Natural Refrigerant Training Summit

Building a Sustainable Workforce

CO_2 Transcritical Systems: Focus on High Pressure Expansion Valve Operation

Bruce R. Hierlmeier P.E.

Zero Zone, Inc.

NORTH AMERICAN Sustainable Refrigeration Council

NORTH AMERICAN Sustainable Refrigeration Council

Natural Refrigerant Training Summit

Thank you to our sponsors!

Premium Sponsors

AHT a member of DAIKIN group

The Arcticom Group

Bitzer

CAREL

Climate Pros

CoolSys

EMERSON

Hillphoenix A DOVER COMPANY

Parker

SPORLAN

P.I.P.E. Piping Industry Progress & Education · Plumbing · Heating · Piping · Labor Management Cooperation Committee

Basic Sponsors

ARCTIC COOLING SYSTEMS ENGINEERING · CONSTRUCTION · SERVICE

Classic Refrigeration SoCal

M&M CARNOT

KW KYSOR WARREN epta refrigeration

Tecumseh

North American Sustainable Refrigeration Council (NASRC)

Mission Create sustainable future for supermarket refrigeration by removing barriers to natural refrigerant adoption

501c3
Non-Profit Organization

150+
Members

51,000+
Food Retail Locations

Goals

- **Build sustainable workforce**
- Increase funding options
- Increase education & awareness

Natural Refrigerants

Carbon Dioxide
R744

Propane
R290

Ammonia
R717

NORTH AMERICAN Sustainable Refrigeration Council

Need help? Look for NASRC staff!

Danielle Wright
Executive Director

Morgan Smith
Program & Communications Director

Jeanne Ackerman
Membership & Communications Coordinator

NORTH AMERICAN Sustainable Refrigeration Council ™

SOUTHERN CALIFORNIA EDISON®

YOUR ENERGY EDUCATION STARTS HERE

Our Energy Education Centers in Irwindale and Tulare offer online and in-person classes to help you advance your career in clean energy, and make better energy decisions for your home or business.

Sign up for a free class or join our email list.

Visit us at **sce.com/classes** or scan the QR code.

Before we get started…

- Please make sure you sign in by the door
- To receive an electronic certificate for this training:
  - Complete the survey at the end of the session
  - Share your name and email at the end of the survey

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

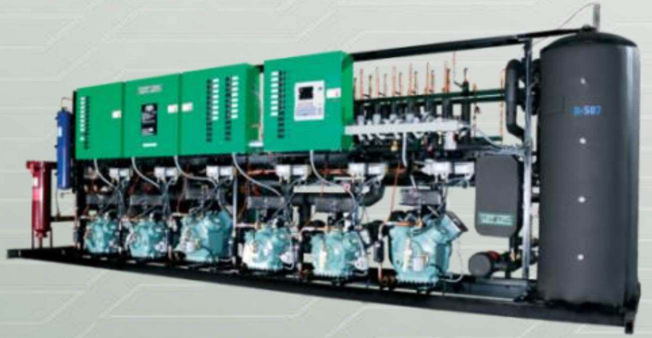

Welcome to the
Zero Zone Experience
ZERO ZONE
TECHNOLOGY CENTER
ZERO ZONE
TECHNOLOGY CENTER
Display Cases &
Refrigeration Systems
ZERO ZONE®
We've Always Been Green™

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
ZERO ZONE

Display Cases

ZERO ZONE

Highlight
MERCHANDISER

Reveal
MERCHANDISER

CRYSTAL
MERCHANDISER

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.

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

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

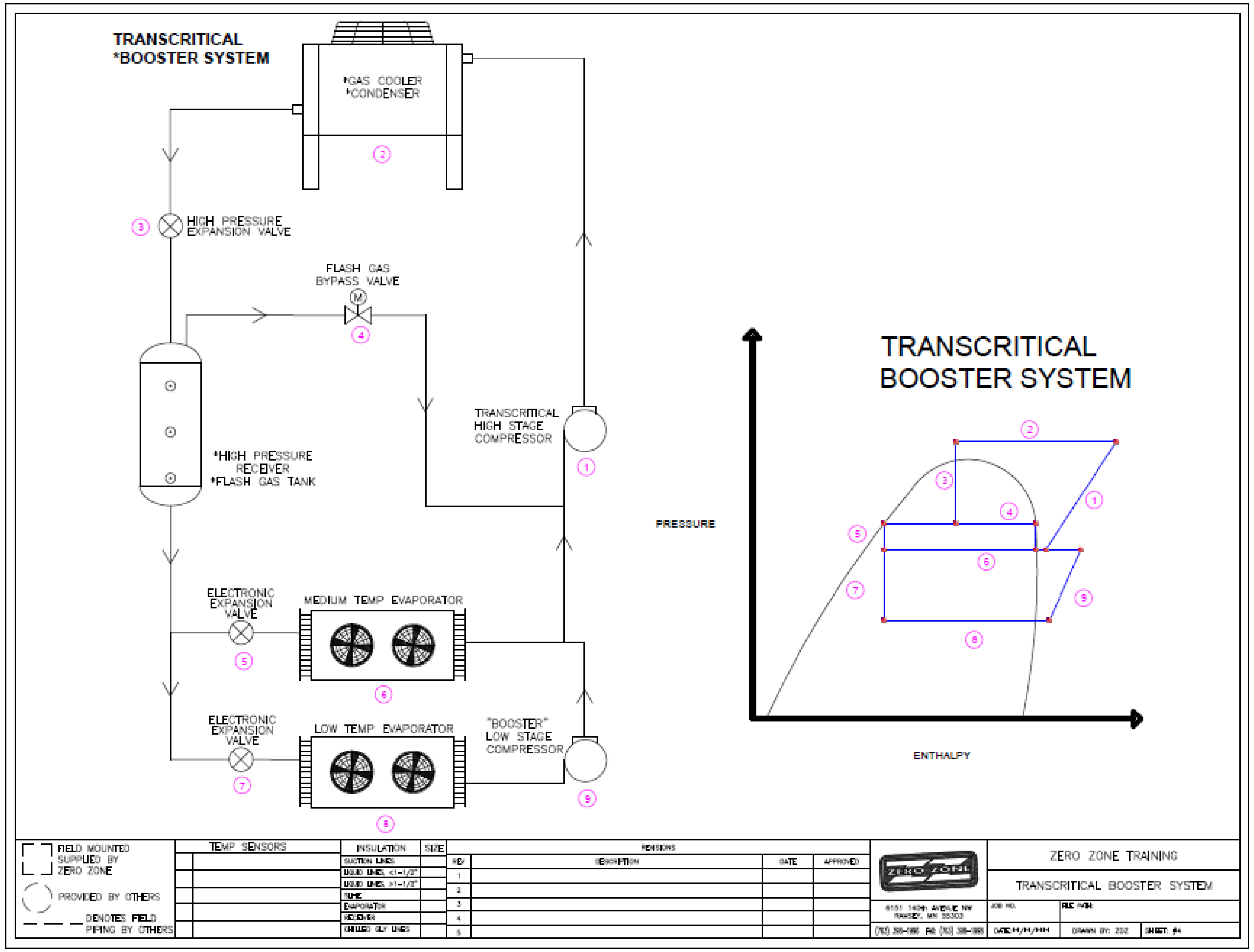
- **Transcritical:** System may gas cool above 88°F or may operate in subcritical mode. It depends on the weather.
  - Single stage one compressor (saturated suction needs to be above 0°F).
  - Can be two compressors a lower pressure compressor (booster) pumping gas into a high stage compressor.
  - 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



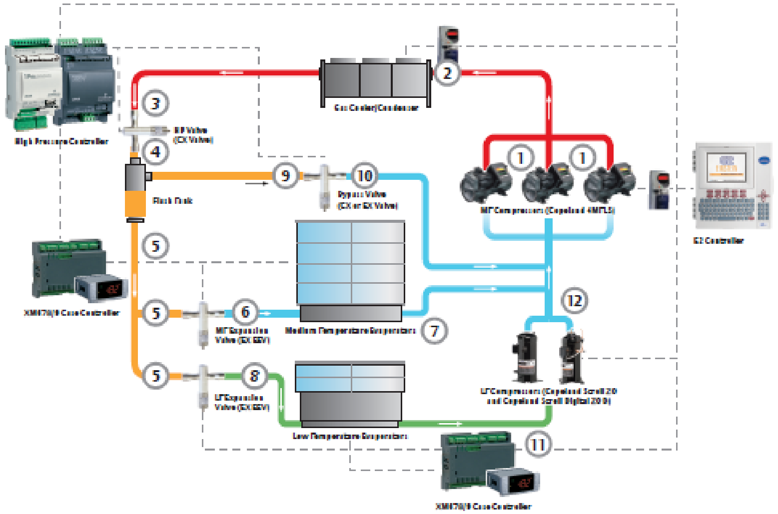
CO_2 Component Overview

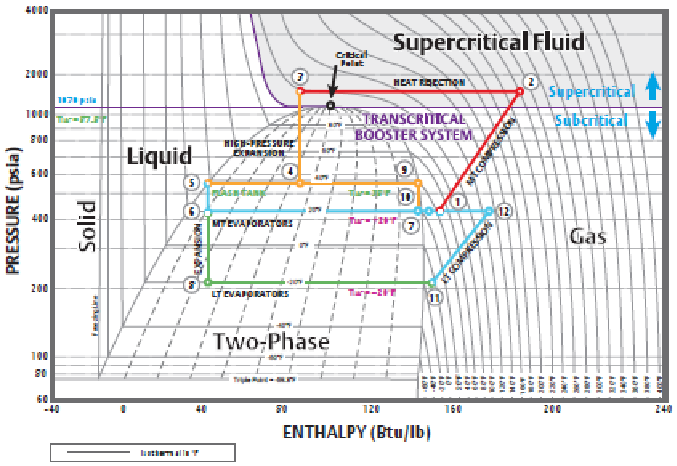
R-744 (Carbon Dioxide or CO_2)

Temp. °F	Temp. °C	Pressure psig	Pressure barg
-69.8	-56.6	60	4.2
-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

Triple Point

Typical CO_2 Transcritical Booster System

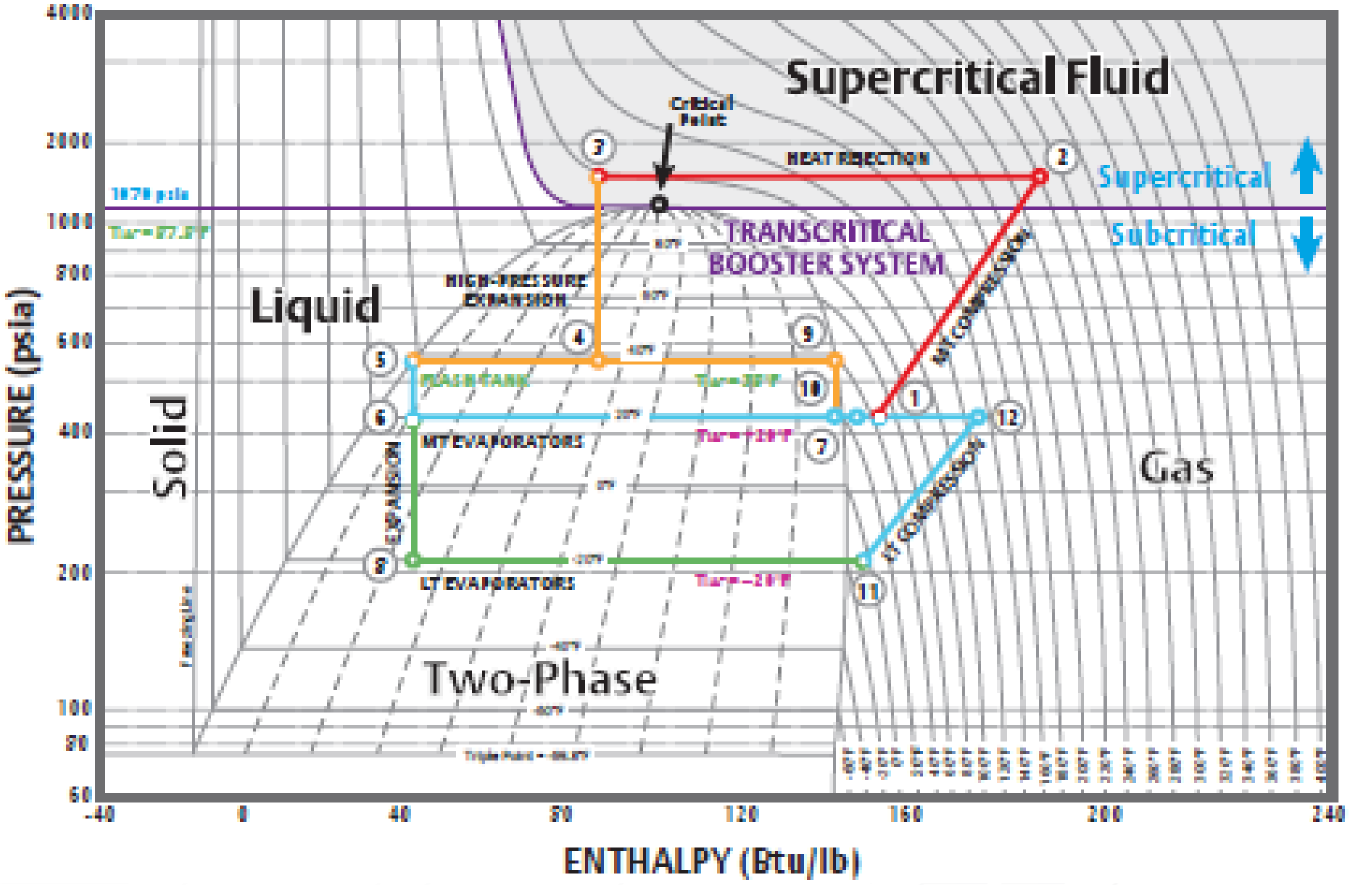




Temp. °F	Temp. °C	Pressure psig	Pressure barg
18.0	-7.8	394	27.2
20.0	-6.7	407	28.1
22.0	-5.6	420	29.0
24.0	-4.4	434	29.9
26.0	-3.3	448	30.9
28.0	-2.2	462	31.8
30.0	-1.1	476	32.8
32.0	0.0	491	33.8
34.0	1.1	506	34.9
36.0	2.2	521	35.9
38.0	3.3	537	37.0
40.0	4.4	553	38.1
42.0	5.6	569	39.2
44.0	6.7	586	40.4
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

CO_2 Component Overview



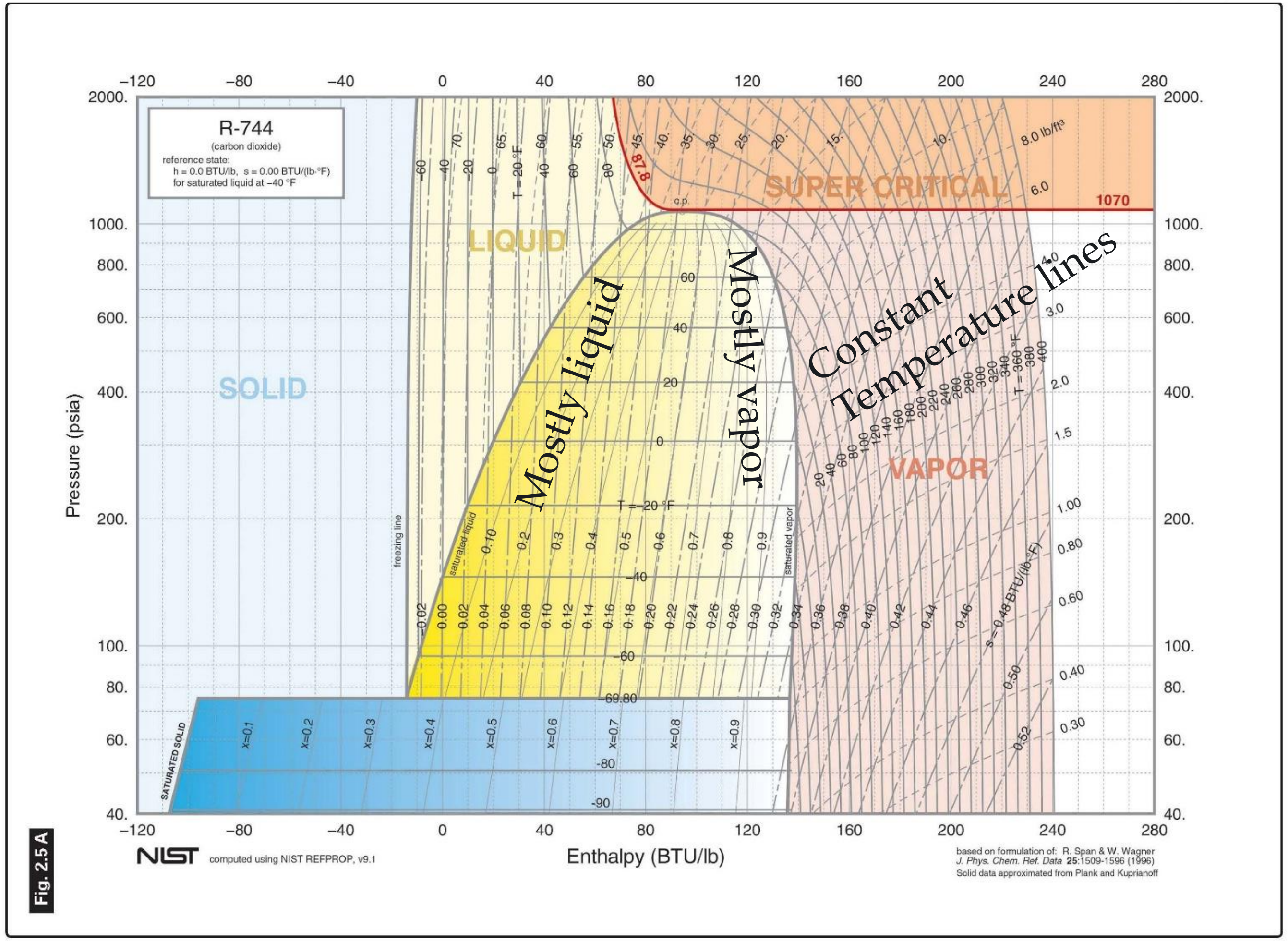
- Info on a PH Diagram
  - Pressure
  - Enthalpy (Energy)
  - Temperature
  - Liquid
  - Vapor
  - % Mix of Liquid and Vapor
- Construction is connecting dots

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

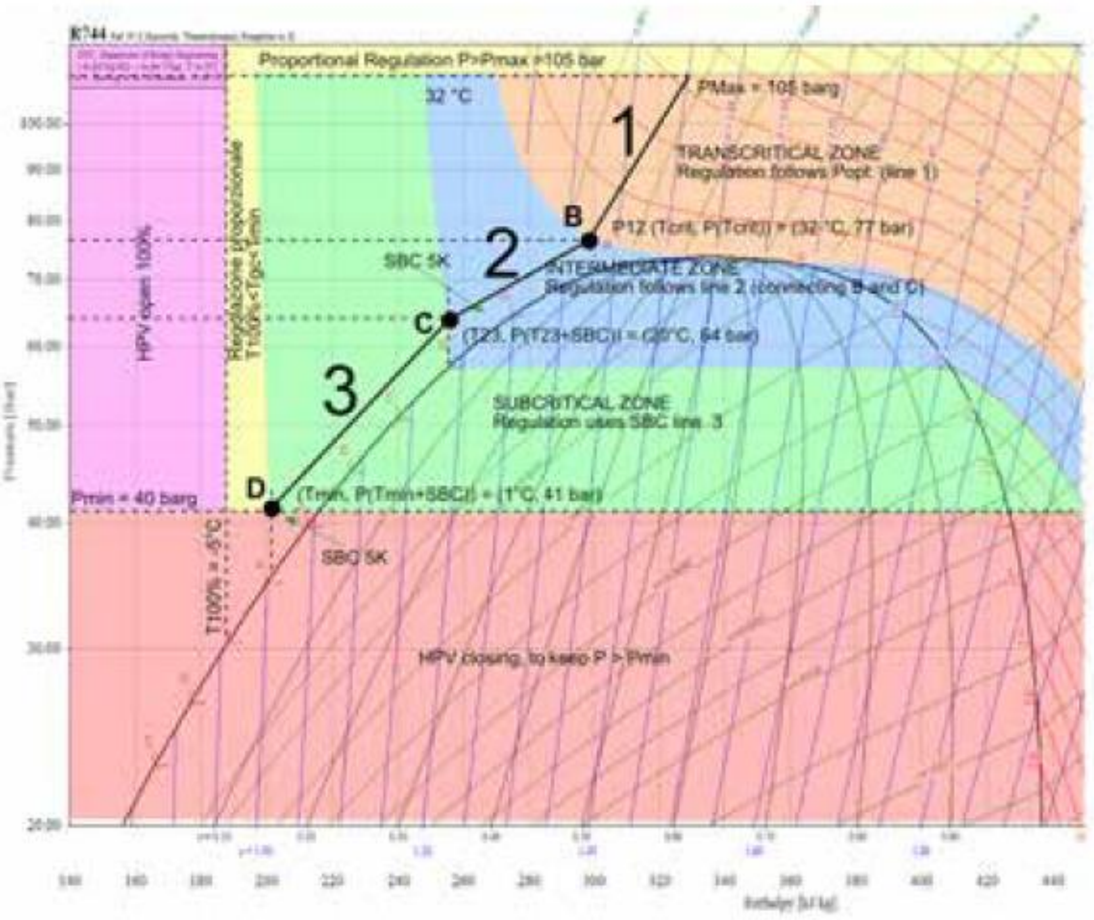
Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

Using a PH Diagram



Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

Optimal Operating Point

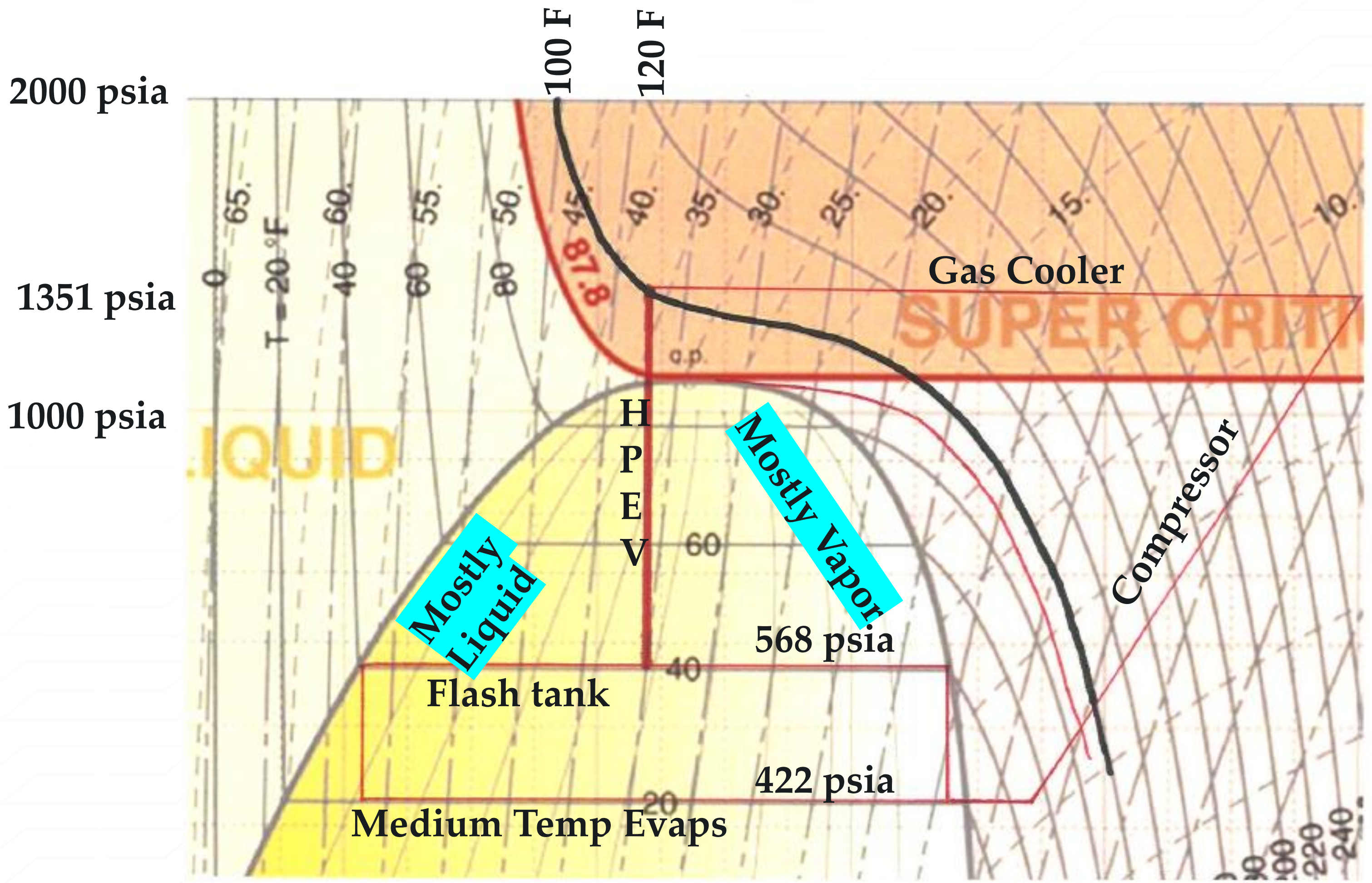


- The optimal transcritical operating point balances increased energy from high discharge pressure with less flash gas.

Carel +4000038EN

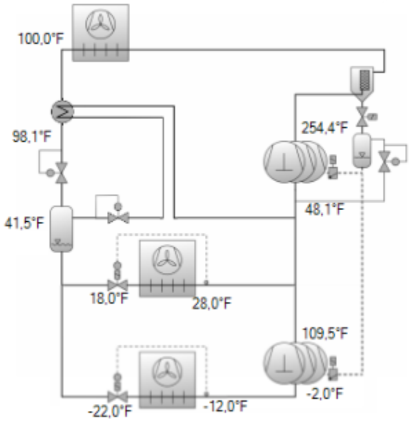
Pressure Enthalpy Diagram and the High-Pressure Expansion Valve

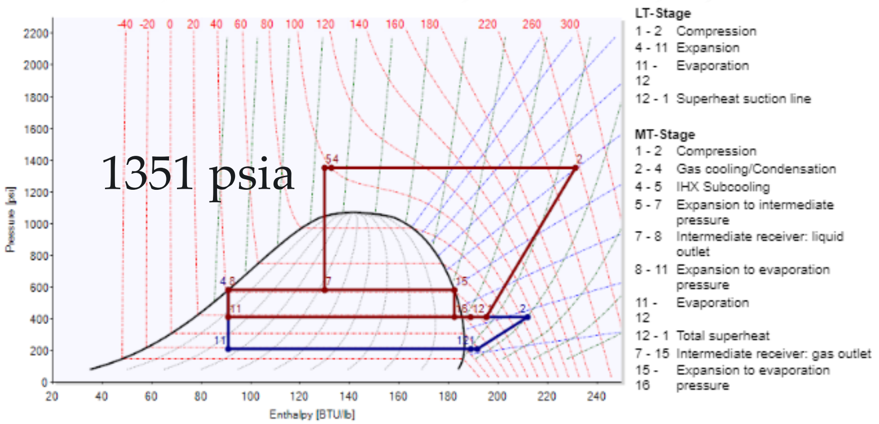
Minimize Flash Gas



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.

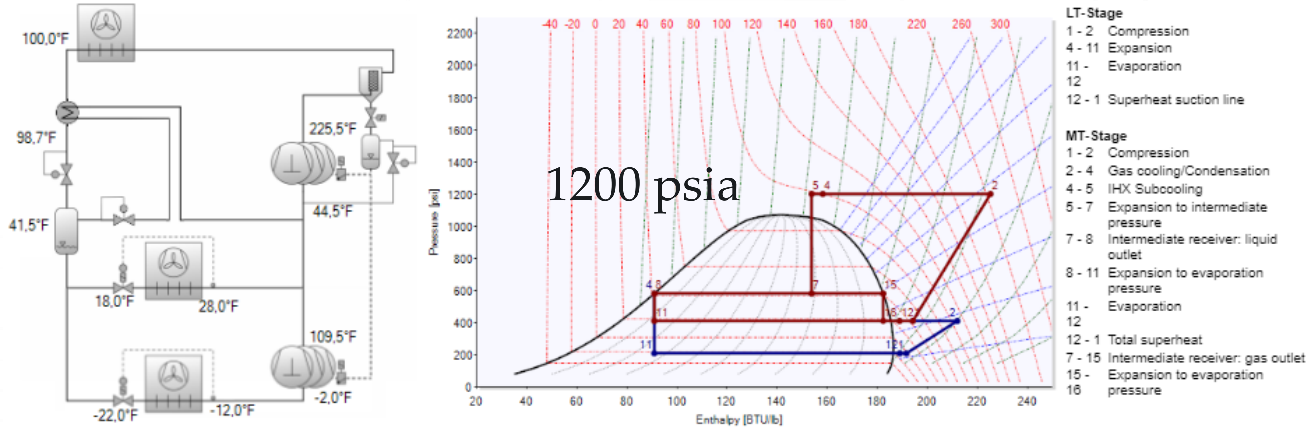
COP/EER Evaporator: 4.72

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	--	--	--

Bitzer Software

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.

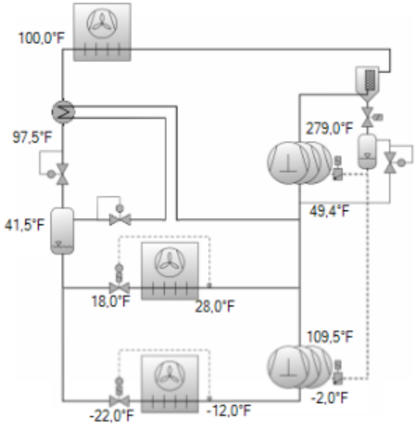
COP/EER Evaporator: 2.95

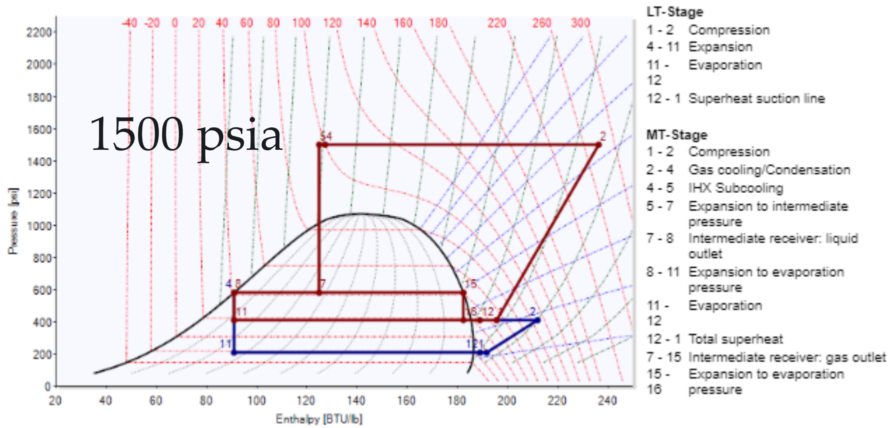
Compressor	LT-Stage	2GSL-3K	2FSL-4K	2FSL-4K
Frequency compressor	--	69.0 Hz	--	--
Evaporator capacity	149.0 kBtu/h	46.5 kBtu/h	51.3 kBtu/h	51.3 kBtu/h
Evaporator mass flow	684 lb/h	--	--	--
Ratio	--	31.2 %	34.4 %	34.4 %
Power input	9.06 kW	2.93 kW	3.06 kW	3.06 kW
Current	16.43 A	5.10 A	5.66 A	5.66 A
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

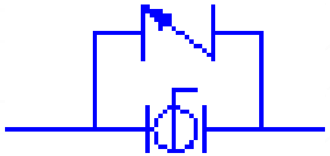
- The optimal transcritical operating point balances increased energy from high discharge pressure with less flash gas.

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

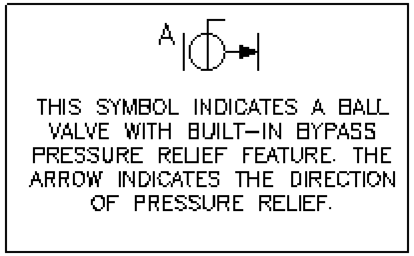
CO_2 System Designs

High Pressure Safety

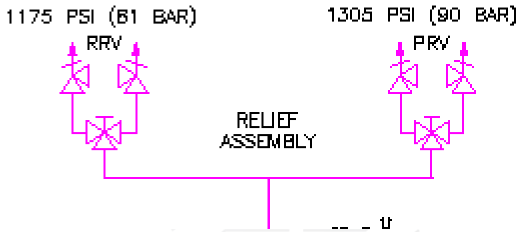
- Back check valves



- Integral back check ball valves



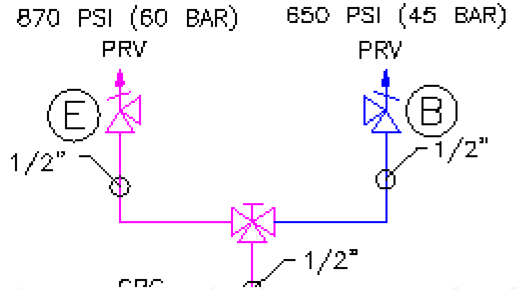
- Regulating relief valves



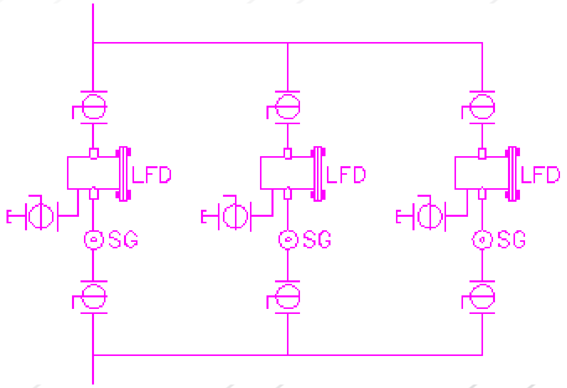
CO_2 System Designs

High Pressure Safety

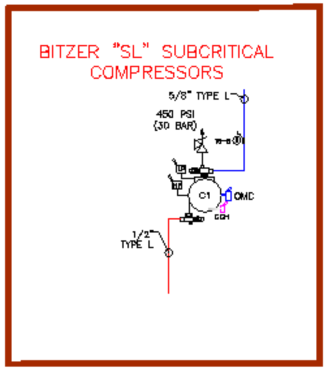
- Relief valves for servicing

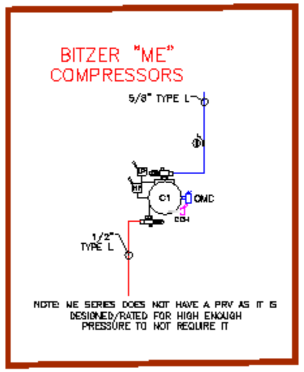


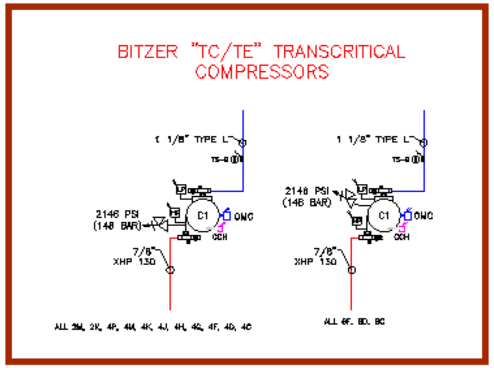
- Administrative controlled component isolation

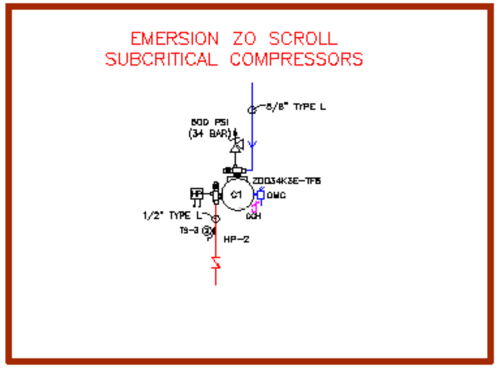


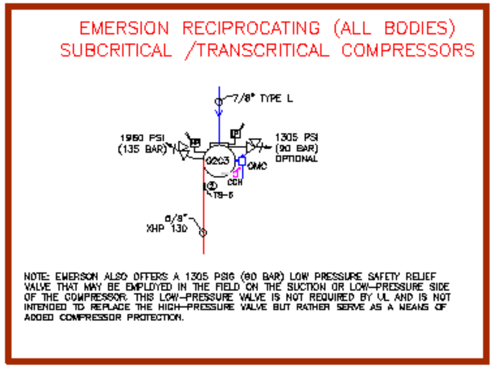
Compressor Safety Valves

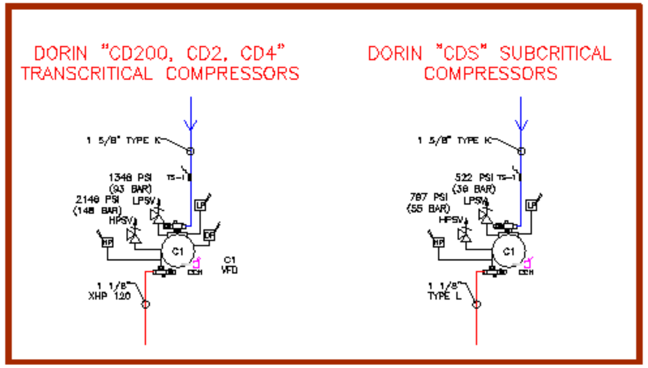


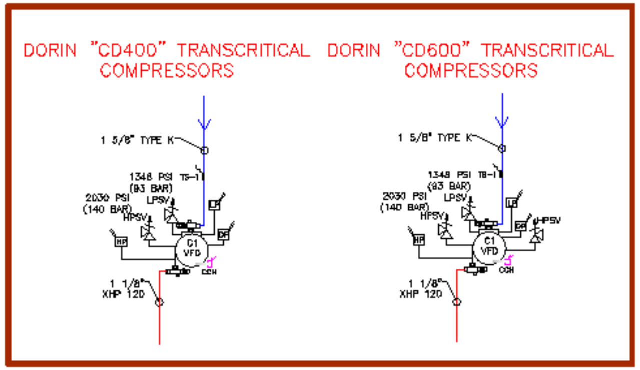






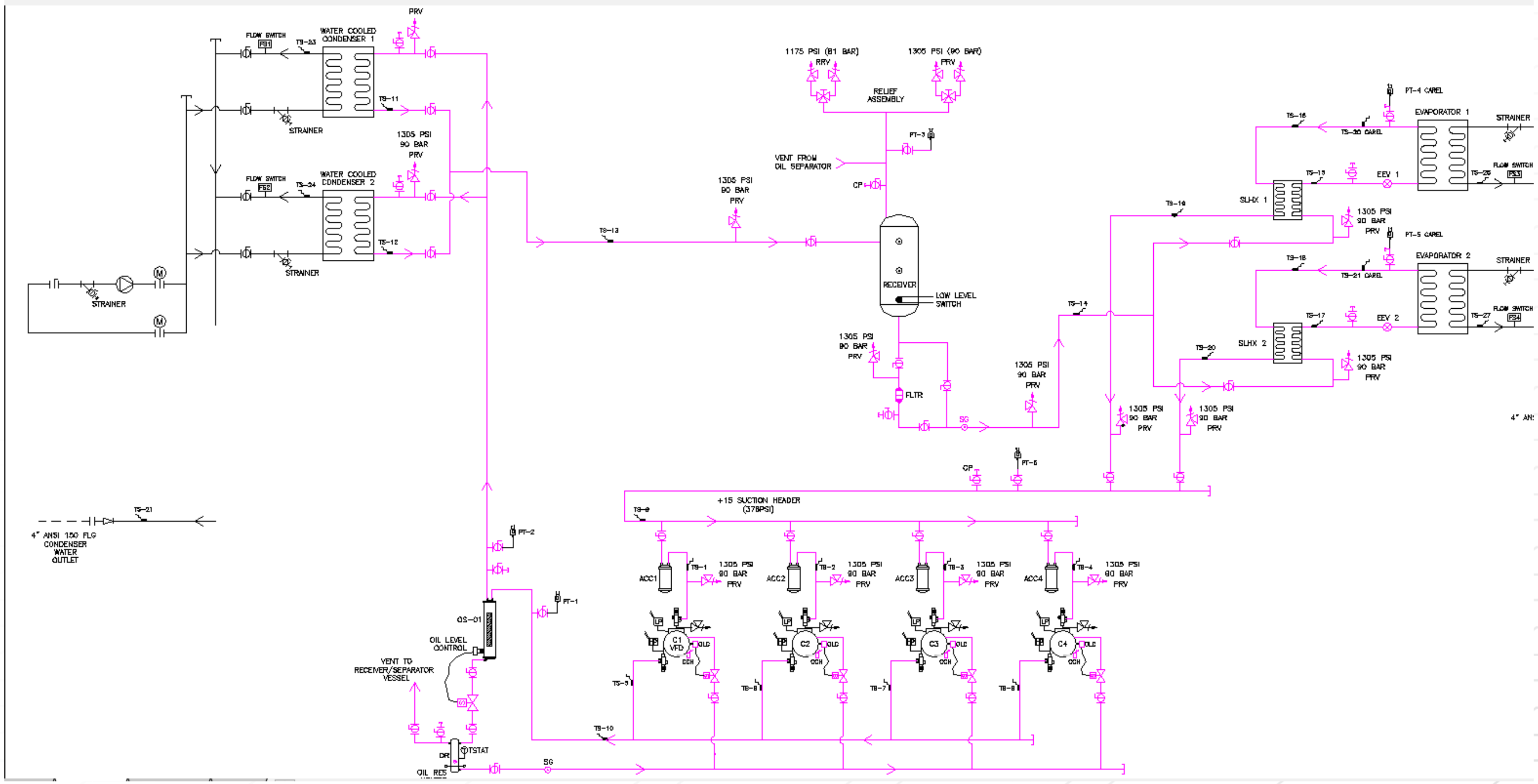






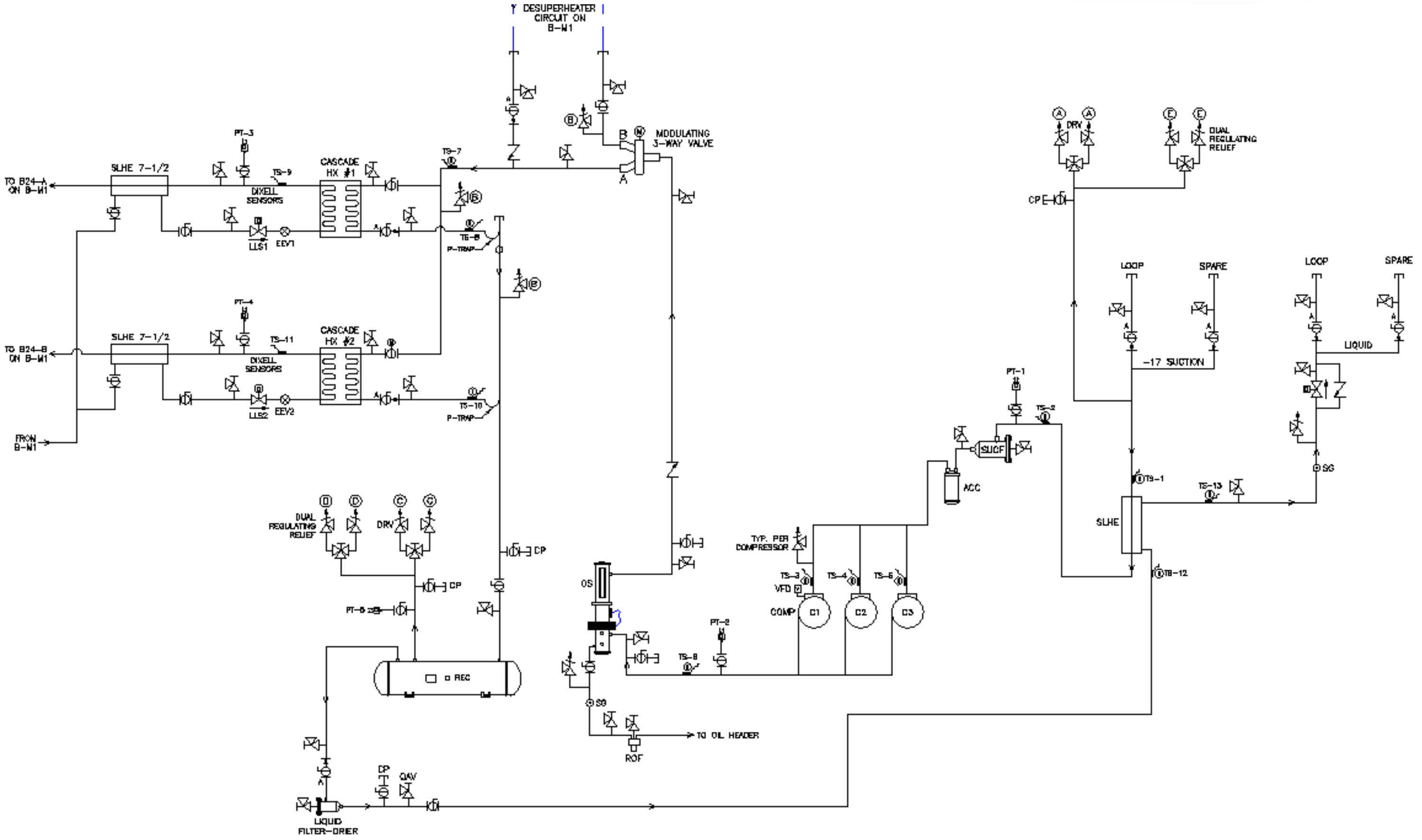
CO_2 System Designs

Subcritical – Water-Cooled



CO_2 System Designs

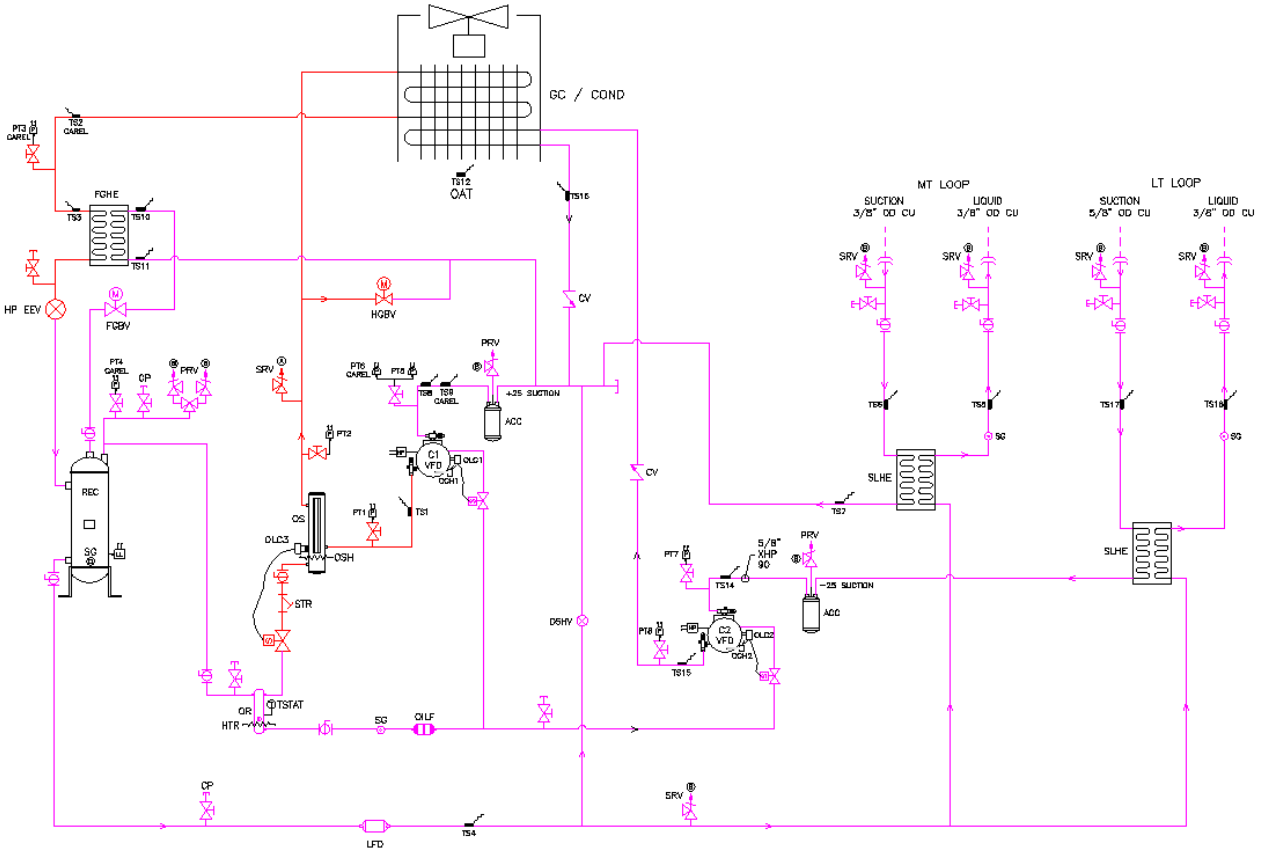
Subcritical – Cascade



CO_2 System Designs

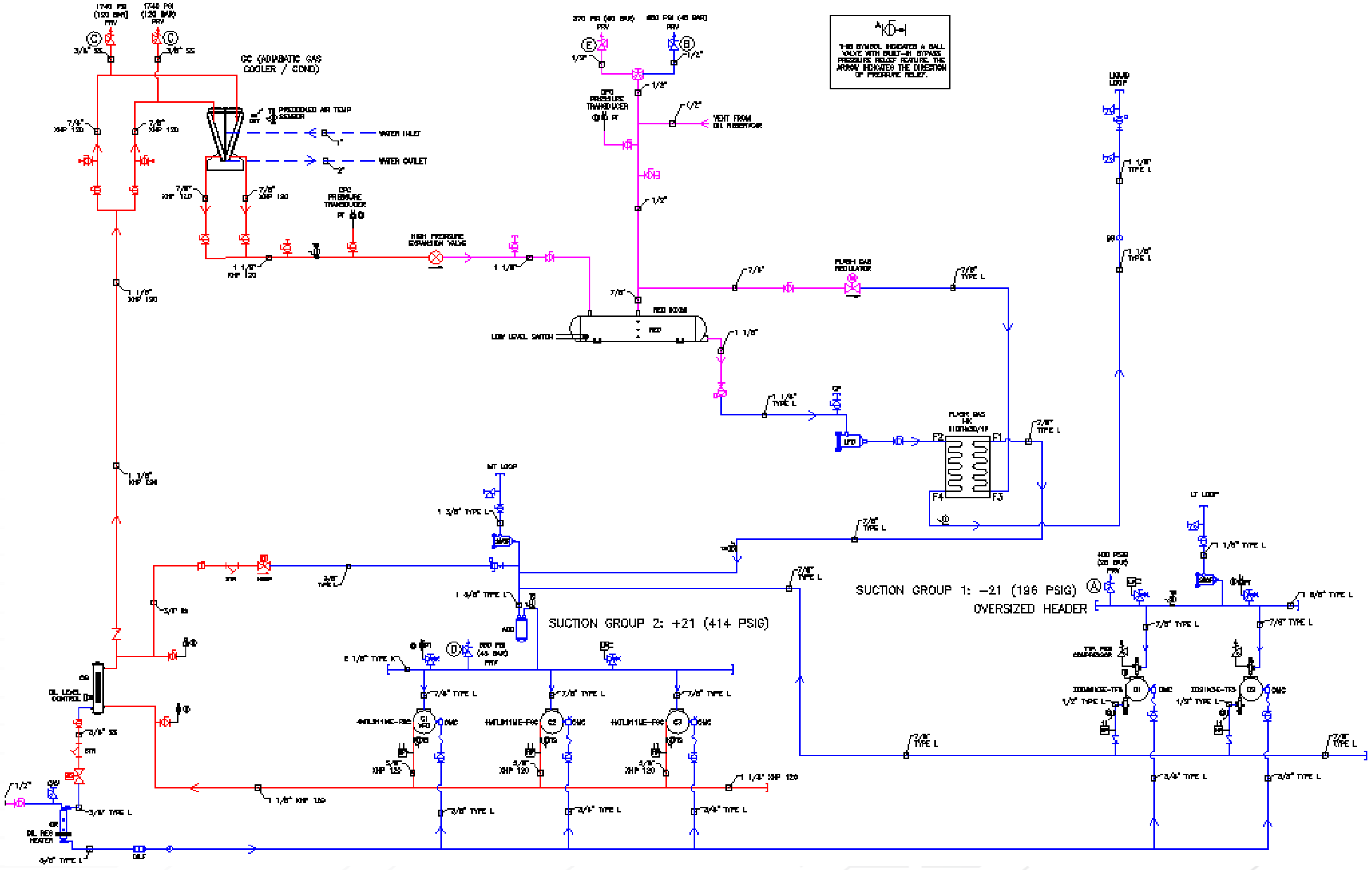
ZERO ZONE®

Transcritical – Desuperheater



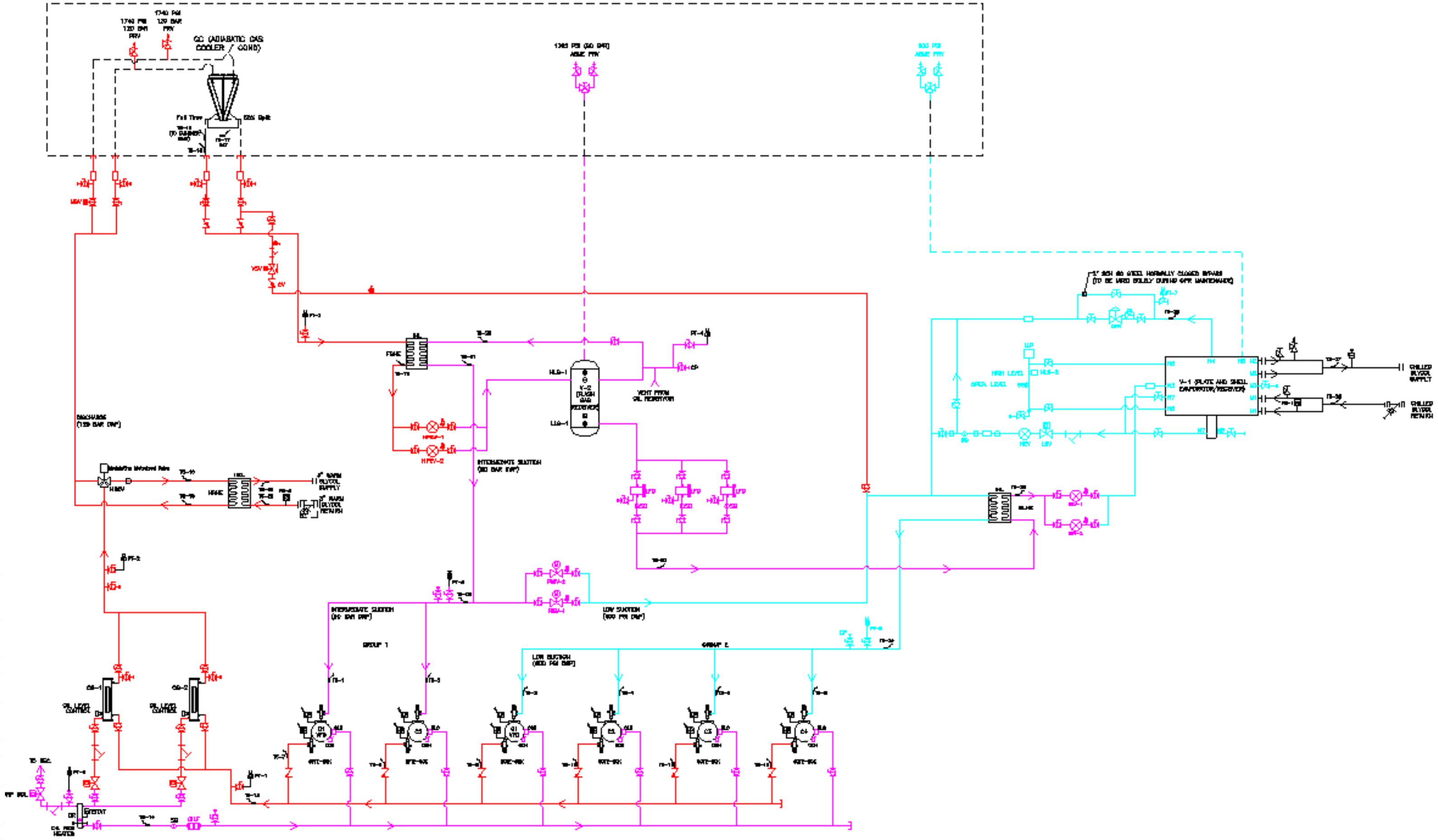
CO_2 System Designs

Transcritical – No Desuperheater



CO_2 System Designs

Transcritical – Parallel Compression



That's All Folks

Thank you for attending

Questions?

Share Your Feedback!

To receive an electronic training certificate:

1. Scan or visit nasrc.org/session-surveys
2. Provide your name and email at the end of the survey

Please Note: *You will not receive a certificate unless you share your name on the survey form.*

CO_2 Transcritical Systems: Focus on High Pressure Expansion Valve Operation

Bruce R. Hierlmeier P.E.

Zero Zone, Inc.

NORTH AMERICAN Sustainable Refrigeration Council