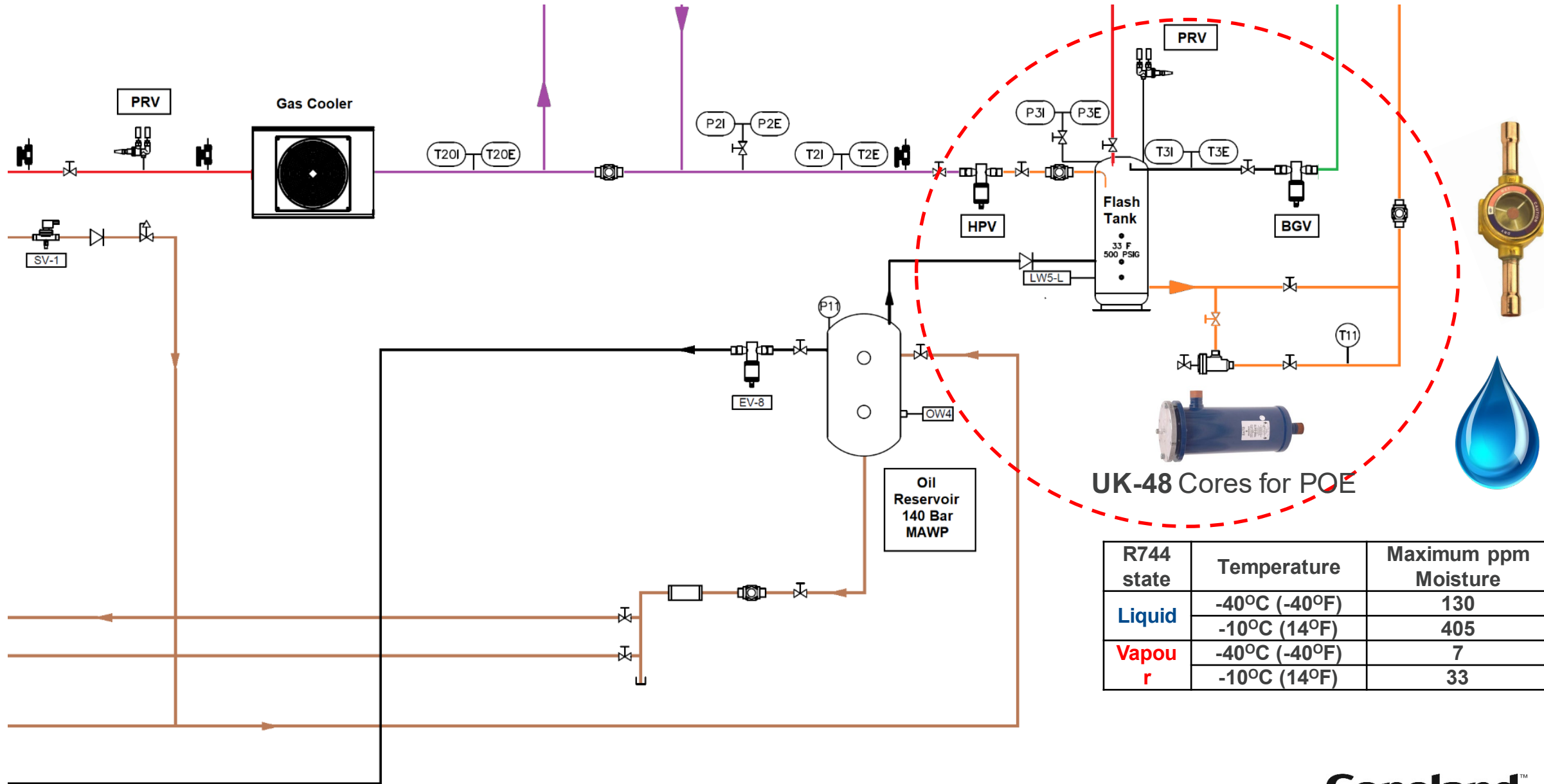


- Insulated
- 38F = 537 psig
- Sizing is Key
- Level Management



Stable Flash Tank
pressure is critical to
smooth performance
Year round

Flash Tank



UK-48 Cores for POE

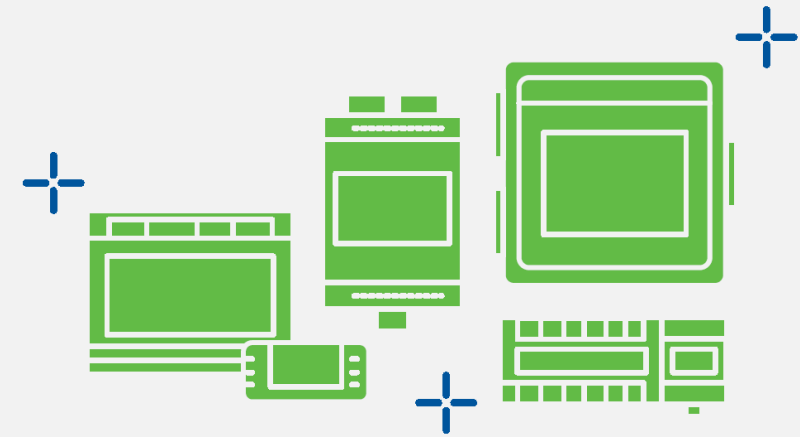
R744 state	Temperature	Maximum ppm Moisture
Liquid	-40°C (-40°F)	130
	-10°C (14°F)	405
Vapour	-40°C (-40°F)	7
	-10°C (14°F)	33

7

RELIANCE ON ELECTRONICS

Because R-744 is a very dynamic refrigerant that reacts quickly to changes in pressures and temperatures, electronic controls are required to perform a variety of key system functions:

- Managing system pressures
- Controlling variable fan speeds
- Modulating the HPV, BGV and EEVs
- Maintaining a consistent flash tank pressure
- Assuring smooth compressor staging



ELECTRONIC CONTROLLERS

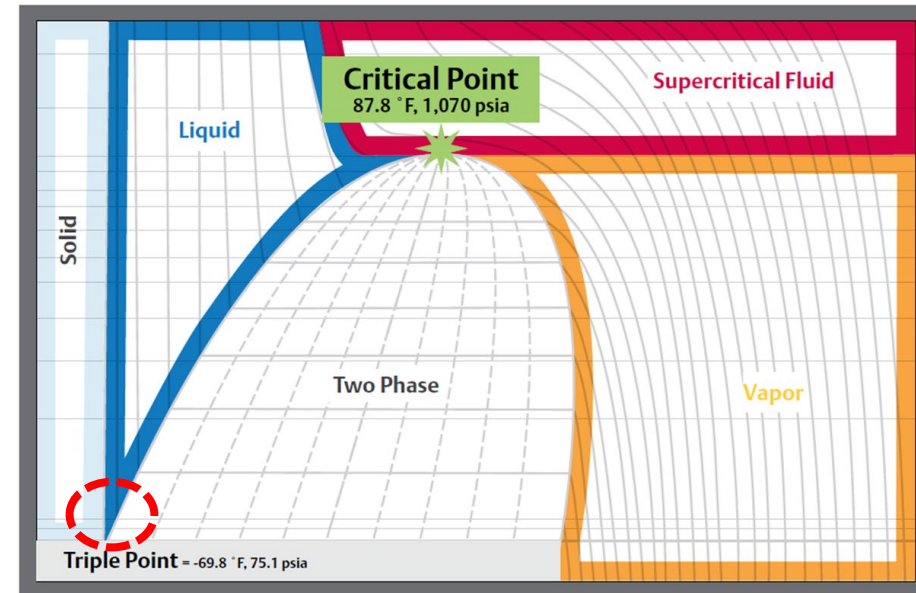
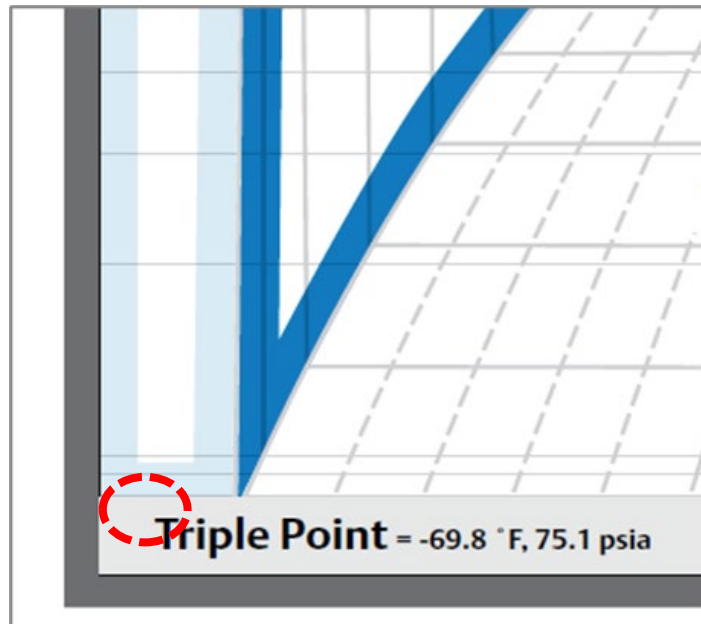
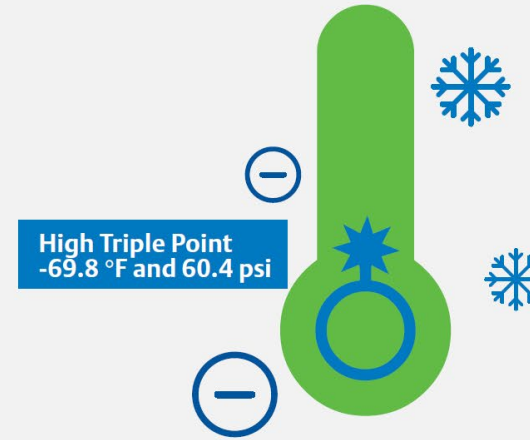


8

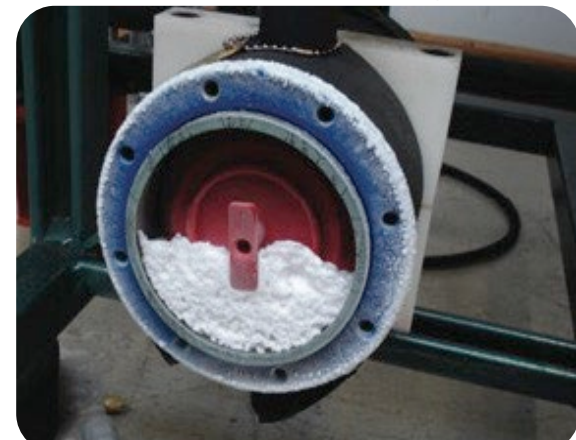
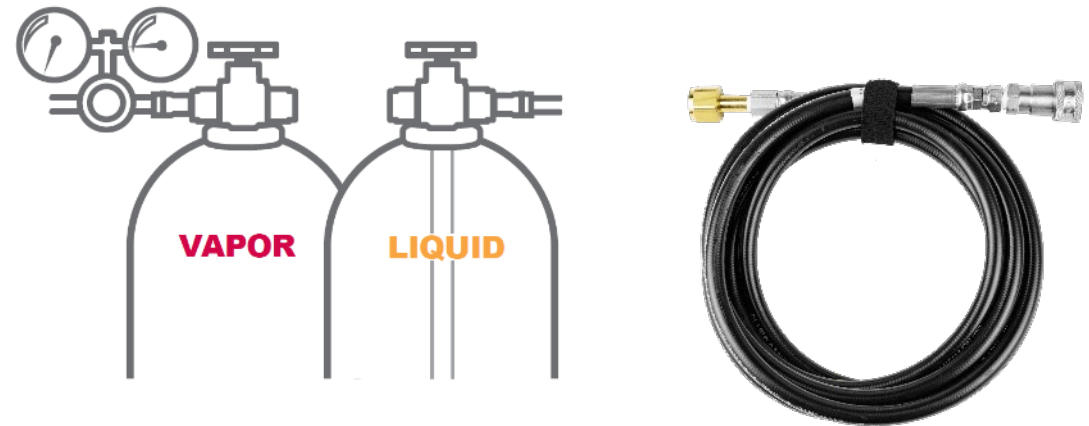
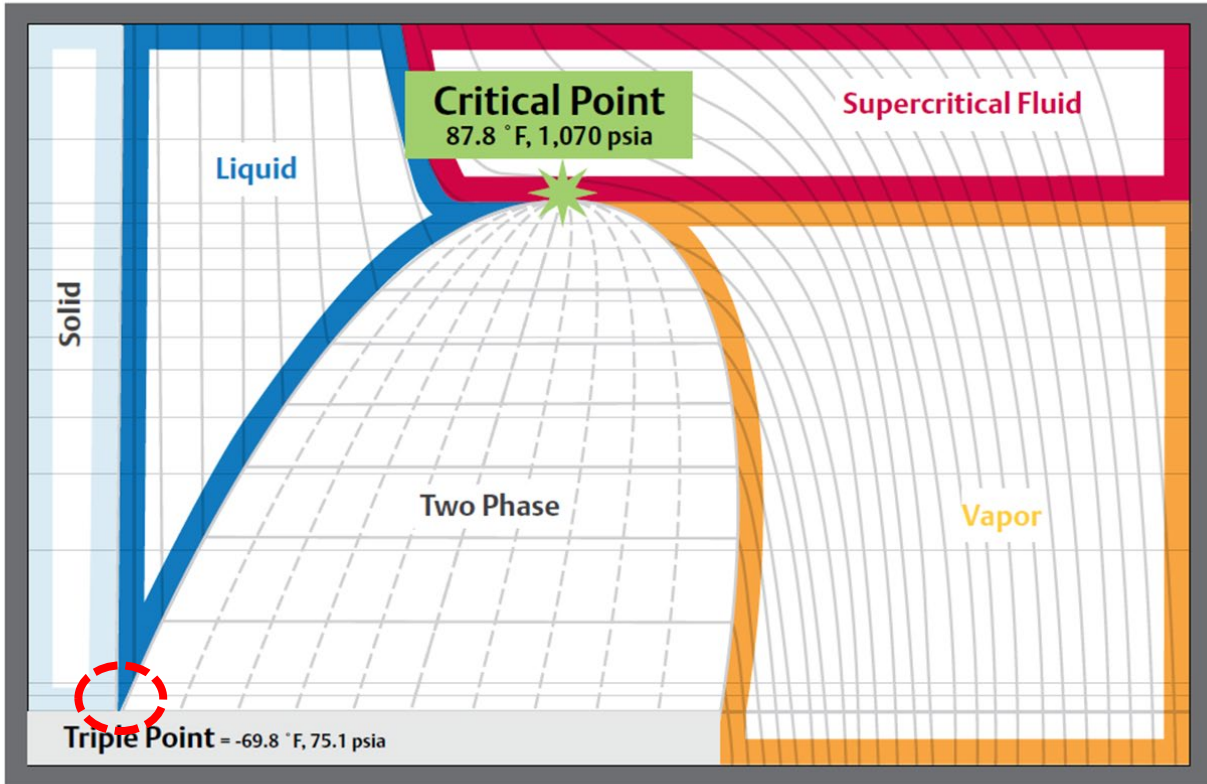
HIGH TRIPLE POINT OF $-69.8\text{ }^{\circ}\text{F}$ AND 60.4 PSI

$-69.8\text{ }^{\circ}\text{F}$ is well below normal operating ranges, but R-744's corresponding saturation pressure of **60.4 psi** can occur, especially during system charging.

- When charging with liquid while system pressures are below the triple point, R-744 turns into dry ice, stops the refrigerant flow, and causes a variety of potential system problems.
- Technicians should charge with vapor until the system reaches **100 psi**, which is safely above R-744's triple point pressure.



High Triple Point (60.4 psig, -69.8 °F)



-109.3 °F =
Surface Temp. of Dry I

- Dry ice formation could form a blockage in a charging line
- Pressure behind the blockage will quickly rise as the dry ice sublimates
- This blockage or “plug” will shrink in size & High pressure behind the blockage could blow the plug out

Charging

- Break vacuum with CO₂ vapour
- Refrigerant to be first charged as a vapor
- Charge vapour into the system high side
- Charge refrigerant vapor slowly
- Keep vapour pressure above the triple point to prevent formation of dry ice

Triple Point = 61 psig (-70 °F)

(4.2 bar g) (-56 °C)



Inappropriate hoses for the pressure....

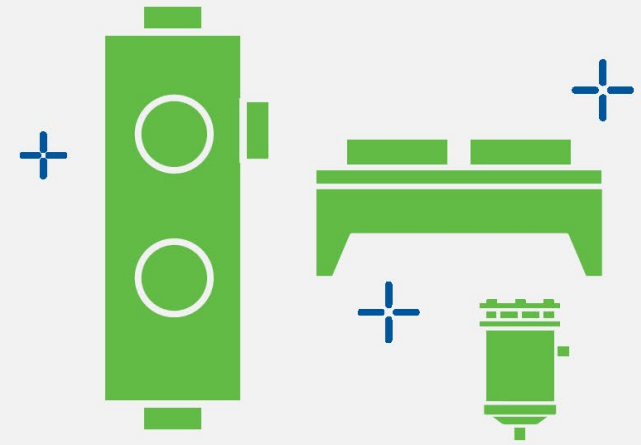


9

STANDSTILL PRESSURES

Managing the potential for rising system pressures during power outages or planned shutdowns is another important CO₂ TCB system design consideration.

- Designers must understand the maximum pressure ratings of cases, valves, evaporators and all system components.
- A system should be designed to maintain the integrity of its weakest point and/or the component with the lowest safe working pressure.

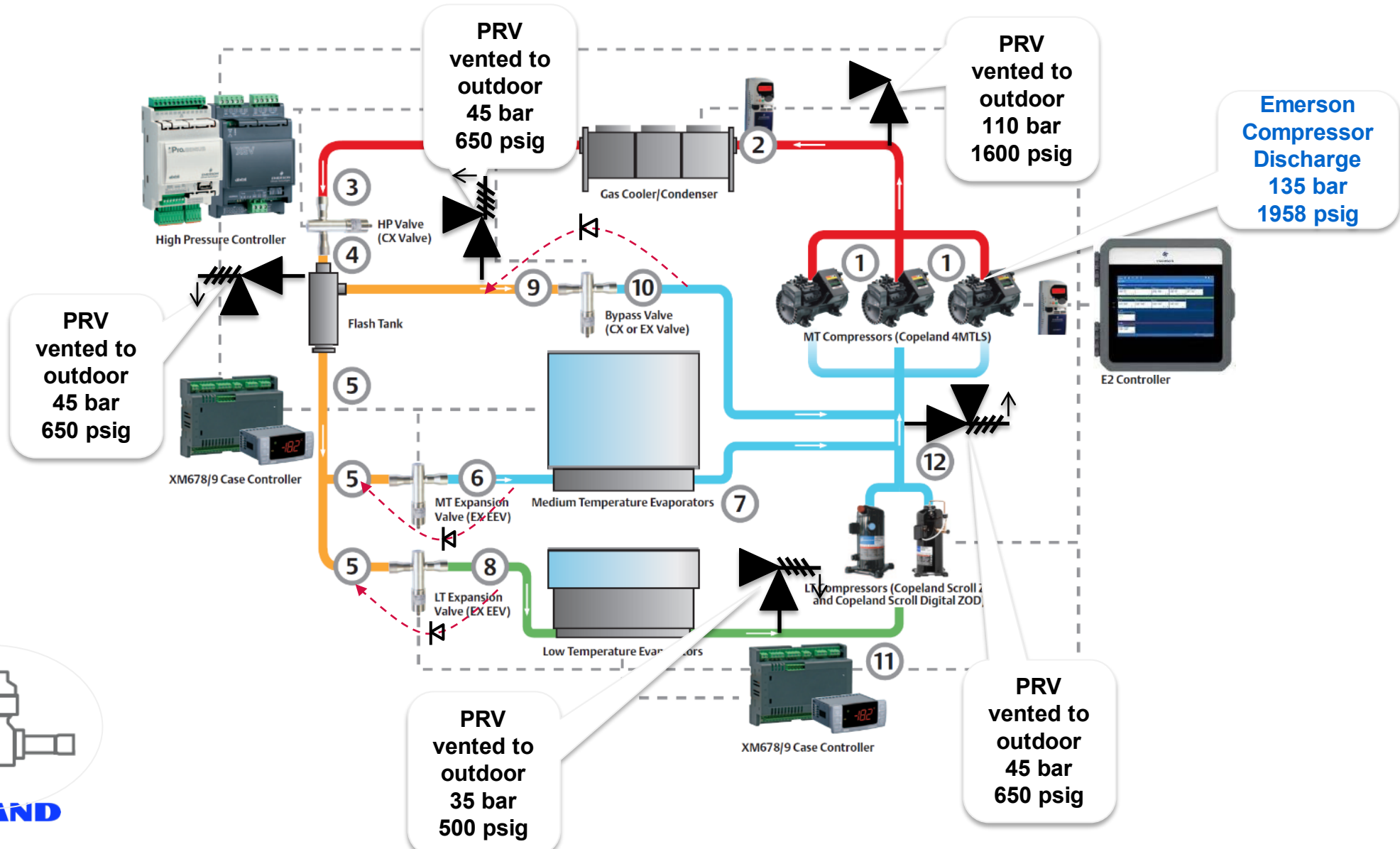


- 10 °C → 44 bar g (50 °F → 638 Psig)
- 20 °C → 56 bar g (68 °F → 815 Psig)
- 30 °C → 71 bar g (86 °F → 1032 Psig)

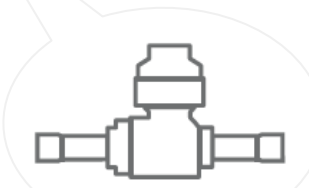


CO₂ Booster Refrigeration System

Understanding Pressure Reliefs – Will Vary based on OEM & Region

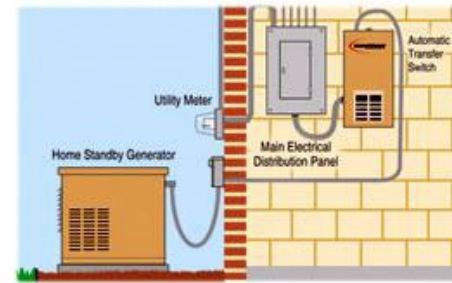


Did you leave it open or closed when servicing?

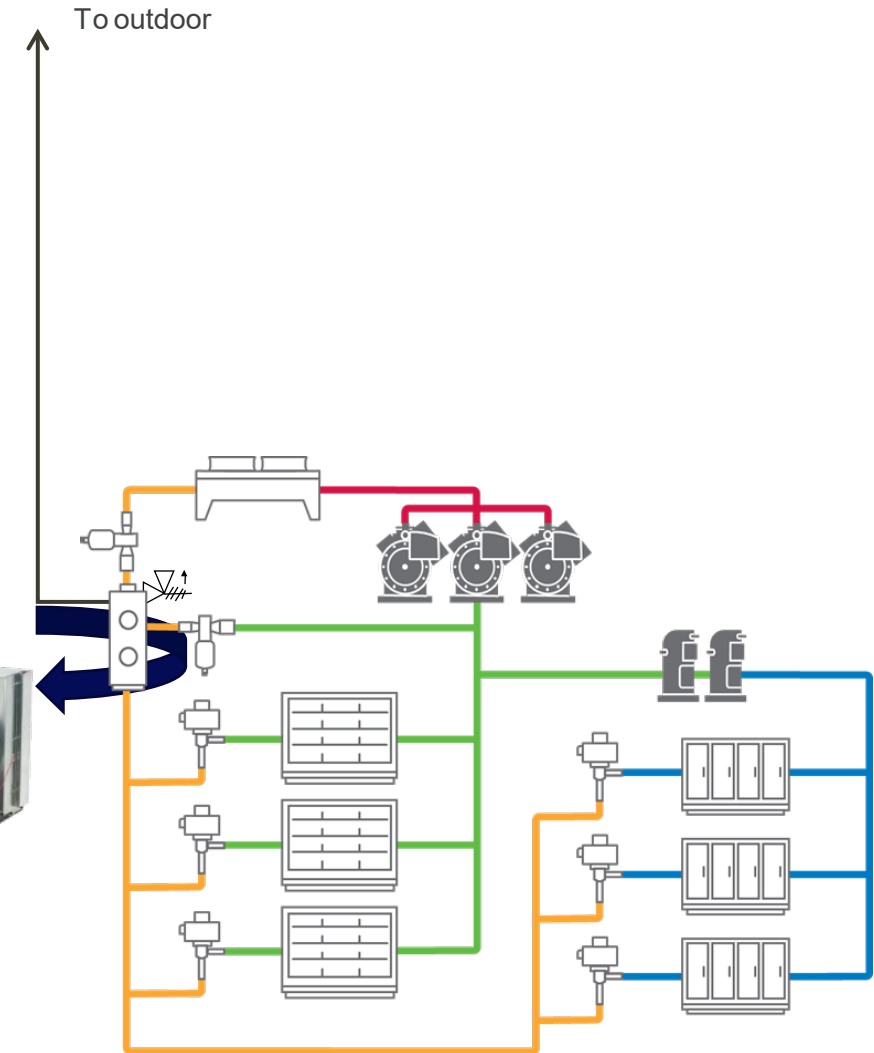


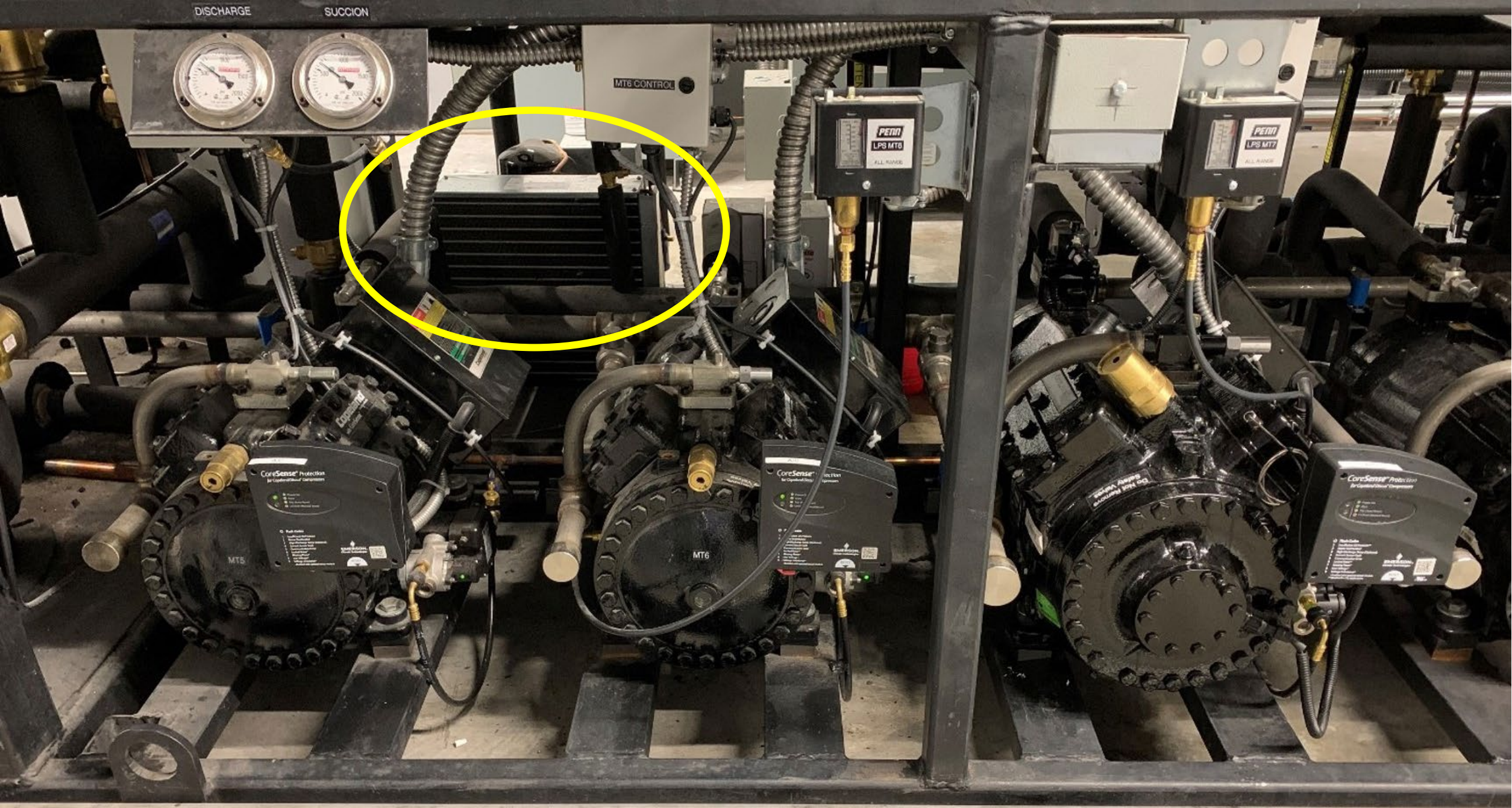
Separate Pressure Relief System

- Auxiliary Condensing unit start on Power Failure which is Powered by Generator
- Recirculates liquid from Receiver / Flash Tank to keep the saturation temperatures below the Pressure Relief Point

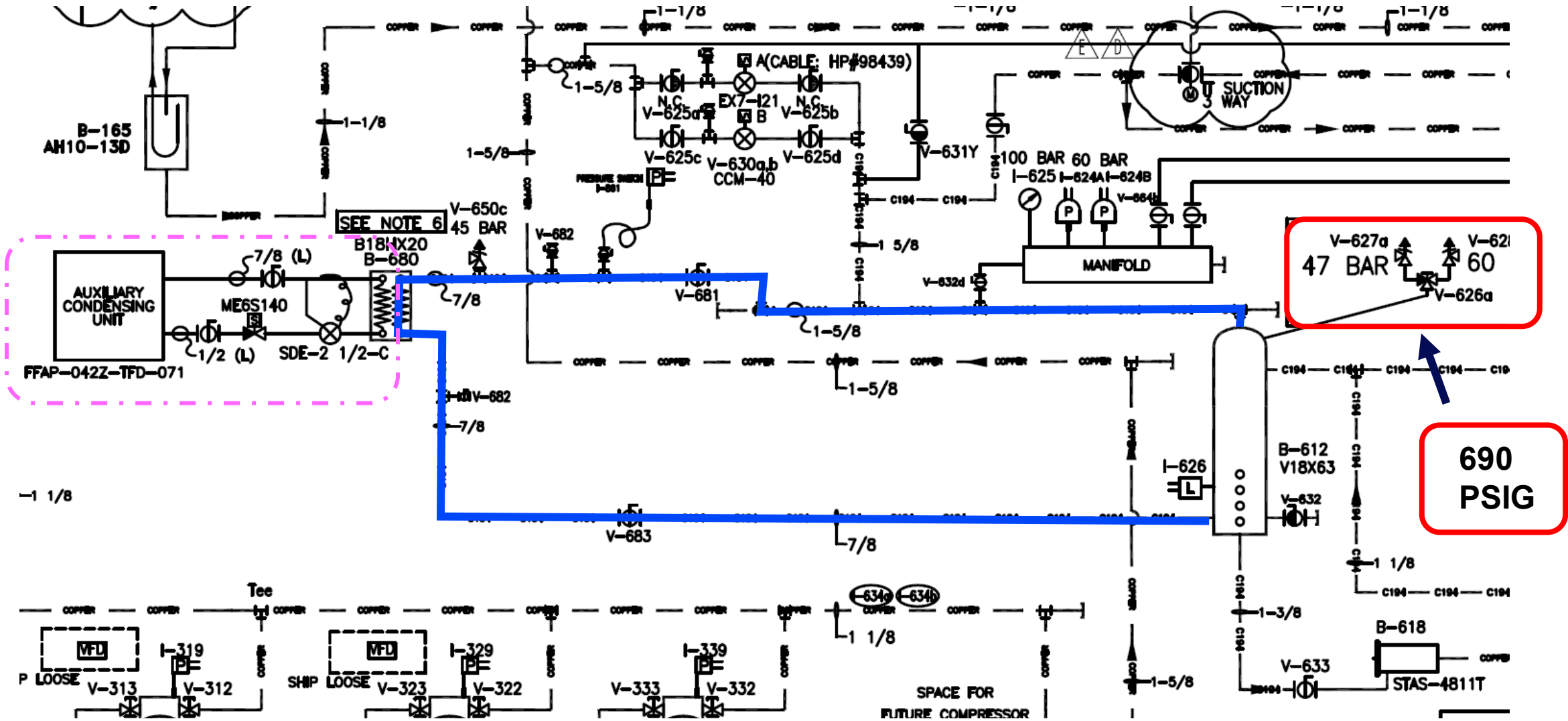


**Generator Powers Auxiliary
Condensing Unit**

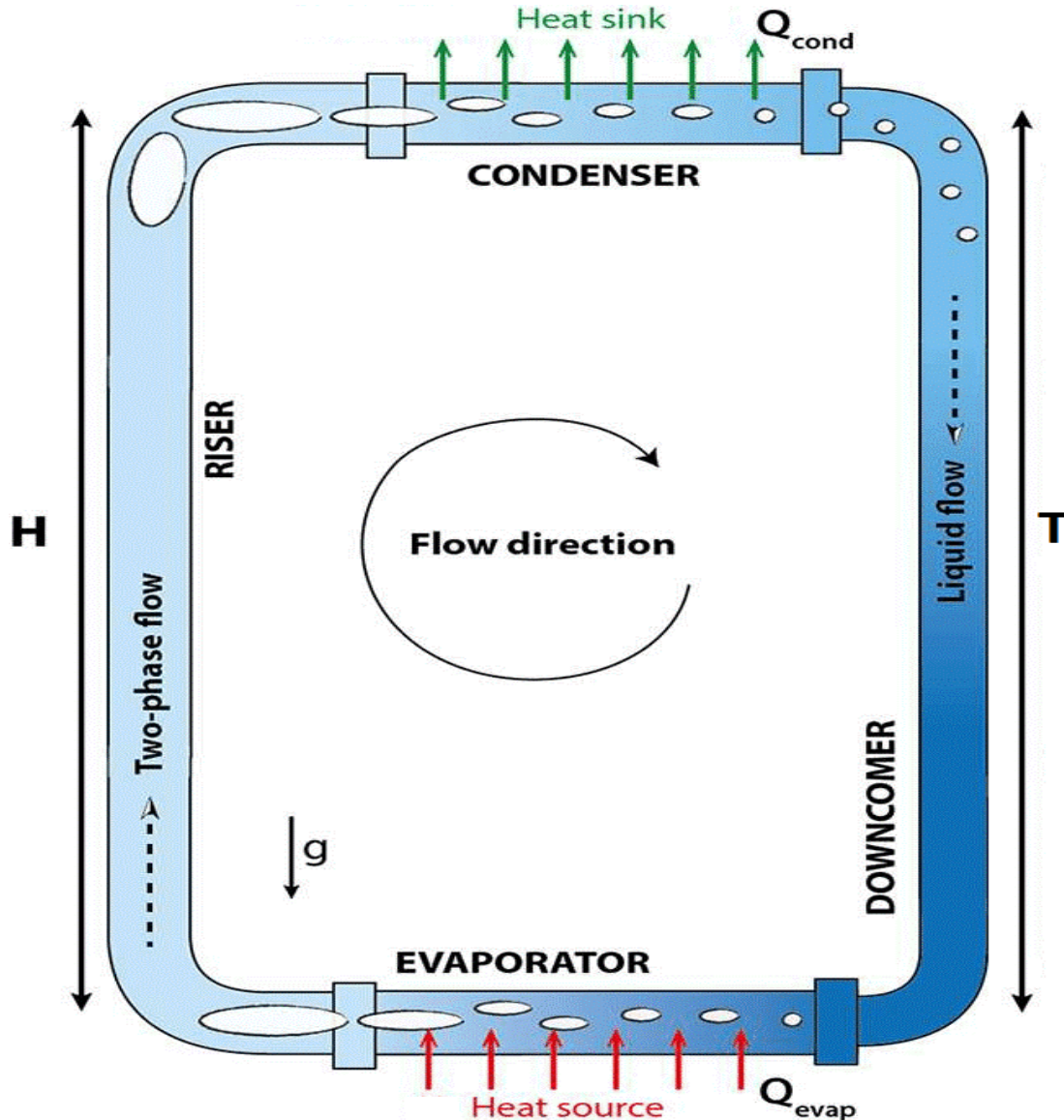




Auxiliary Condensing Unit Required for Power Outage or Planned Shutdown



Great Thermosyphon Effect Potential of CO2



1C Delta T \approx 10 PSI Delta P

So for example, with only 4C temperature differential available we could have 40 PSI pressure differential !

Passive Heat Exchange







LIÈGE DE CHANGEMENT



RCS PIS
EAU GLYCOLÉE

ACS PIN EAU GLYCOLÉE

RCS PIN EAU GLYCOLÉE

GREENLEE

786

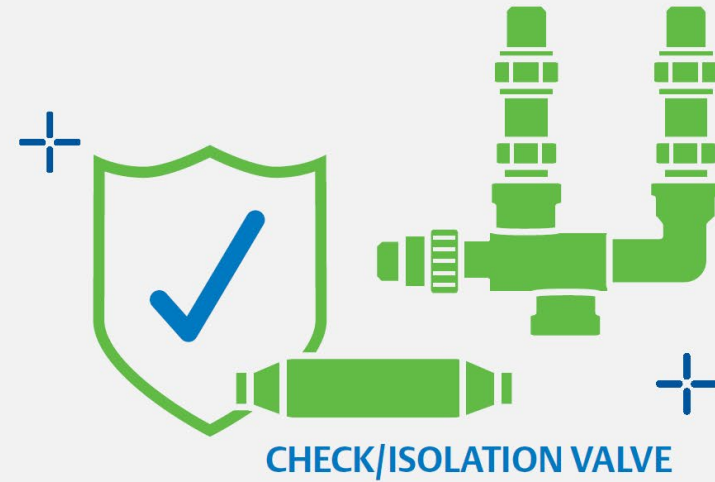
ROCK

10

SYSTEM SAFETIES AND PRESSURE-RELIEF VALVES

High-pressure safety and/or mitigation strategies are primarily focused on system- and compressor-specific protection.

- Pressure-relief valves (PRVs) or check/isolation valves should be installed in various system sections to prevent a full loss of refrigerant charge.
- A system should be designed to vent its charge outdoors — per applicable codes and PRV venting standards. If the system exceeds maximum pressures, discharge lines with PRVs will safely release the charge.



Pressure Relief Valve Installation

Dual-Isolatable valve assemblies

Vented outdoors

Flash Tank
650 psig (45 bar g)
2 PRVs with
3 way Valve



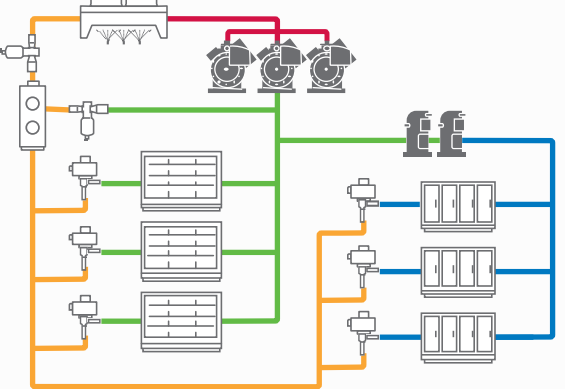
Gas Cooler
1600 psig (110 bar g)
2 PRVs with
3 way Valve



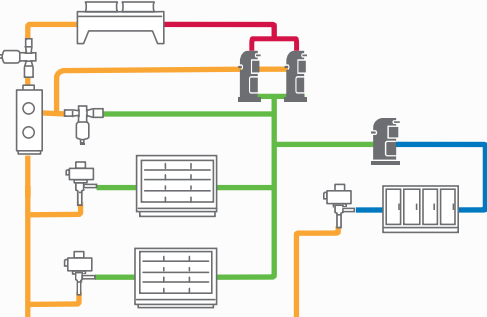


CO₂ System Solutions for Commercial & Industrial Refrigeration

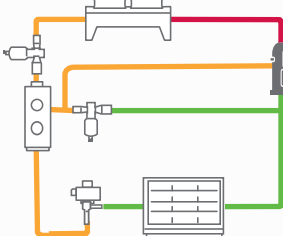
Centralized CO₂
Transcritical Booster



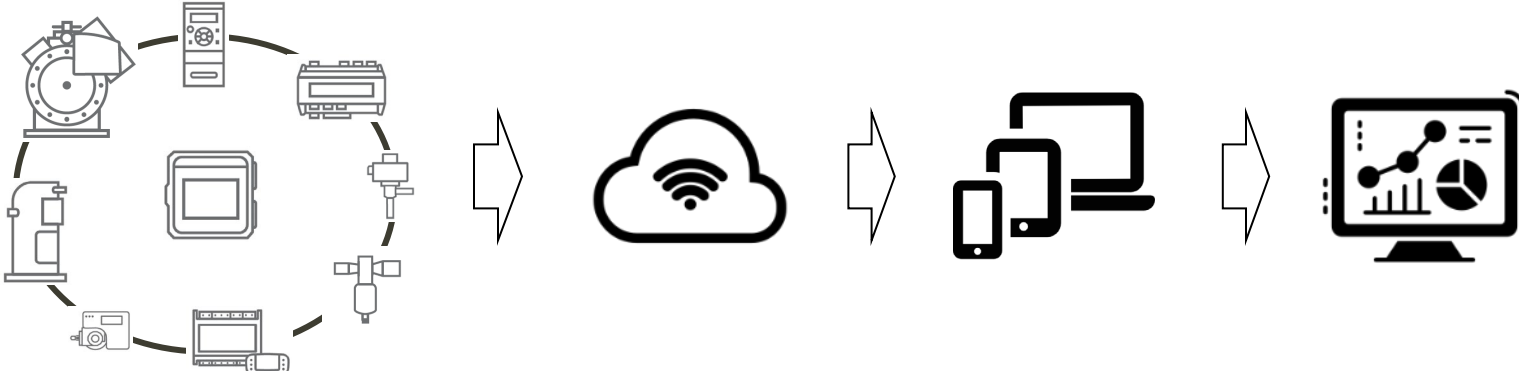
Distributed CO₂
Transcritical Booster



CO₂ Condensing Unit
CO₂ Heat Pumps



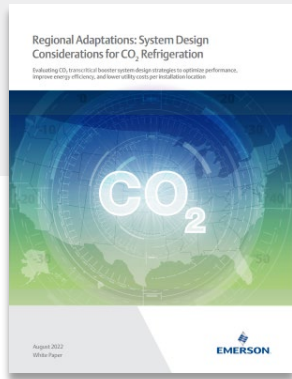
Vilter
Single
Screw





CO₂ Technical White Papers – Update and Promotional Plan

1 *Regional Adaptations: System Design Considerations for CO₂ Refrigeration (Not Published Yet)



2 CO₂ Transcritical Booster System Design



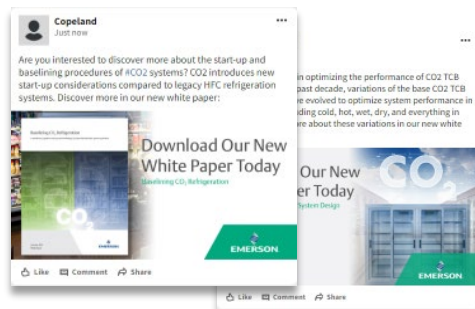
3 Baselineing CO₂ Refrigeration



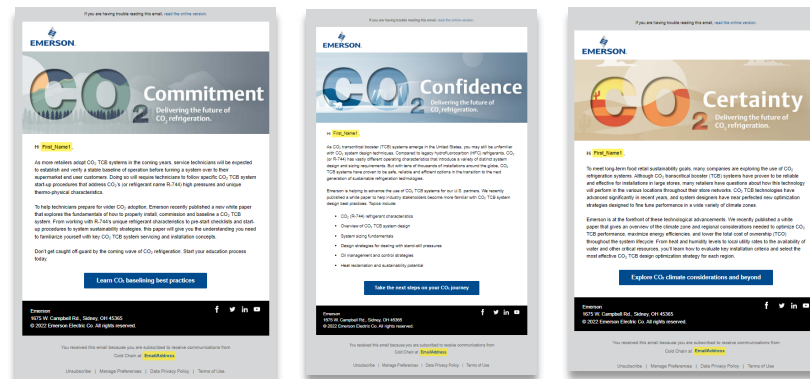
4 Connectivity & Controls

Coming soon

Social



Email Communications



→ You can access the white papers within our **E360 Resources Hub**.

Copeland's E360 Content Hub

<https://e360hub.copeland.com/>

Copeland's vast repository of E360 content can be found within our E360 resource hub – here's what you can expect:



Content Type — articles, blogs, brochures, infographics, webinars, case studies, podcasts, videos, white papers



Industry — aftermarket, convenience store, distribution and transportation, foodservice, **food retail**, industrial, healthcare



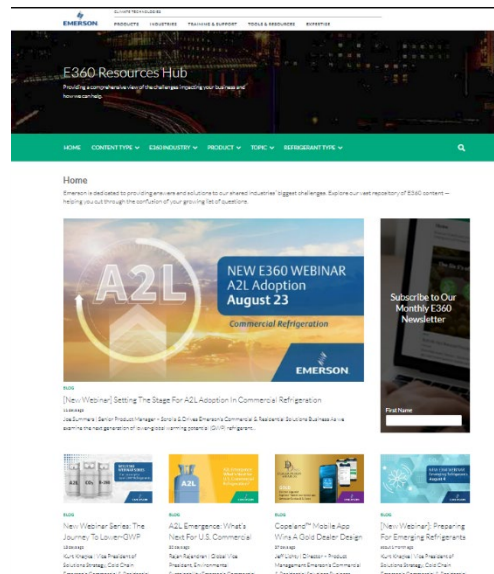
Product — compressors, condensing units, facility controls and electronics, foodservice HACCP solutions, variable frequency drives



Topic — connectivity, IoT and insights, contractor training, tips and safety, energy, utility and power management, innovation, maintenance and repair, refrigerant and energy regulations, sustainability



Refrigerant Type — CO₂, R-290 and A2Ls



E360Hub.copeland.com



Natural Refrigerant Training Summit

CO₂ Training Unit Walk Around

Building a Sustainable Technician Workforce