# Natural Refrigerant Training Summit

Building a Sustainable Workforce

## Presentation Title

Presenter Name

Affiliation/Company

NORTH AMERICAN Sustainable Refrigeration Council

# Your Presenter

Bruce Hierlmeier

Director or Regulatory Compliance and Refrigeration Technology

Zero Zone, Inc.

# Today's Agenda

- Company Introduction
- Safety
- $CO_2$ Component Overview
- Pressure Enthalpy Diagram and the High-Pressure Expansion Valve
- $CO_2$ System Designs
- Questions

# Learning Objectives

- Understand safety concerns when working with $CO_2$ and proper PPE
- Understand the role of the high-pressure valve and flash gas in system efficiency
- Understand the designs used to protect against system over pressurization


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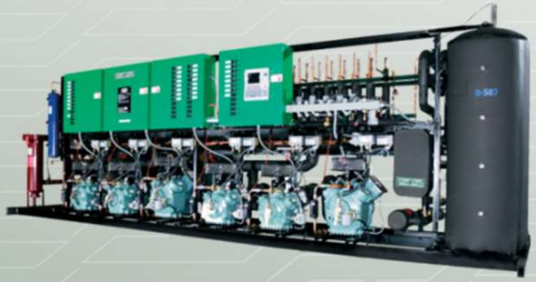
# Refrigeration Systems

- Outstanding Engineering Support
- Customer and Field Support
- Ease of Serviceability
- Longevity of Equipment
- Custom Solutions

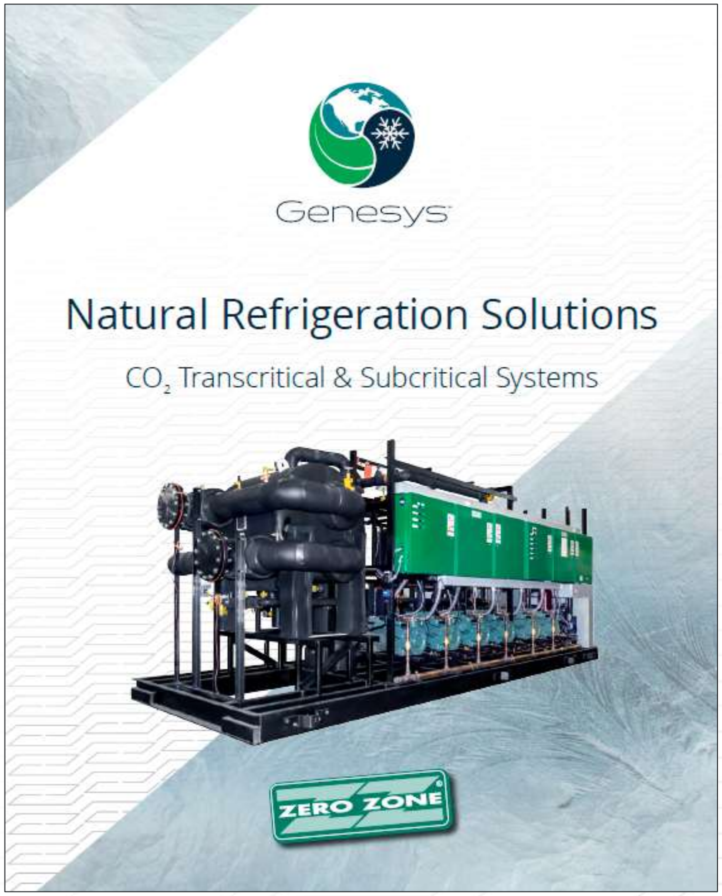








# Genesys™


Genesys
Natural Refrigeration Solutions
$CO_2$ Transcritical & Subcritical Systems
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# Display Cases

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# Safety

- It is important to know that **all refrigerant gases could be fatal** simply by a lack of oxygen through air displacement.
- Most refrigerant gases including $CO_2$ are denser than air, so they tend to collect near the floor.

# Safety

- $CO_2$ is not only an asphyxiant gas; it's also a narcotic agent which reduces awarness of the danger.
- Our breathing rate is controlled by $CO_2$ levels in our blood. The higher the level, the faster we breathe it in.

# Safety

## Effects of $CO_2$ Over Exposure

- A lack of oxygen is caused when Carbon Dioxide replaces air. When larger amounts of $CO_2$ are present, a narcotic effect is to be expected. Smaller amounts of $CO_2$ in the air typically target the respiratory system. Symptoms can include irritation of the nasal passages, throat, and eyes—as well as induce coughing.
- Consequences of elevated $CO_2$ levels in the air (results based on normal healthy adults)
  - 0.04% Normal atmospheric concentration (400 ppm)
  - 2% Breathing rate increases by 50% (2000 ppm)
  - 3% At 10 minutes exposure; breathing rate increases by 100%
  - 5% Breathing rate increases by 300%, headache and sweating may begin after about an hour. (5000 ppm)
  - 8-10% After 10 to 15 minutes exposure, the onset of symptoms such as headache, dizziness, buzzing in the ears, increased blood pressure, high pulse rate, excitation, and nausea will appear.
  - 10-18% After only a few minutes, cramps similar to epileptic fits, loss of consciousness, and shock (i.e., a sharp drop in blood pressure) will occur. Victims should recover very quickly in fresh air.
  - 18-20% Symptoms are similar to those of a stroke.

# Safety

## Safety Placards


- NFPA:
  - For **$CO_2$** HEALTH = 2, FLAMMABILITY = 0, INSTABILITY = 0,
  - For **R-404A** HEALTH = 2, FLAMMABILITY = 1, INSTABILITY = 0

# Safety

## Personal Protection Methods

- Due to the high pressures encountered, greater awareness needs to be exercised around $CO_2$ systems.
- Safety glasses, face shields, long sleeves, and gloves are needed to prevent an encounter with a jet of hot, high pressure discharge gas or being hit with a blast of dry ice.
- Closing off lines containing liquid $CO_2$ will cause pressure in the line to rise over 1000 psi causing a possible rupture.
- Depressurizing lines containing liquid will make dry ice plugs. If heat is then applied at the wrong spot, the line may rupture.
- Numerous relief valves on the system are a blast hazard or could cause fright if relieving unexpectedly.

# Safety

## PPE Minimum

- Minimum Requirements:
  - For standard operations such as making adjustments and using standard diagnostic equipment.
  - Safety Glasses with side shields
  - Long sleeve shirt or jacket
  - Safety shoes with leather tops
  - Leather or mechanics gloves

# Safety

## PPE Higher Risk operations

- Higher risk operations include operations such as :
  - Charging the system
  - Opening pipes of unknown pressure
  - Opening pipes where liquid may be present
  - Initial system start up
- PPE for higher risk operations include:
  - ***All minimal PPE previously discussed***
  - Face shield
  - Cryogenic rated apron
  - Cryogenic rated gloves

# $CO_2$ Component Overview

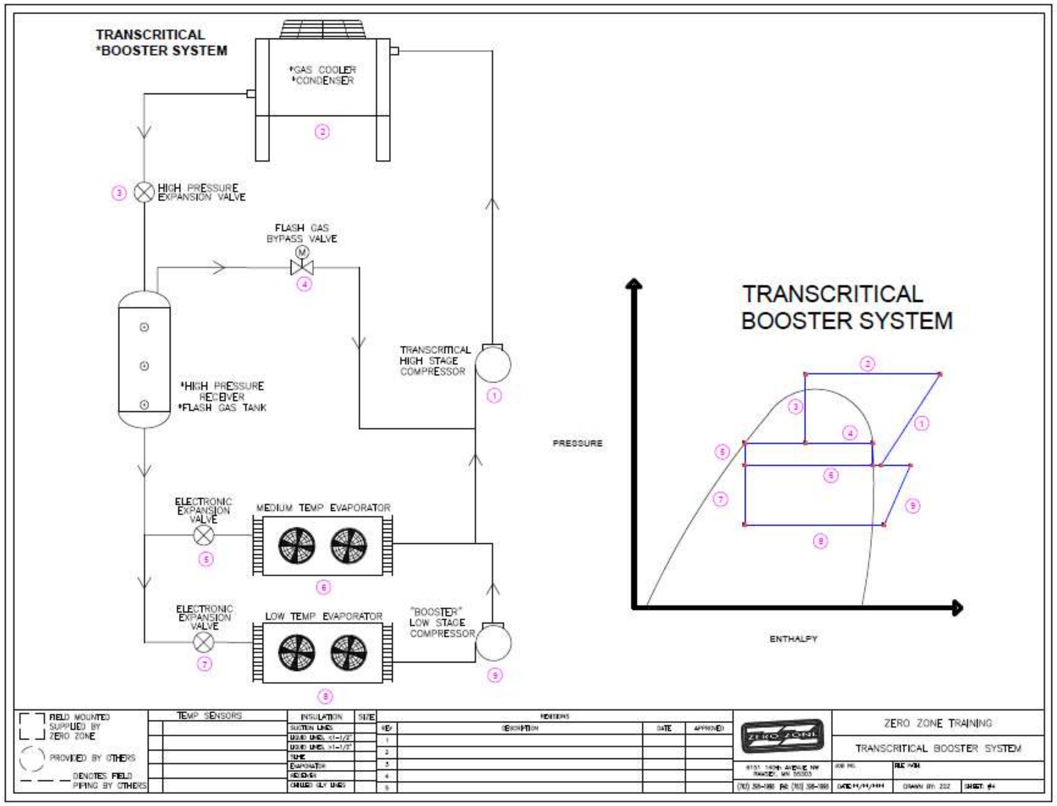
- **Transcritical:** System may gas cool above 88°F or may operate in subcritical mode. It depends on the weather.
  - Single stage one compressor (saturated suction needs to be above 0°F ).
  - Can be two compressors a lower pressure compressor (booster) pumping gas into a high stage compressor.
  - Evaporator - Direct expansion or liquid overfeed.
  - May include energy efficient components like ejectors and parallel compressors.
- **Gas Cooler/Condenser:** Cools high stage compressor discharge gas.
- **High Pressure Valve:** (HPEV) drops pressure from condenser/gas cooler to flash tank pressure. Keeps pressure high in the gas cooler/condenser -similar to a back pressure valve.
- **Flash Tank:** Operates like a receiver and accumulator.
- **Flash Gas Valve:** (FGBV) controls pressure in flash tank similar to a back pressure valve.

# $CO_2$ Component Overview

- **Parallel Compressor:** A compressor that runs in parallel to the high stage compressor but at a higher suction pressure than the high stage compressor.
- **Ejector:** Similar to garden hose sprayer where passing fluid sucks up a gas or a liquid.
- **Electronic Expansion Valve:** EEV for short, expands liquid $CO_2$ into the evaporator.
- **Adiabatic condenser/gas cooler:** Water is sprayed on pads that are on the inlet air going to the condenser/gas cooler. Evaporating water cools the air.

# $CO_2$ Component Overview

## Basic System Architecture

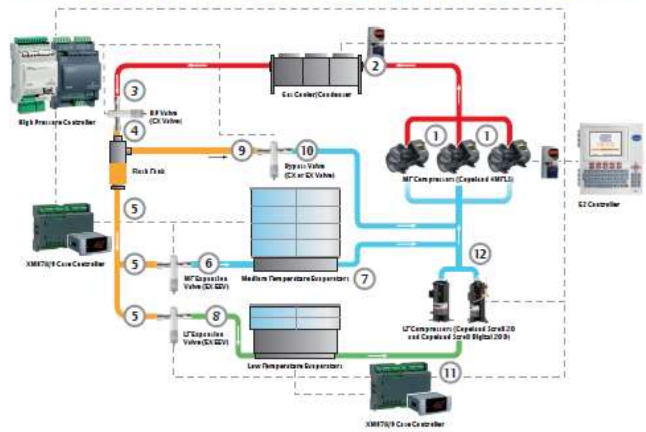


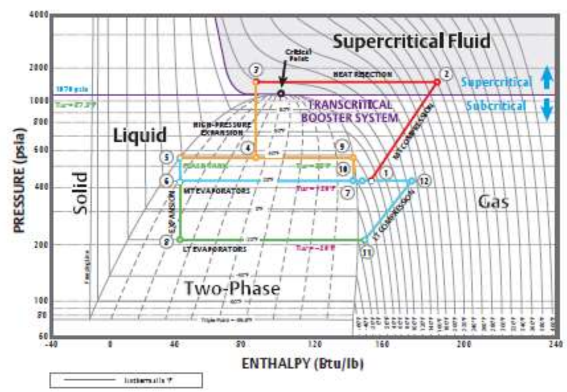
# $CO_2$ Component Overview

**R-744**
**(Carbon Dioxide or $CO_2$)**

| Temp. °F | Temp. °C | Pressure psig | Pressure barg | |
|---|---|---|---|---|
| -69.8 | -56.6 | 60 | 4.2 | Triple Point |
| -65.0 | -53.9 | 70 | 4.8 | |
| -60.0 | -51.1 | 80 | 5.5 | |
| -55.0 | -48.3 | 91 | 6.3 | |
| -50.0 | -45.6 | 103 | 7.1 | |
| -48.0 | -44.4 | 109 | 7.5 | |
| -46.0 | -43.3 | 114 | 7.9 | |
| -44.0 | -42.2 | 119 | 8.2 | |
| -42.0 | -41.1 | 125 | 8.6 | |
| -40.0 | -40.0 | 131 | 9.0 | |
| -38.0 | -38.9 | 137 | 9.4 | |
| -36.0 | -37.8 | 143 | 9.9 | |
| -34.0 | -36.7 | 150 | 10.3 | |
| -32.0 | -35.6 | 156 | 10.8 | |
| -30.0 | -34.4 | 163 | 11.2 | |
| -28.0 | -33.3 | 170 | 11.7 | |
| -26.0 | -32.2 | 177 | 12.2 | |
| -24.0 | -31.1 | 185 | 12.7 | |
| -22.0 | -30.0 | 192 | 13.3 | |
| -20.0 | -28.9 | 200 | 13.8 | |
| -18.0 | -27.8 | 208 | 14.4 | |
| -16.0 | -26.7 | 217 | 14.9 | |
| -14.0 | -25.6 | 225 | 15.5 | |
| -12.0 | -24.4 | 234 | 16.1 | |
| -10.0 | -23.3 | 243 | 16.7 | |
| -8.0 | -22.2 | 252 | 17.4 | |
| -6.0 | -21.1 | 261 | 18.0 | |
| -4.0 | -20.0 | 271 | 18.7 | |
| -2.0 | -18.9 | 281 | 19.4 | |
| 0.0 | -17.8 | 291 | 20.1 | |
| 2.0 | -16.7 | 301 | 20.8 | |
| 4.0 | -15.6 | 312 | 21.5 | |
| 6.0 | -14.4 | 323 | 22.3 | |
| 8.0 | -13.3 | 334 | 23.0 | |
| 10.0 | -12.2 | 346 | 23.8 | |
| 12.0 | -11.1 | 357 | 24.6 | |
| 14.0 | -10.0 | 369 | 25.5 | |
| 16.0 | -8.9 | 382 | 26.3 | |

## Typical $CO_2$ Transcritical Booster System

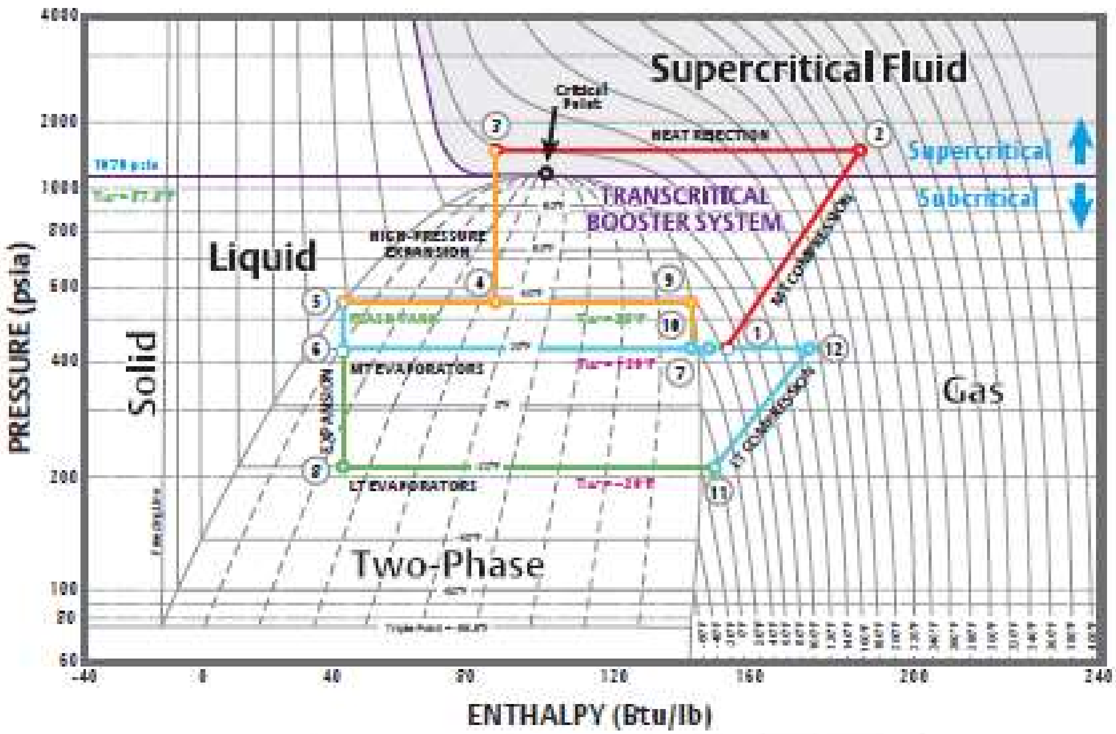



| Temp. °F | Temp. °C | Pressure psig | Pressure barg | |
|---|---|---|---|---|
| 18.0 | -7.8 | 394 | 27.2 | |
| 20.0 | -6.7 | 407 | 28.1 | |
| 22.0 | -5.6 | 420 | 29.0 | |
| 24.0 | -4.4 | 434 | 29.9 | |
| 26.0 | -3.3 | 448 | 30.9 | |
| 28.0 | -2.2 | 462 | 31.8 | |
| 30.0 | -1.1 | 476 | 32.8 | |
| 32.0 | 0.0 | 491 | 33.8 | |
| 34.0 | 1.1 | 506 | 34.9 | |
| 36.0 | 2.2 | 521 | 35.9 | |
| 38.0 | 3.3 | 537 | 37.0 | |
| 40.0 | 4.4 | 553 | 38.1 | |
| 42.0 | 5.6 | 569 | 39.2 | |
| 44.0 | 6.7 | 586 | 40.4 | |
| 46.0 | 7.8 | 603 | 41.6 | |
| 48.0 | 8.9 | 620 | 42.8 | |
| 50.0 | 10.0 | 638 | 44.0 | |
| 52.0 | 11.1 | 656 | 45.3 | |
| 54.0 | 12.2 | 675 | 46.5 | |
| 56.0 | 13.3 | 694 | 47.8 | |
| 58.0 | 14.4 | 713 | 49.2 | |
| 60.0 | 15.6 | 733 | 50.5 | |
| 62.0 | 16.7 | 753 | 51.9 | |
| 64.0 | 17.8 | 774 | 53.4 | |
| 66.0 | 18.9 | 795 | 54.8 | |
| 68.0 | 20.0 | 816 | 56.3 | |
| 70.0 | 21.1 | 838 | 57.8 | |
| 75.0 | 23.9 | 895 | 61.7 | |
| 80.0 | 26.7 | 955 | 65.8 | |
| 85.0 | 29.4 | 1018 | 70.2 | |
| 87.8 | 31.0 | 1055 | 72.8 | Critical Point |

EMERSON.

# $CO_2$ Component Overview



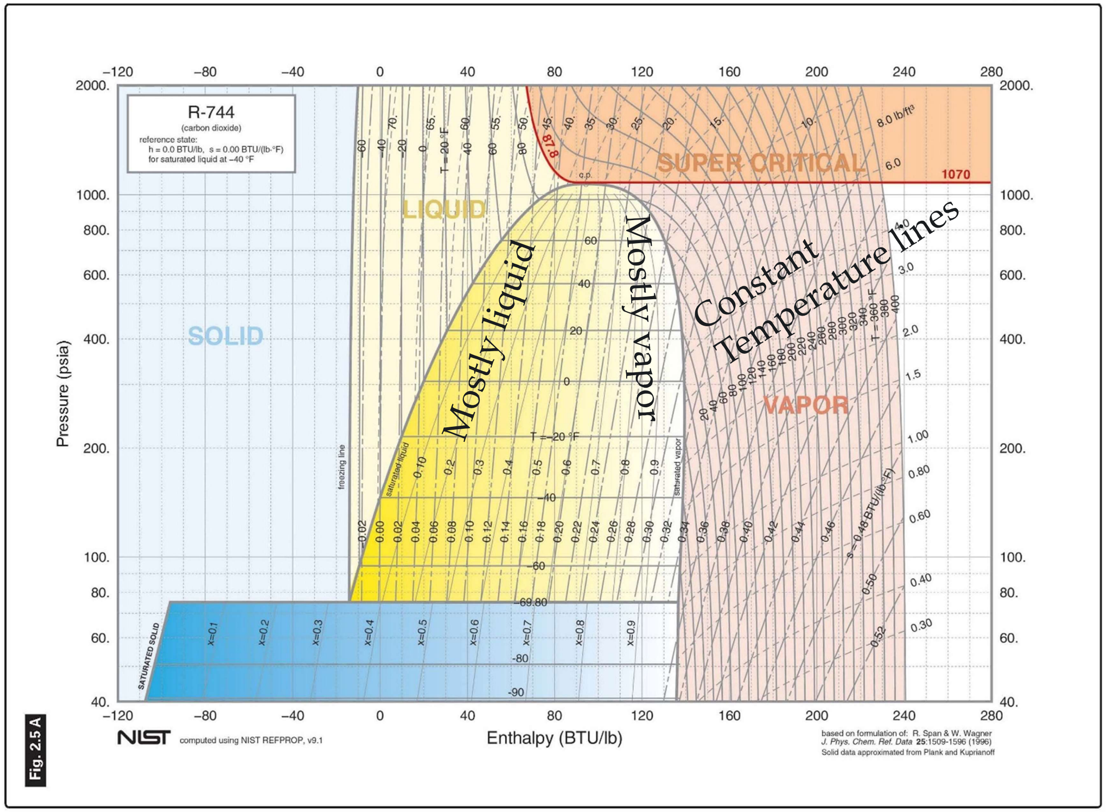

- Info on a PH Diagram
  - Pressure
  - Enthalpy (Energy)
  - Temperature
  - Liquid
  - Vapor
  - % Mix of Liquid and Vapor
- Construction is connecting dots

# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

- Using a PH Diagram
- Optimal Operating Point
- Minimize Flash Gas
- Comparing System Efficiency
- Optimal Operating point

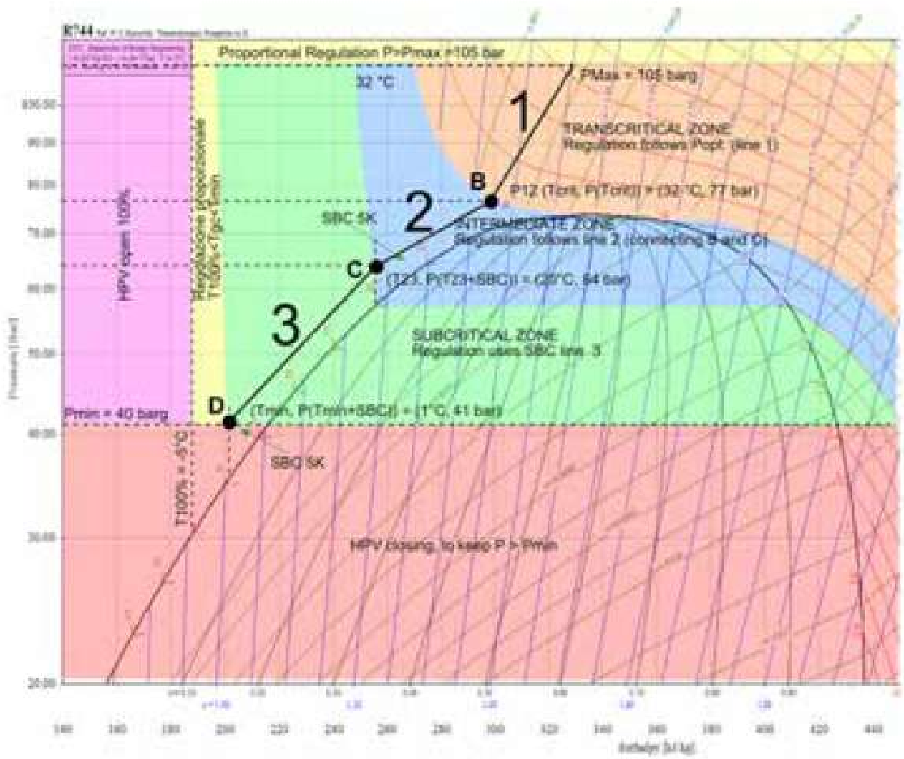
# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Using a PH Diagram



# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Optimal Operating Point




- The optimal transcritical operating point balances increased energy from high discharge pressure with less flash gas.

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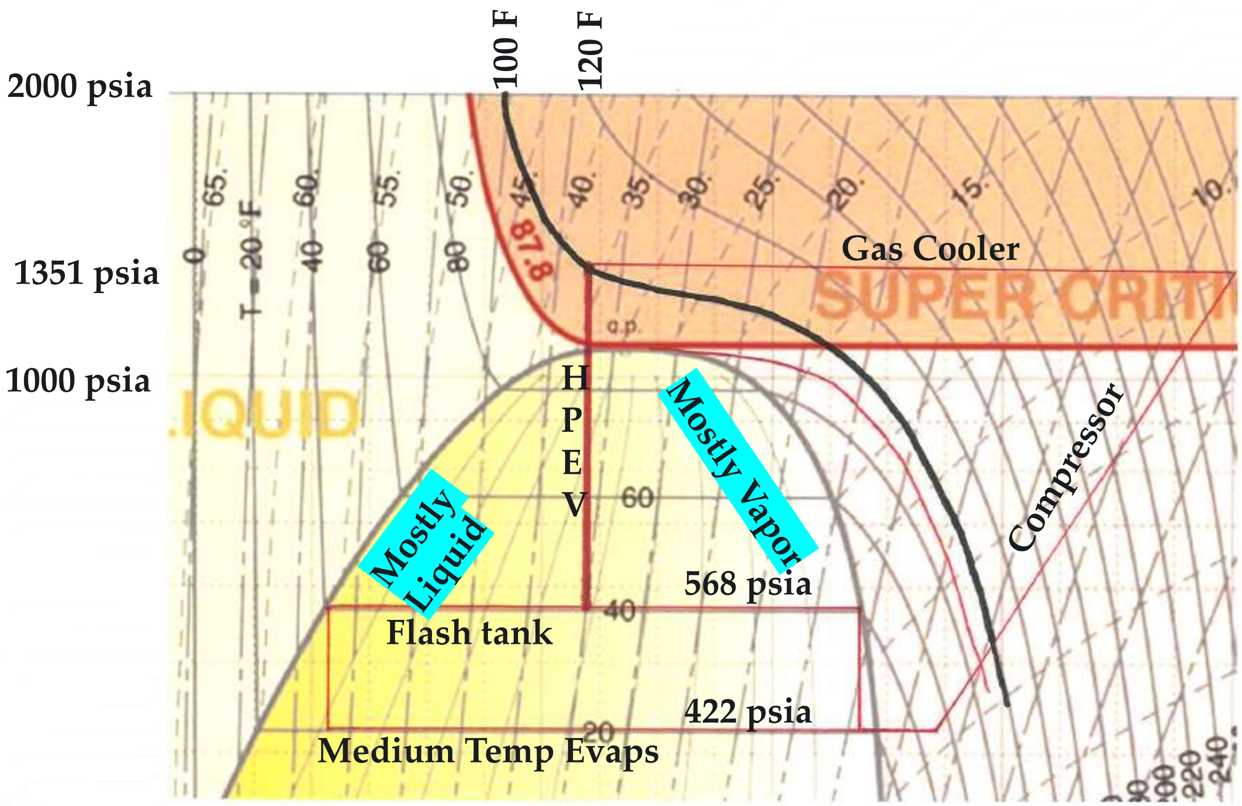
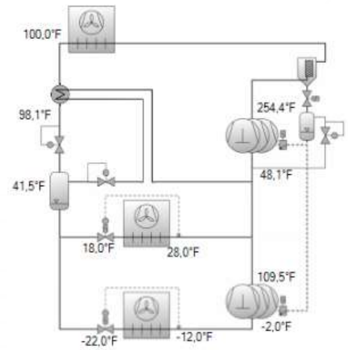
# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

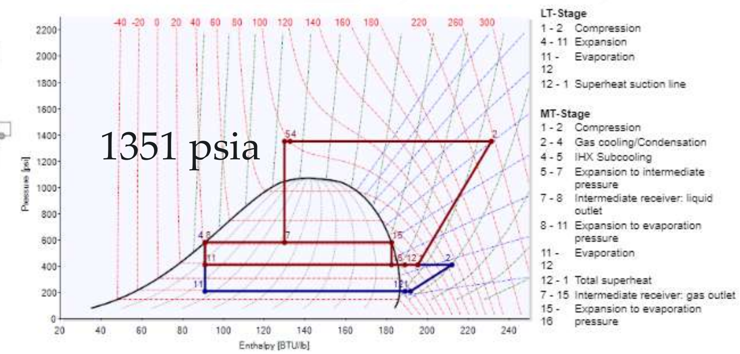
## Minimize Flash Gas



# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Comparing System Efficiency




Result | Limits | Technical Data | Dimensions | Information | Documentation | Trainings

LT-Stage: Tentative Data.
LT-Stage: Discharge gas temperature at least 50°C (122°F)
LT-Stage: Power consumption at compressor inlet.

COP/EER Evaporator: 4.72

| Compressor | LT-Stage | 2GSL-3K | 2FSL-4K | 2FSL-4K |
|---|---|---|---|---|
| Frequency compressor | -- | 69.0 Hz | -- | -- |
| Evaporator capacity | 149.0 kBtu/h | 46.5 kBtu/h | 51.3 kBtu/h | 51.3 kBtu/h |
| Evaporator mass flow | 684 lb/h | -- | -- | -- |
| Ratio | -- | 31.2 % | 34.4 % | 34.4 % |
| Power input | 9.06 kW | 2.93 kW | 3.06 kW | 3.06 kW |
| Current | 16.43 A | 5.10 A | 5.66 A | 5.66 A |
| Voltage range | -- | 440-480V | 440-480V | 440-480V |
| Mass flow | 1508 lb/h | 470 lb/h | 519 lb/h | 519 lb/h |
| Total superheat | 19.90 °F | 19.90 °F | 19.90 °F | 19.90 °F |
| Discharge gas temp. w/o cooling | 109.5 °F | 112.6 °F | 108.1 °F | 108.1 °F |
| **Compressor** | **MT-Stage** | **4FTE-30K** | **4GTE-20K** | **4GTE-20K** |
| Frequency compressor | -- | 62.0 Hz | -- | -- |
| Evaporator capacity | 229 kBtu/h | 88.8 kBtu/h | 70.0 kBtu/h | 70.0 kBtu/h |
| Evaporator mass flow | 1052 lb/h | -- | -- | -- |
| Ratio | -- | 38.8 % | 30.6 % | 30.6 % |
| Gas cooler capacity | 662 kBtu/h | 257 kBtu/h | 203 kBtu/h | 203 kBtu/h |
| Gas cooler mass flow | 3024 lb/h | -- | -- | -- |
| Power input | 70.9 kW | 26.5 kW | 22.2 kW | 22.2 kW |
| Current | 101.2 A | 39.1 A | 31.0 A | 31.0 A |
| Voltage range | -- | 440-480V | 440-480V | 440-480V |
| Mass flow | 6666 lb/h | 2586 lb/h | 2040 lb/h | 2040 lb/h |
| Flashgas mass flow | 2839 lb/h | -- | -- | -- |
| Total superheat | 30.0 °F | 30.0 °F | 30.0 °F | 30.0 °F |
| Discharge gas temp. w/o cooling | 254 °F | 250 °F | 257 °F | 257 °F |
| optimal high pressure | 1351 psia | -- | -- | -- |

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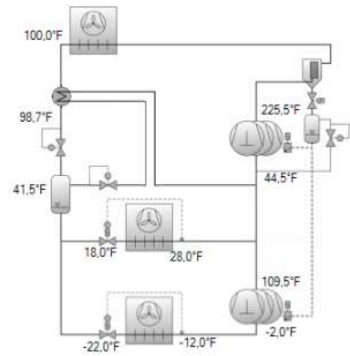
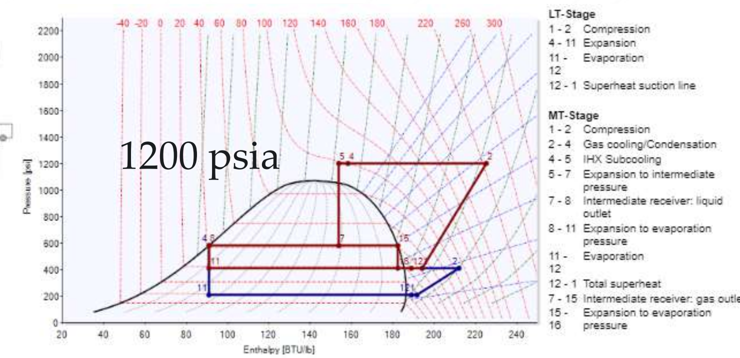
# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Comparing System Efficiency




Result | Limits | Technical Data | Dimensions | Information | Documentation | Trainings

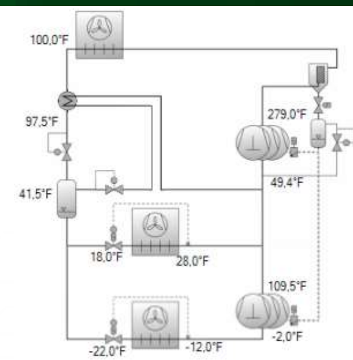
LT-Stage: Tentative Data.
LT-Stage: Discharge gas temperature at least 50°C (122°F)
LT-Stage: Power consumption at compressor inlet.

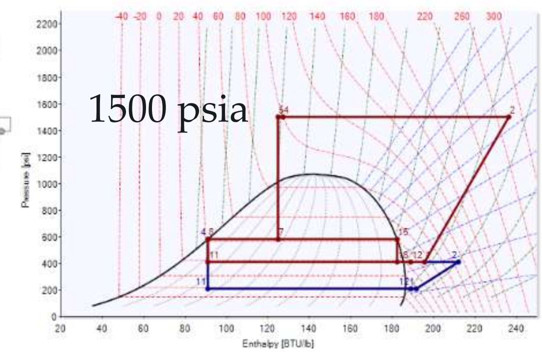
COP/EER Evaporator: 2.95

| Compressor | LT-Stage | 2GSL-3K | 2FSL-4K | 2FSL-4K |
|---|---|---|---|---|
| Frequency compressor | -- | 69.0 Hz | -- | -- |
| Evaporator capacity | 149.0 kBtu/h | 46.5 kBtu/h | 51.3 kBtu/h | 51.3 kBtu/h |
| Evaporator mass flow | 684 lb/h | -- | -- | -- |
| Ratio | -- | 31.2 % | 34.4 % | 34.4 % |
| Power input | 9.06 kW | 2.93 kW | 3.06 kW | 3.06 kW |
| Current | 16.43 A | 5.10 A | 5.66 A | 5.66 A |
| Voltage range | -- | 440-480V | 440-480V | 440-480V |
| Mass flow | 1508 lb/h | 470 lb/h | 519 lb/h | 519 lb/h |
| Total superheat | 19.90 °F | 19.90 °F | 19.90 °F | 19.90 °F |
| Discharge gas temp. w/o cooling | 109.5 °F | 112.6 °F | 108.1 °F | 108.1 °F |
| Compressor | MT-Stage | 4FTE-30K | 4GTE-20K | 4GTE-20K |
| Frequency compressor | -- | 62.0 Hz | -- | -- |
| Evaporator capacity | 67.9 kBtu/h | 26.2 kBtu/h | 20.8 kBtu/h | 20.8 kBtu/h |
| Evaporator mass flow | 312 lb/h | -- | -- | -- |
| Ratio | -- | 38.6 % | 30.7 % | 30.7 % |
| Gas cooler capacity | 474 kBtu/h | 182.9 kBtu/h | 145.3 kBtu/h | 145.3 kBtu/h |
| Gas cooler mass flow | 3184 lb/h | -- | -- | -- |
| Power input | 64.4 kW | 24.2 kW | 20.1 kW | 20.1 kW |
| Current | 92.7 A | 36.2 A | 28.3 A | 28.3 A |
| Voltage range | -- | 440-480V | 440-480V | 440-480V |
| Mass flow | 7020 lb/h | 2712 lb/h | 2154 lb/h | 2154 lb/h |
| Flashgas mass flow | 4824 lb/h | -- | -- | -- |
| Total superheat | 26.4 °F | 26.4 °F | 26.4 °F | 26.4 °F |
| Discharge gas temp. w/o cooling | 226 °F | 223 °F | 227 °F | 227 °F |
| optimal high pressure | 1351 psia | -- | -- | -- |

# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Comparing System Efficiency




Result | Limits | Technical Data | Dimensions | Information | Documentation | Trainings

LT-Stage: Tentative Data.
LT-Stage: *Compressor-Performance data certified by ASERCOM (see T.Data/ Notes)
LT-Stage: Discharge gas temperature at least 50°C (122°F)

COP/EER Evaporator: 4.63

| Compressor | LT-Stage | 2GSL-3K | 2FSL-4K | 2FSL-4K |
|---|---|---|---|---|
| Frequency compressor | -- | 69.0 Hz | -- | -- |
| Evaporator capacity | 149.0 kBtu/h | 46.5 kBtu/h | 51.3 kBtu/h | 51.3 kBtu/h |
| Evaporator mass flow | 684 lb/h | -- | -- | -- |
| Ratio | -- | 31.2 % | 34.4 % | 34.4 % |
| Power input | 9.06 kW | 2.93 kW | 3.06 kW | 3.06 kW |
| Current | 16.43 A | 5.10 A | 5.66 A | 5.66 A |
| Voltage range | -- | 440-480V | 440-480V | 440-480V |
| Mass flow | 1508 lb/h | 470 lb/h | 519 lb/h | 519 lb/h |
| Total superheat | 19.90 °F | 19.90 °F | 19.90 °F | 19.90 °F |
| Discharge gas temp. w/o cooling | 109.5 °F | 112.6 °F | 108.1 °F | 108.1 °F |
| **Compressor** | **MT-Stage** | **4FTE-30K** | **4GTE-20K** | **4GTE-20K** |
| Frequency compressor | -- | 62.0 Hz | -- | -- |
| Evaporator capacity | 248 kBtu/h | 96.8 kBtu/h | 75.7 kBtu/h | 75.7 kBtu/h |
| Evaporator mass flow | 1141 lb/h | -- | -- | -- |
| Ratio | -- | 39.0 % | 30.5 % | 30.5 % |
| Gas cooler capacity | 702 kBtu/h | 274 kBtu/h | 214 kBtu/h | 214 kBtu/h |
| Gas cooler mass flow | 2901 lb/h | -- | -- | -- |
| Power input | 76.8 kW | 28.5 kW | 24.1 kW | 24.1 kW |
| Current | 108.9 A | 41.8 A | 33.6 A | 33.6 A |
| Voltage range | -- | 440-480V | 440-480V | 440-480V |
| Mass flow | 6395 lb/h | 2493 lb/h | 1951 lb/h | 1951 lb/h |
| Flashgas mass flow | 2372 lb/h | -- | -- | -- |
| Total superheat | 31.3 °F | 31.3 °F | 31.3 °F | 31.3 °F |
| Discharge gas temp. w/o cooling | 279 °F | 273 °F | 283 °F | 283 °F |
| optimal high pressure | 1351 psia | -- | -- | -- |

# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Optimal Operating Point

| Low Temp | | | |
|---|---|---|---|
| Gas cooler pressure | 1351 psia | 1200 psia | 1500 psia |
| COP | 4.72 | 2.95 | 4.63 |
| Evaporator capacity | 149.0 kBtu/h | 149.0 kBtu/h | 149.0 kBtu/h |
| Evaporator mass flow | 684 lb/h | 684 lb/h | 684 lb/h |
| Power input | 9.06 kW | 9.06 kW | 9.06 kW |
| Current | 16.43 A | 16.43 A | 16.43 A |
| Mass flow | 1508 lb/h | 1508 lb/h | 1508 lb/h |
| Total superheat | 19.90°F | 19.90°F | 19.90°F |
| Discharge gas temp. w/o cooling | 109.5°F | 109.5°F | 109.5°F |

# Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

## Optimal Operating Point

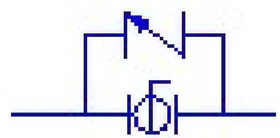
- The optimal transcritical operating point balances increased energy from high discharge pressure with less flash gas.

| Medium Temp | | | |
|---|---|---|---|
| Gas cooler pressure | 1351 psia | 1200 psia | 1500 psia |
| COP | 4.72 | 2.95 | 4.63 |
| Evaporator capacity | 229 kBtu/h | 67.9 kBtu/h | 248 kBtu/h |
| Evaporator mass flow | 1052 lb/h | 312 lb/h | 1141 lb/h |
| Gas cooler capacity | 662 kBtu/h | 474 kBtu/h | 702 kBtu/h |
| Gas cooler mass flow | 3024 lb/h | 3184 lb/h | 2901 lb/h |
| Power input | 70.9 kW | 64.4 kW | 76.8 kW |
| Current | 101.2 A | 92.7 A | 108.9 A |
| Mass flow | 6666 lb/h | 7020 lb/h | 6395 lb/h |
| Flashgas mass flow | 2839 lb/h | 4824 lb/h | 2372 lb/h |
| Total superheat | 30.0°F | 26.4°F | 31.3°F |
| Discharge gas temp. w/o cooling | 254°F | 226°F | 279°F |
| Optimal high pressure | 1351 psia | 1351 psia | 1351 psia |

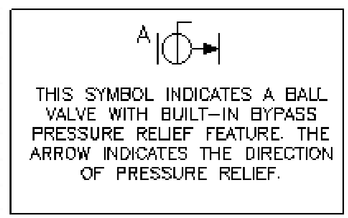
# $CO_2$ System Designs

## High Pressure Safety

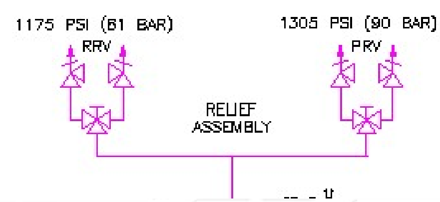
- Back check valves



- Integral back check ball valves



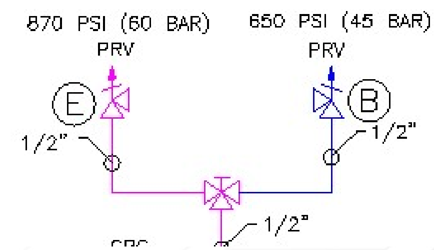

- Regulating relief valves



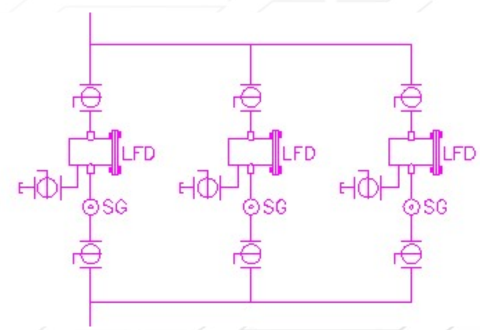
# $CO_2$ System Designs

## High Pressure Safety

- Relief valves for servicing

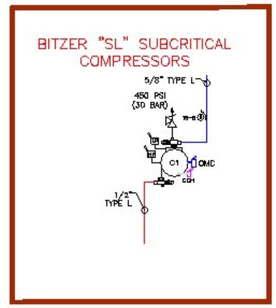


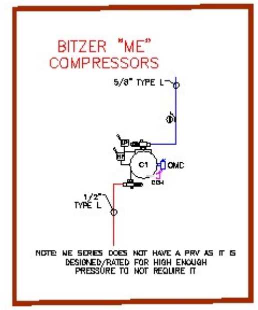

- Administrative controlled component isolation

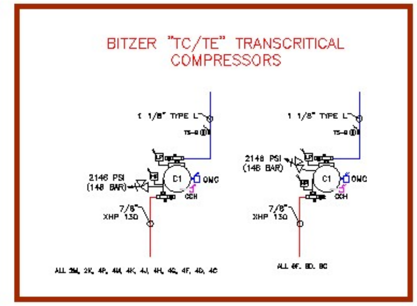


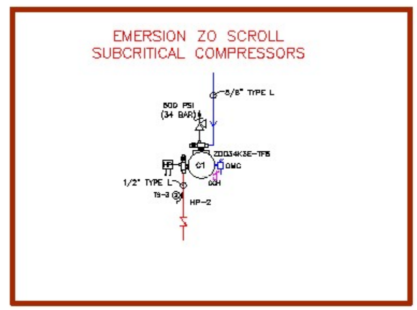
# $CO_2$ System Designs

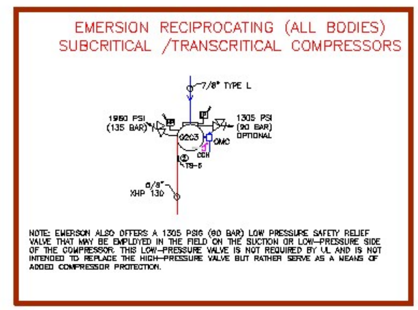
## Compressor Safety Valves

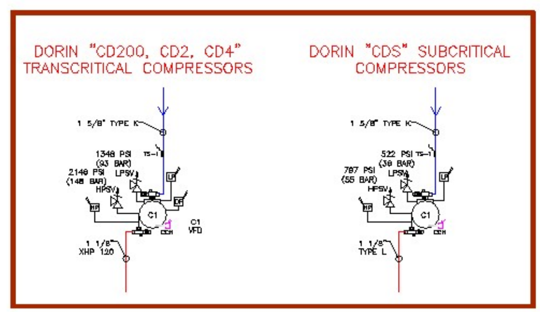


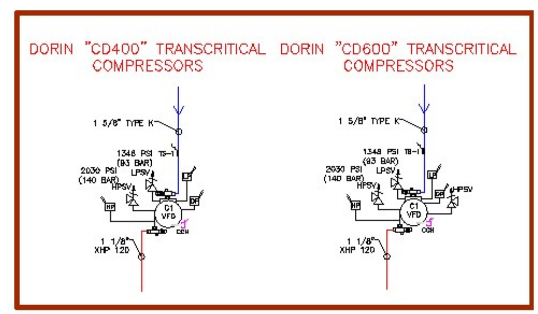



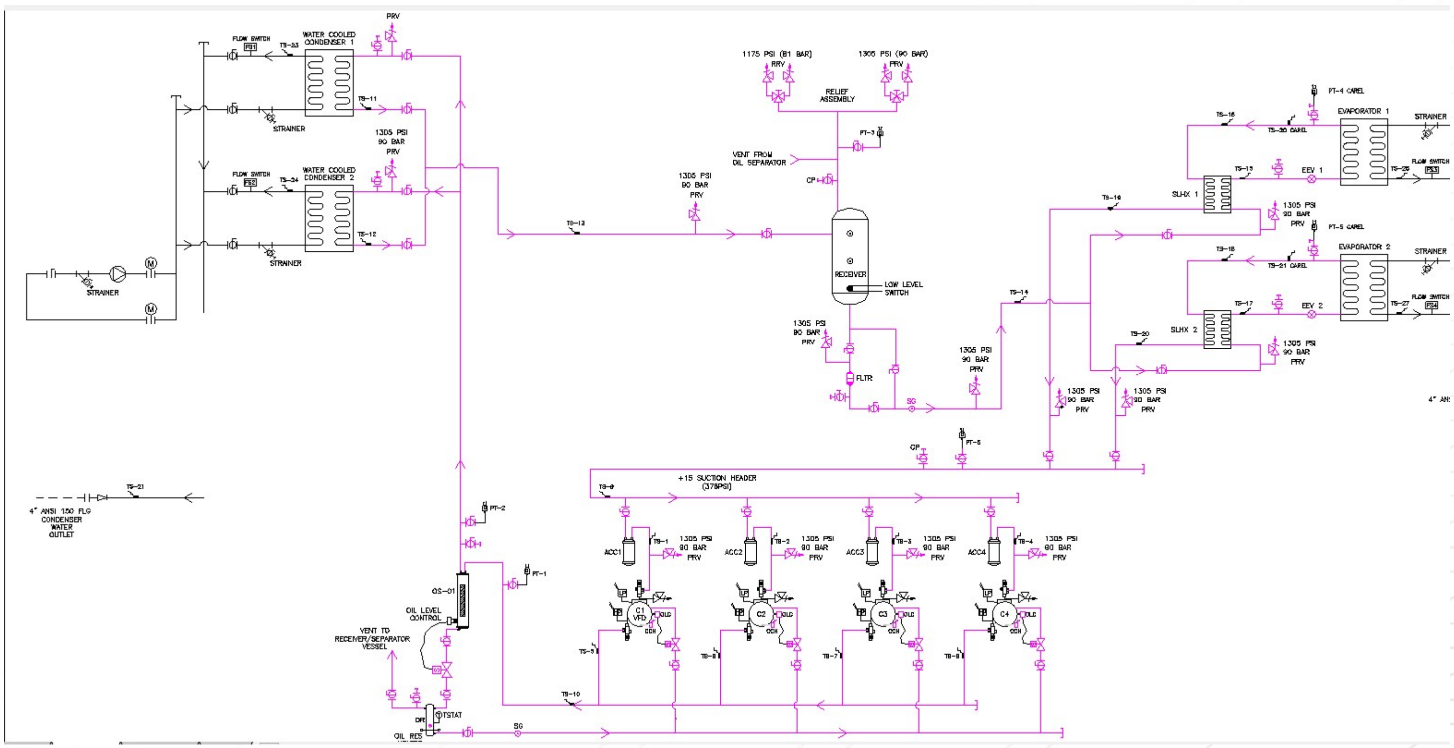



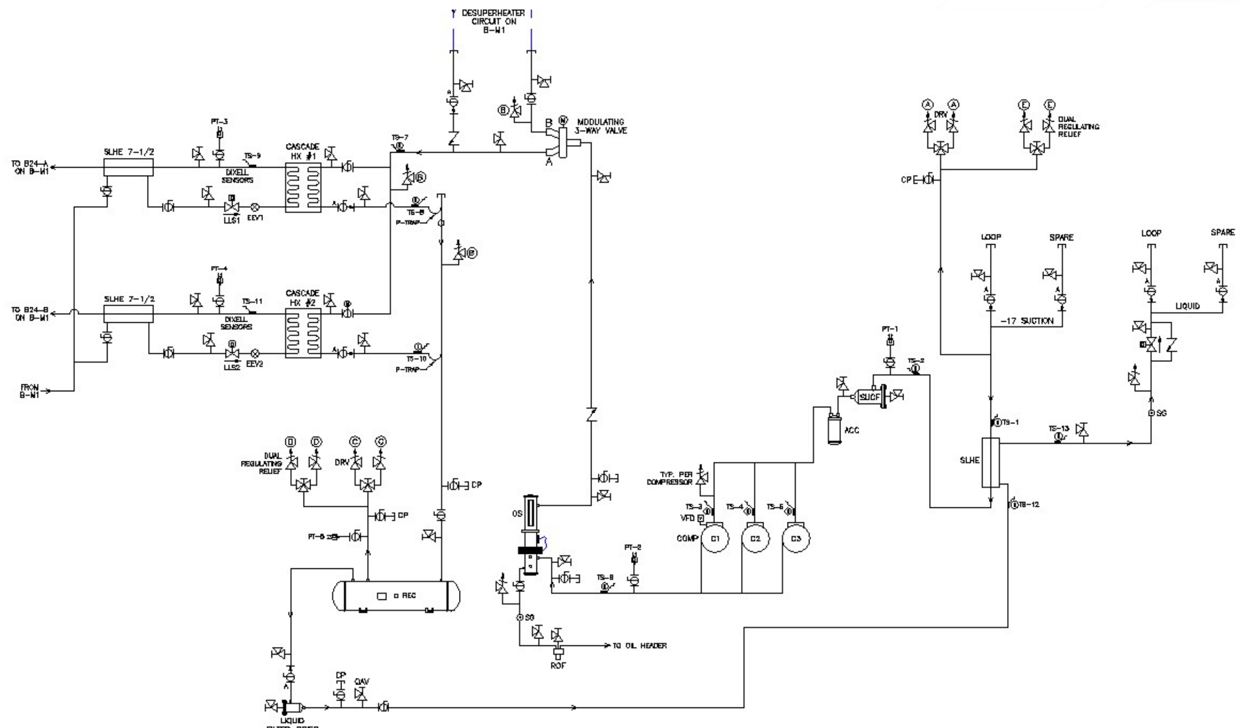
# $CO_2$ System Designs

## Subcritical – Water-Cooled



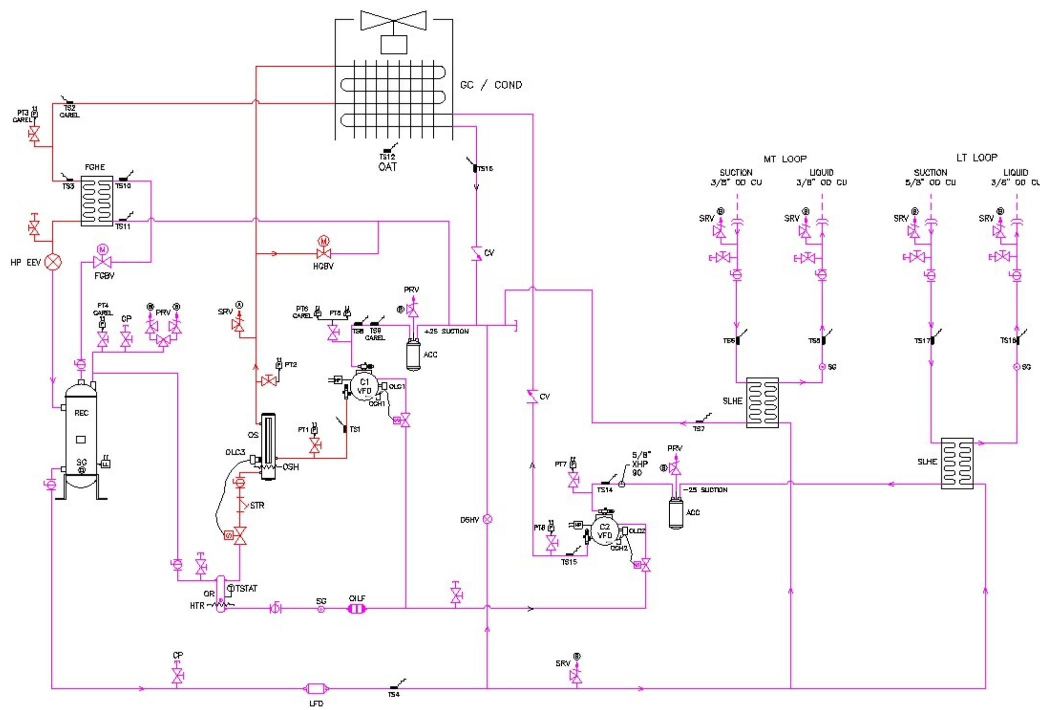
# $CO_2$ System Designs

## Subcritical – Cascade



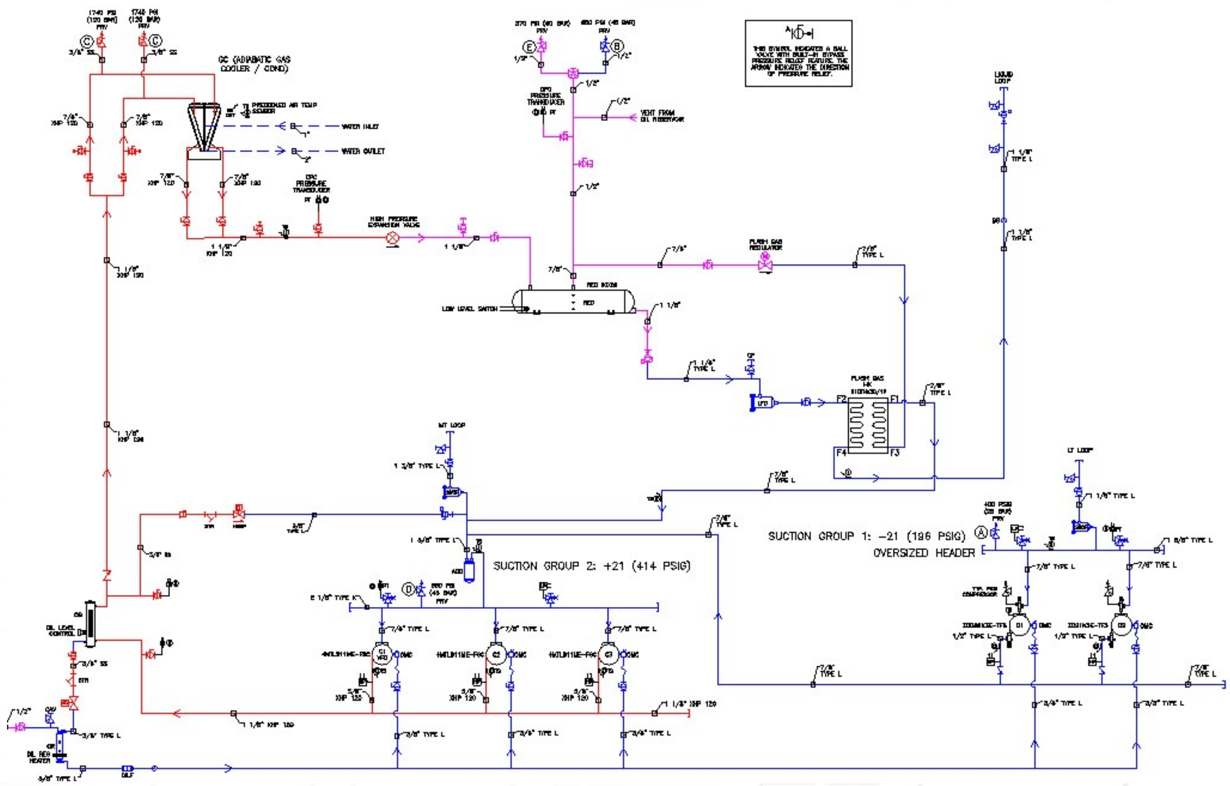
# $CO_2$ System Designs

## Transcritical – Desuperheater



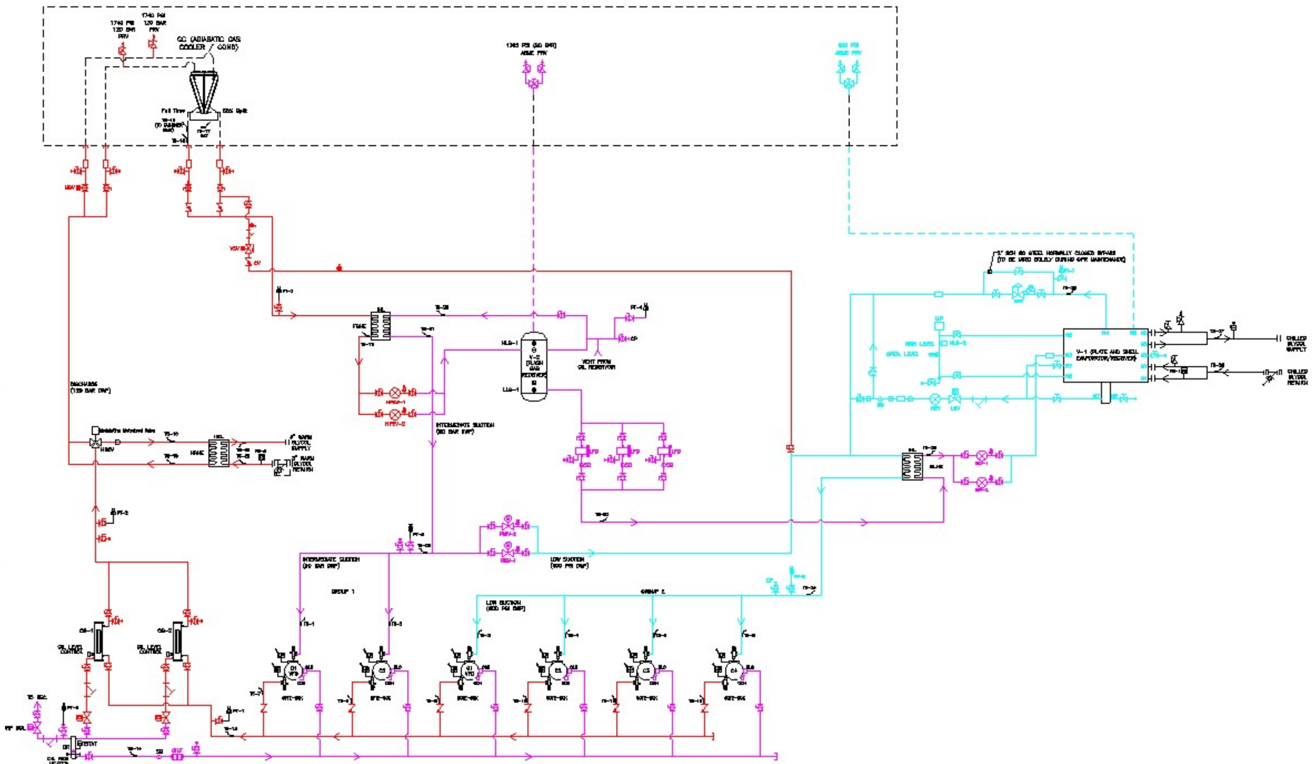
# $CO_2$ System Designs

## Transcritical – No Desuperheater



# $CO_2$ System Designs

## Transcritical – Parallel Compression



# *That's All Folks*

Thank you for attending

Questions?

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NORTH AMERICAN Sustainable Refrigeration Council