Natural Refrigerant Training Summit

Building a Sustainable Workforce

CO2 Transcritical Systems and Controls

Ernie Lynch

Danfoss

NORTH AMERICAN Sustainable Refrigeration Council

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?

CO_2	C_3H_8	NH_3
R744	**R290**	**R717**
Carbon Dioxide	Propane	Ammonia

NORTH AMERICAN
Sustainable Refrigeration Council

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CO_2 Transcritical System Overview

Ernie Lynch – Training Program Manager

Agenda

CO2 Review

AK-PC782B Transcritical Control

Service Tool Software (ST500)

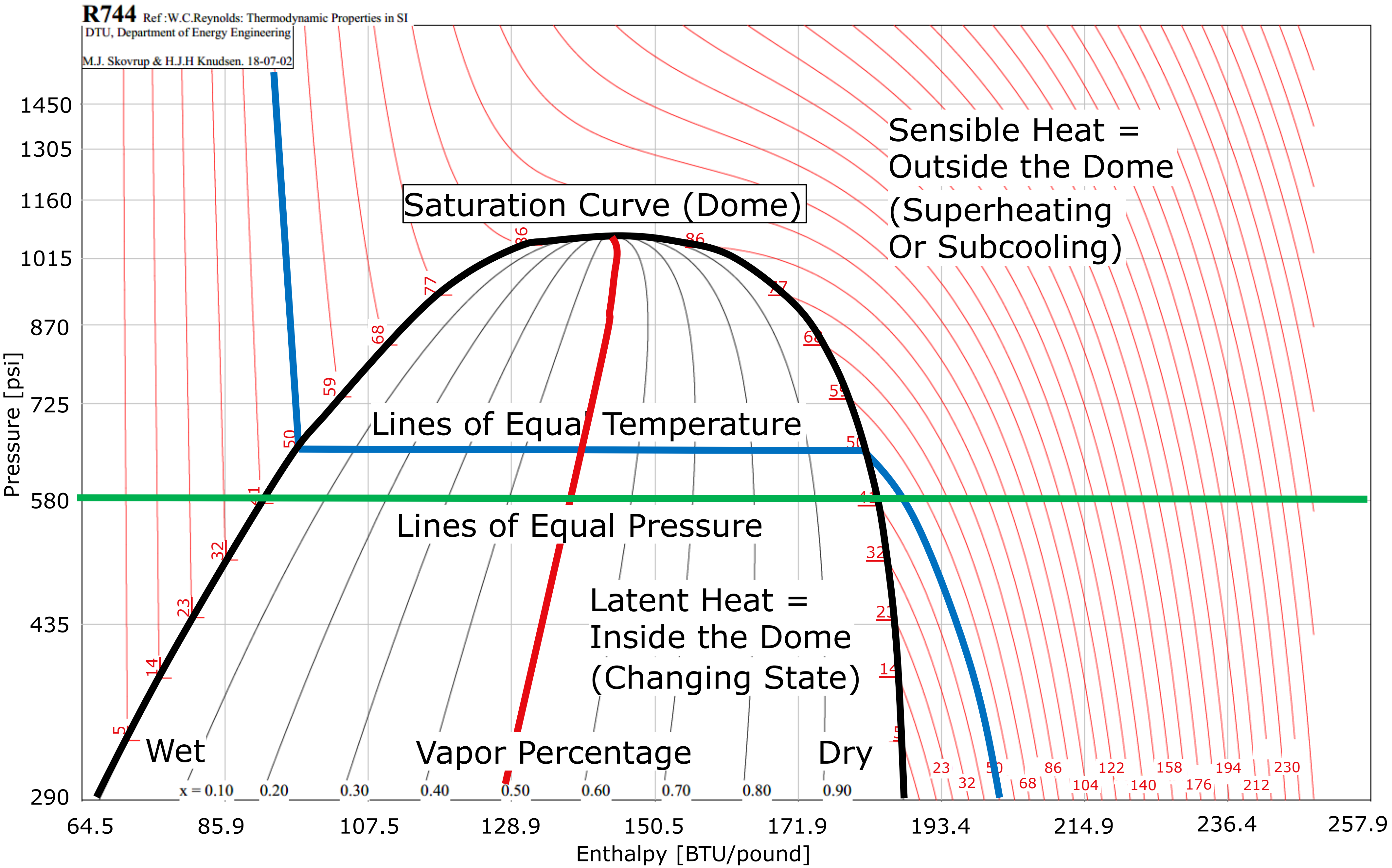
Parallel Compression

High Pressure Ejectors

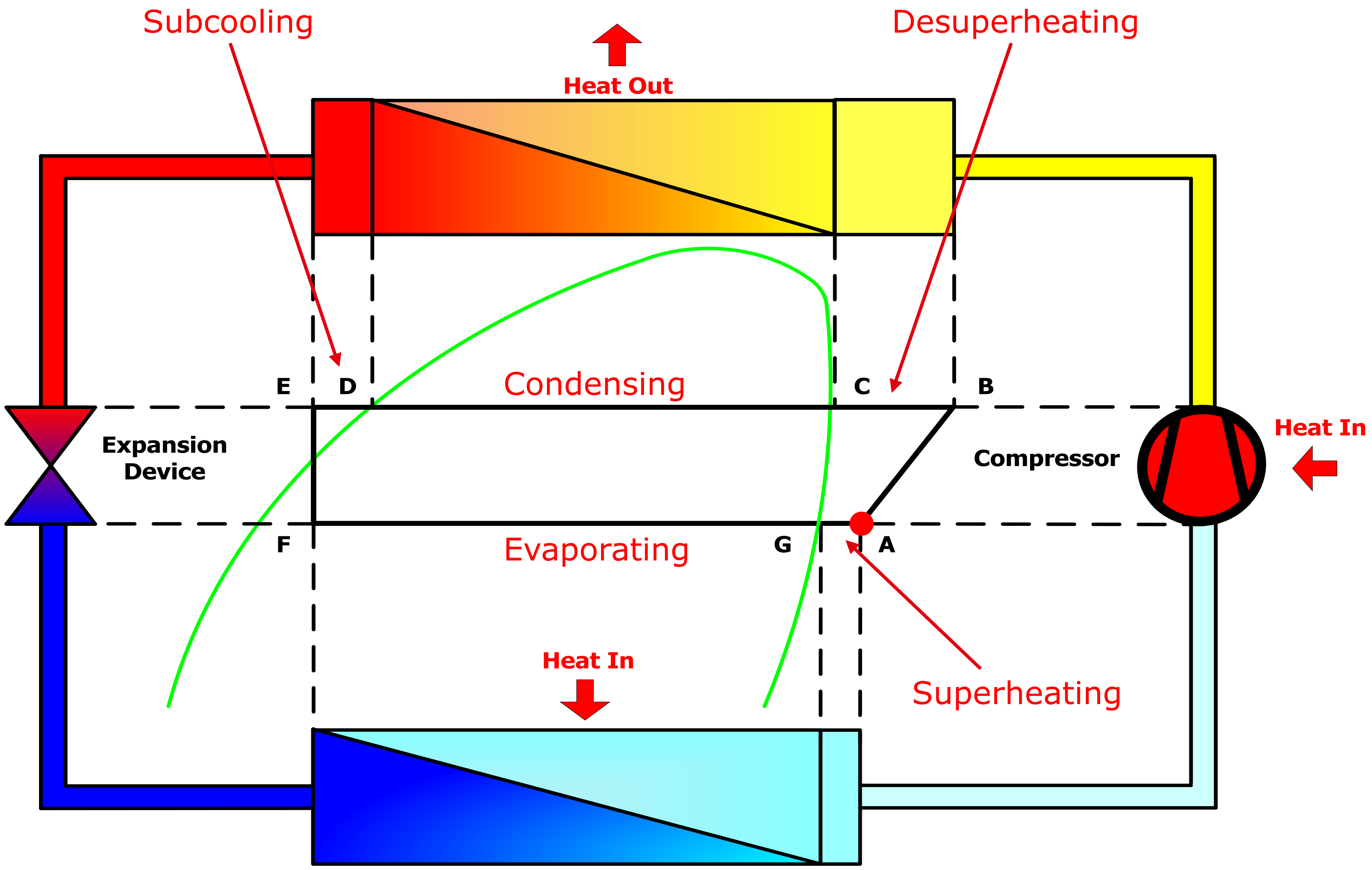
CO_2 Refrigeration Cycle

What is similar to HFC? (Subcritical)

What is different from HFC? (Supercritical)


R744 Ref :W.C.Reynolds: Thermodynamic Properties in SI
DTU, Department of Energy Engineering
M.J. Skovrup & H.J.H Knudsen. 18-07-02
Saturation Curve (Dome)
Sensible Heat = Outside the Dome (Superheating Or Subcooling)
Lines of Equal Temperature
Lines of Equal Pressure
Latent Heat = Inside the Dome (Changing State)
Wet
Vapor Percentage
Dry
Pressure [psi]
1450
1305
1160
1015
870
725
580
435
290
Enthalpy [BTU/pound]
64.5
85.9
107.5
128.9
150.5
171.9
193.4
214.9
236.4
257.9
x = 0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
23
32
50
68
86
104
122
140
158
176
194
212
230

Basic Refrigeration Cycle – R448a



Point A = Low Temp, Low PSI, SH Vapor

Point B = Hi PSI, Hi Temp, SH Vapor

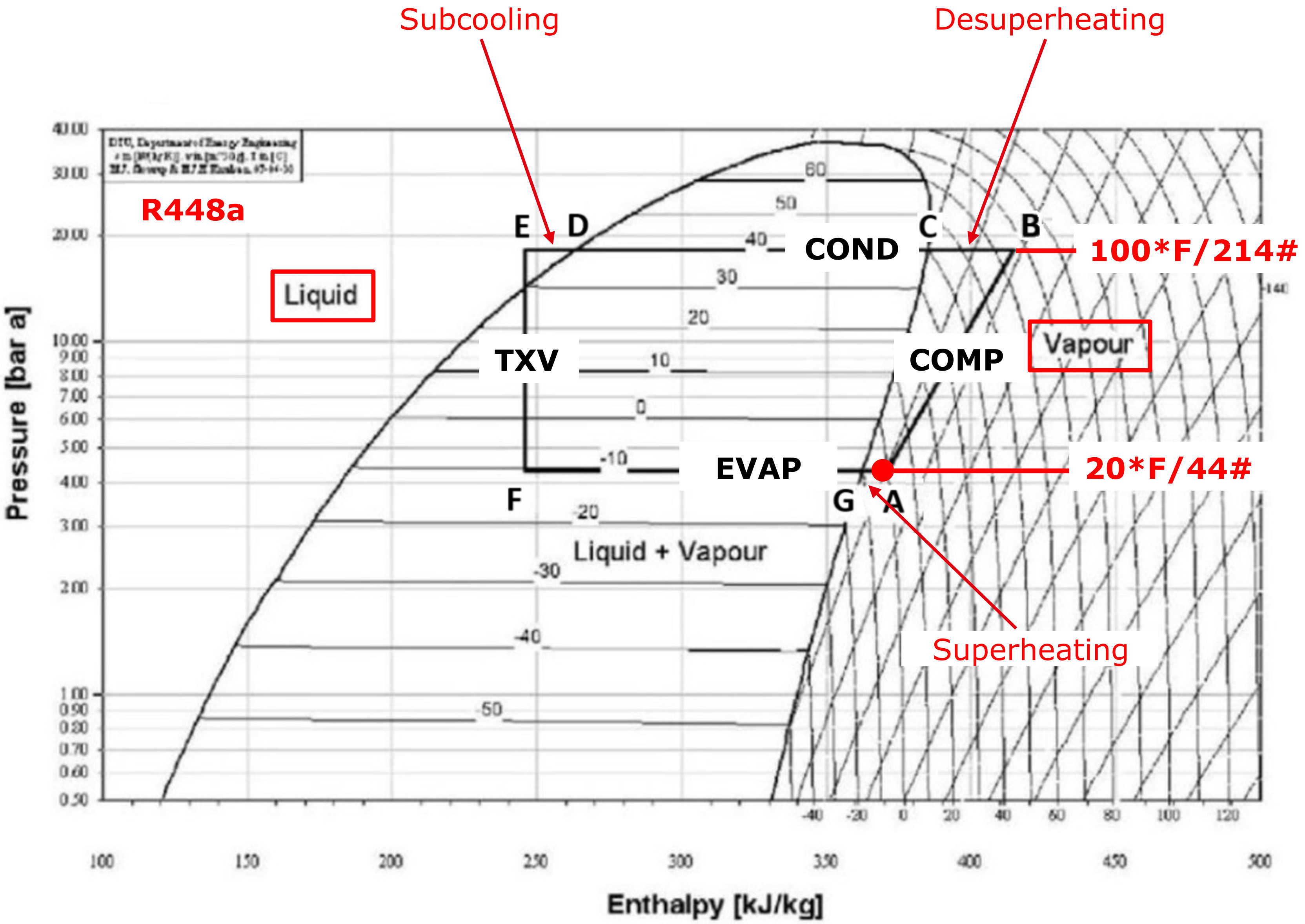
Point C = Hi PSI, Hi Temp Saturated Vapor

Point D = Hi PSI, Hi Temp, Saturated Liquid

Point E = Hi PSI, Hi Temp, SC Liquid

Point F = Low Temp, Low PSI, Liq/Vapor Mix

Point G = Low Temp, Low PSI, Saturated Vapor



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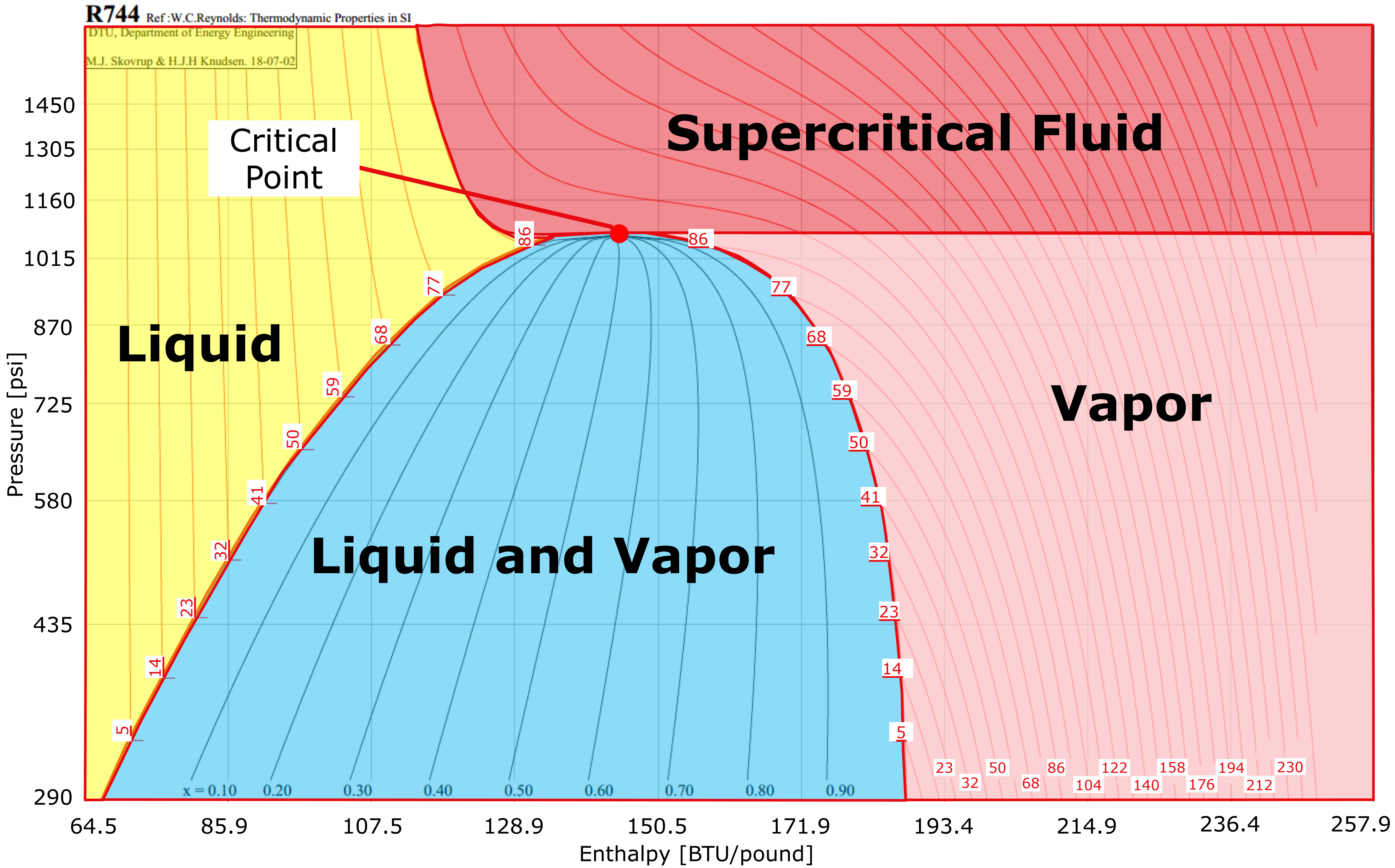
R744 Ref :W.C.Reynolds: Thermodynamic Properties in SI
DTU, Department of Energy Engineering
M.J. Skovrup & H.J.H Knudsen. 18-07-02
Critical Point
Supercritical Fluid
Liquid
Vapor
Liquid and Vapor
Pressure [psi]
1450
1305
1160
1015
870
725
580
435
290
Enthalpy [BTU/pound]
64.5
85.9
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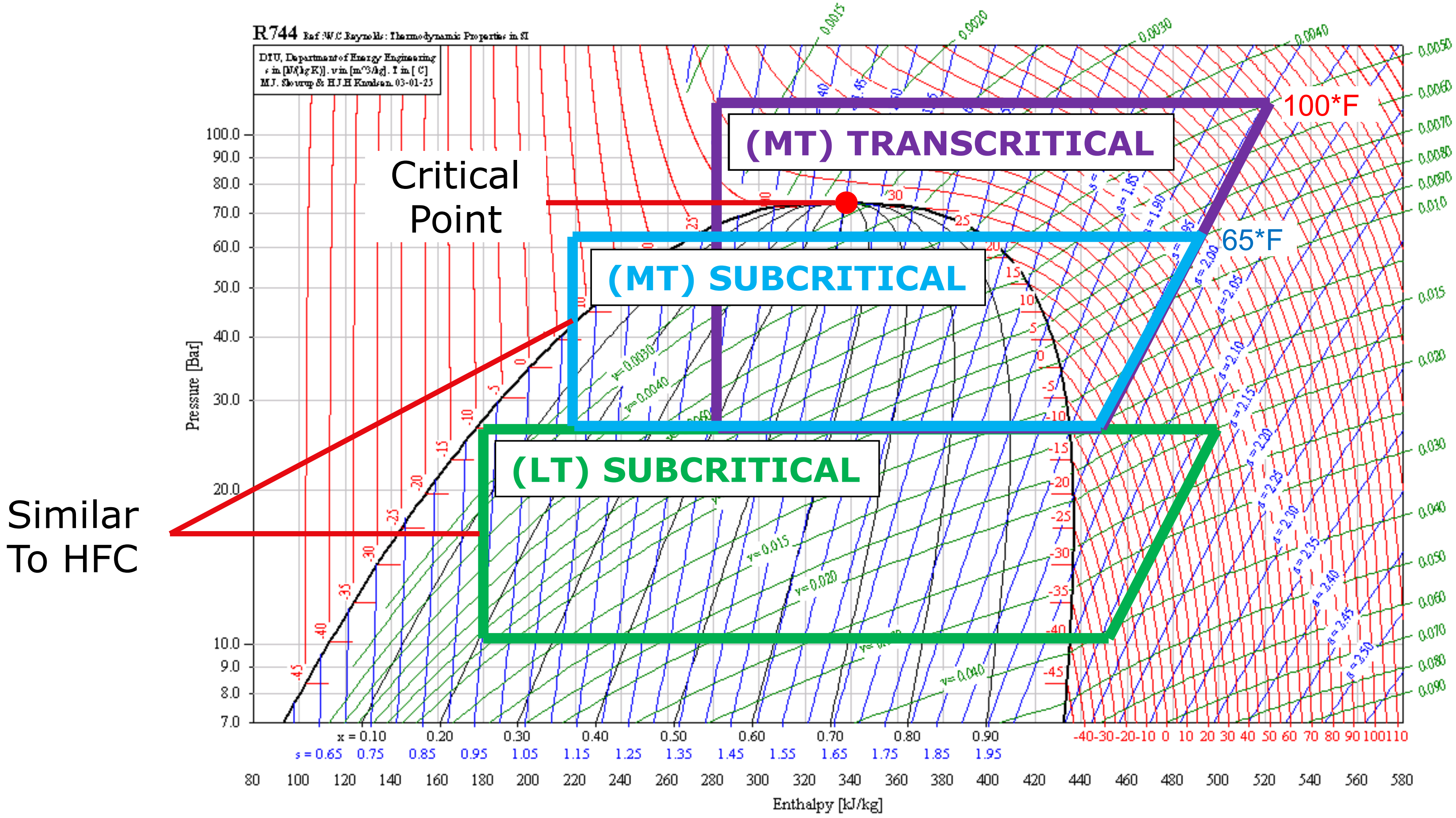
0.80
0.90
5
14
23
32
41
50
59
68
77
86
104
122
140
158
176
194
212
230

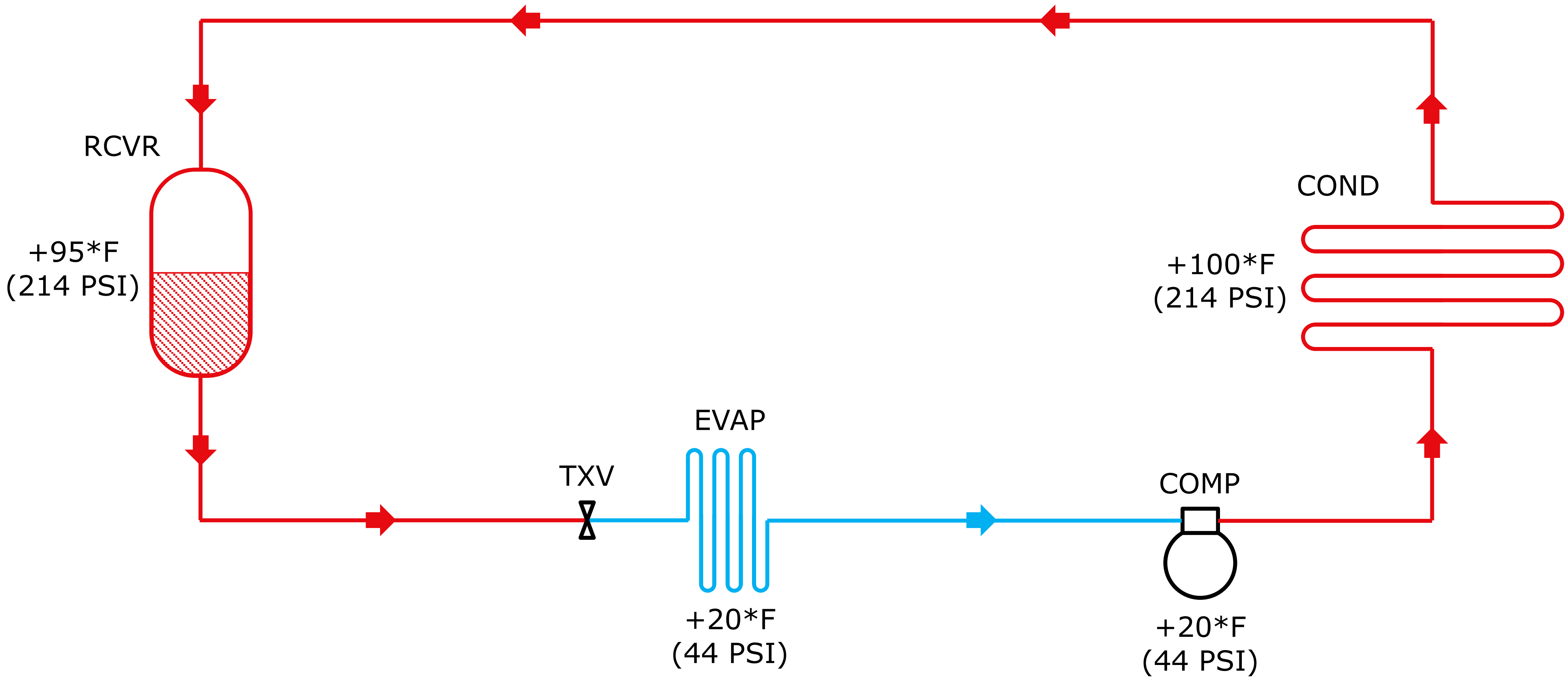
Transcritical & Subcritical Cycles



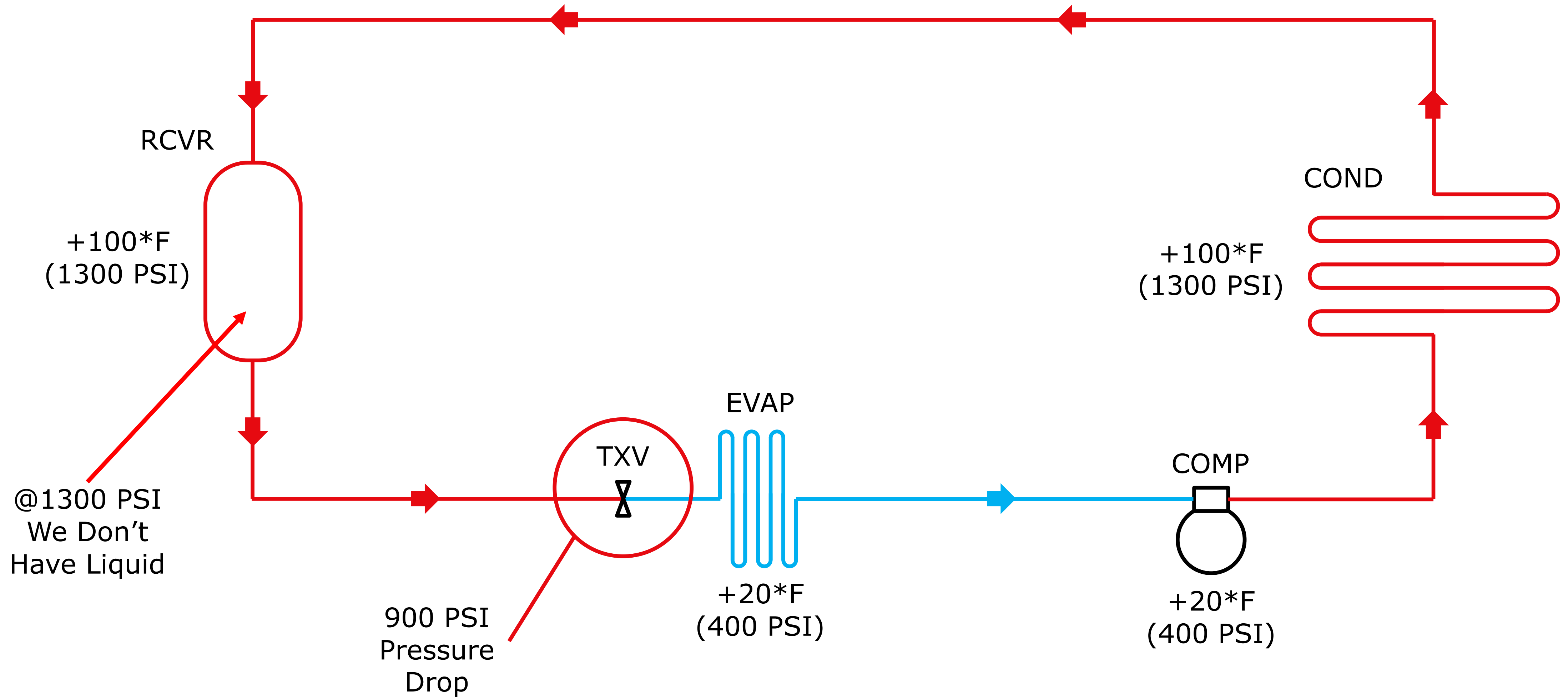
100*F Ambient
65*F Ambient
The High Side of the system **Transitions** between Supercritical and Subcritical as gas cooler outlet temp goes above or below the critical point, hence the term **Transcritical**

Supercritical operation is commonly referred to as **Transcritical Mode**

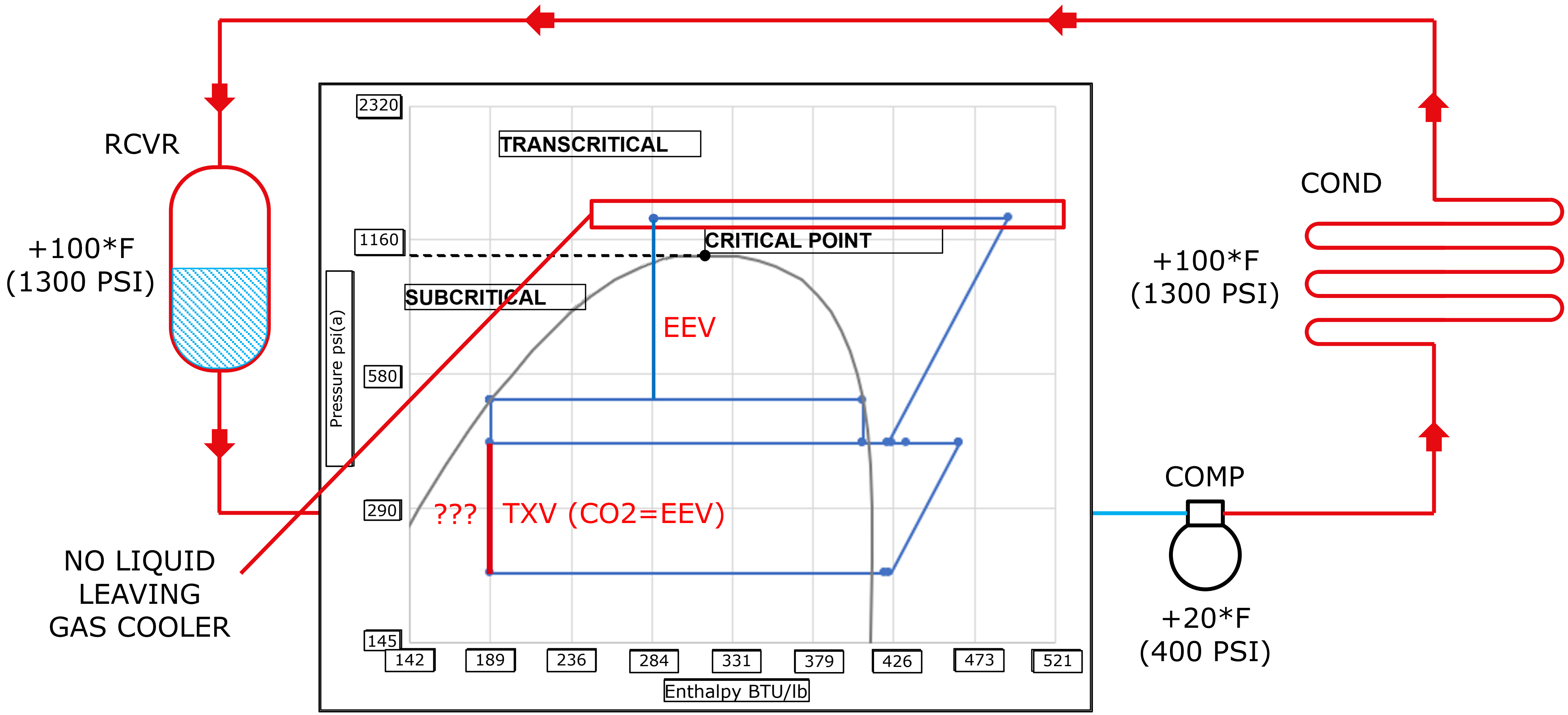
R448A Refrigeration Cycle



R448A Refrigeration Cycle with R744 Pressures

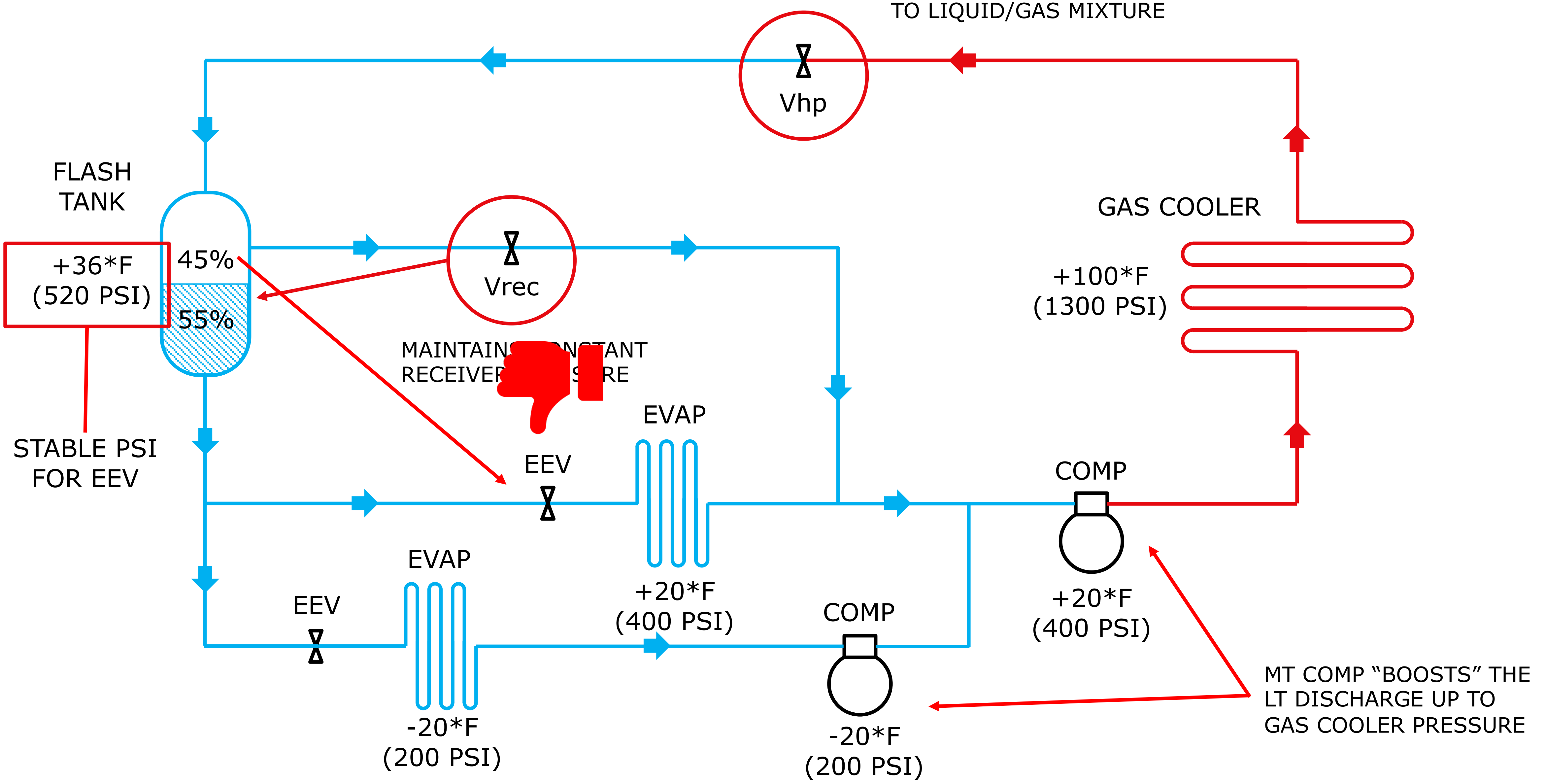


R448A Refrigeration Cycle with R744 Pressures

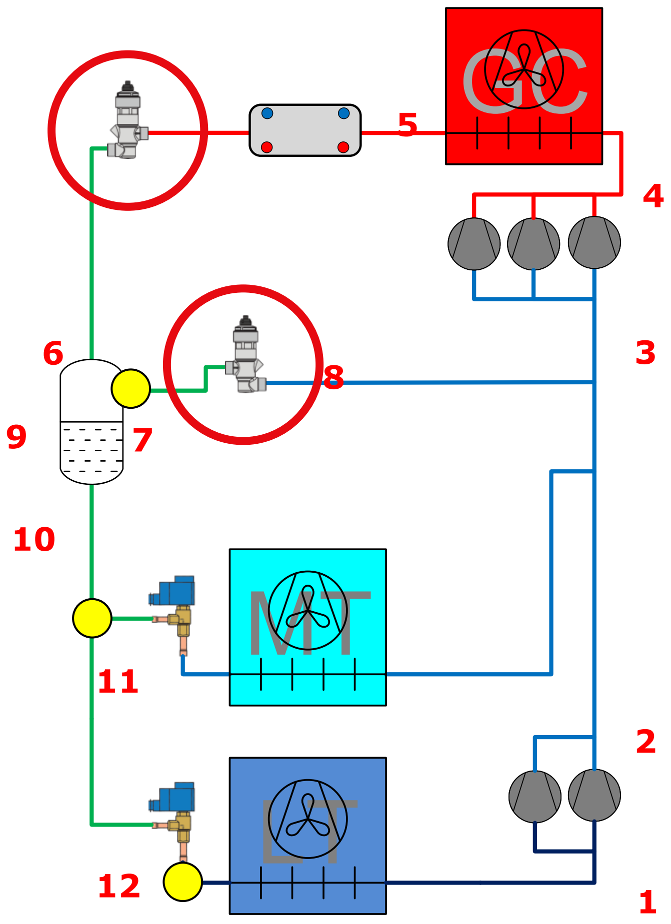


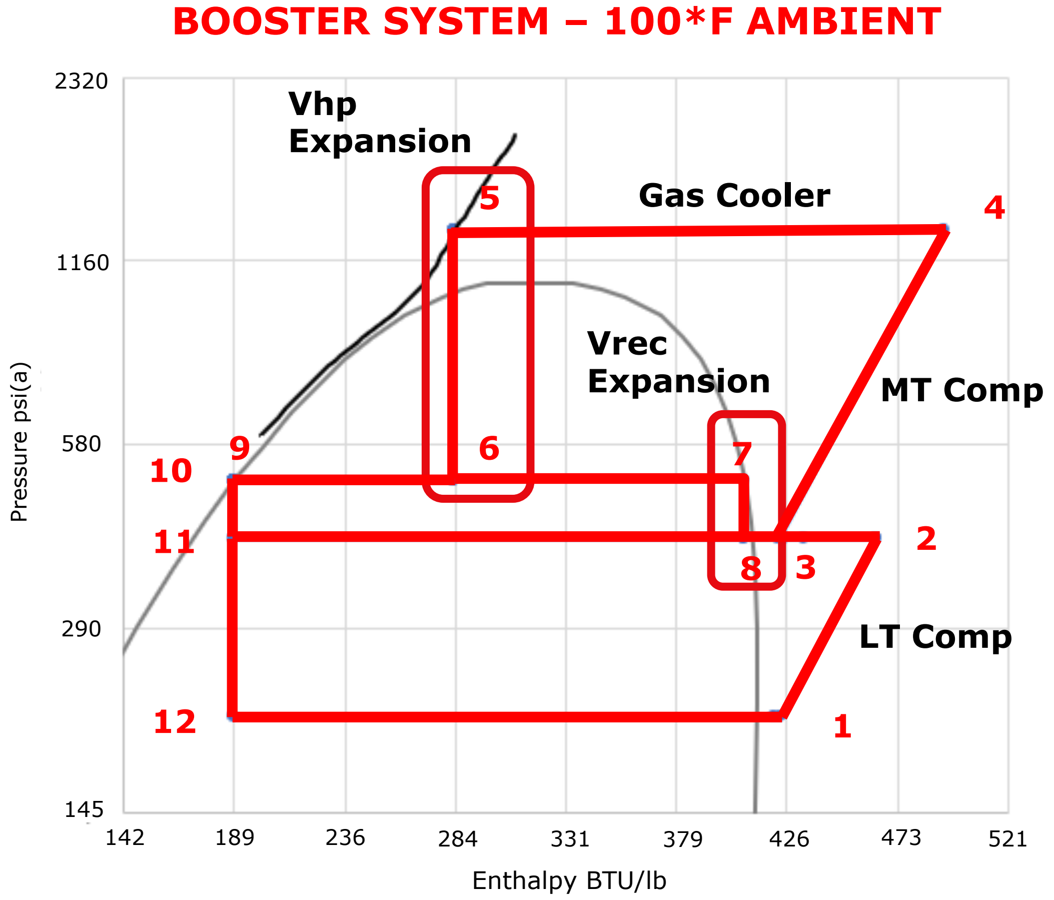
R744 Refrigeration Cycle

THE PRESSURE DROP ACROSS Vhp
IS HOW WE CHANGE FROM SC FLUID
TO LIQUID/GAS MIXTURE

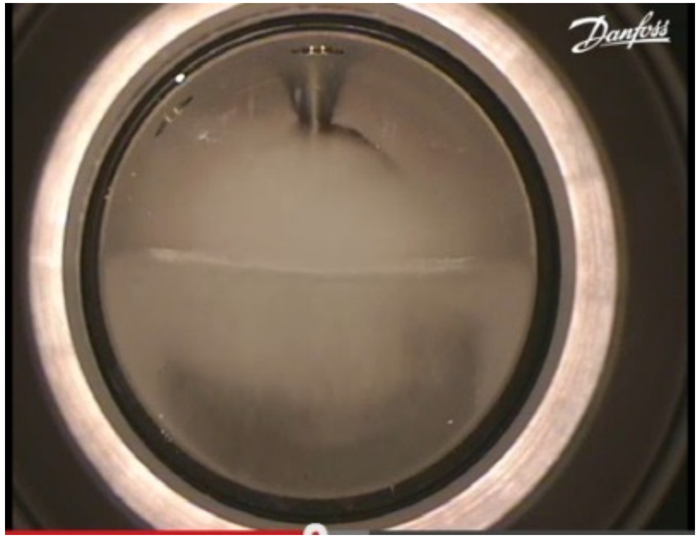


CO_2 Transcritical Booster system





Transcritical CO2 in Action



Phase Change Video

CO2 Video
1bar = 14.5psia
10bar = 145.5psia
100bar = 1450psia
140barg = 2044.5psig
-40C = -40F
0C = 32F
40C = 104F
20’C = 68’F 57.2bar-a = 829.6psia
Triple Point
5.2bar-a = 75.4psia
-56.6C = -69.88F
-78.4’C = -109.1’F @ 0psig
Critical Point
73.6bar-a = 1067.4psia
31’C = 88’F
Density @ Critical Point
468 kg/m3 = 30lb/ft3

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Questions?

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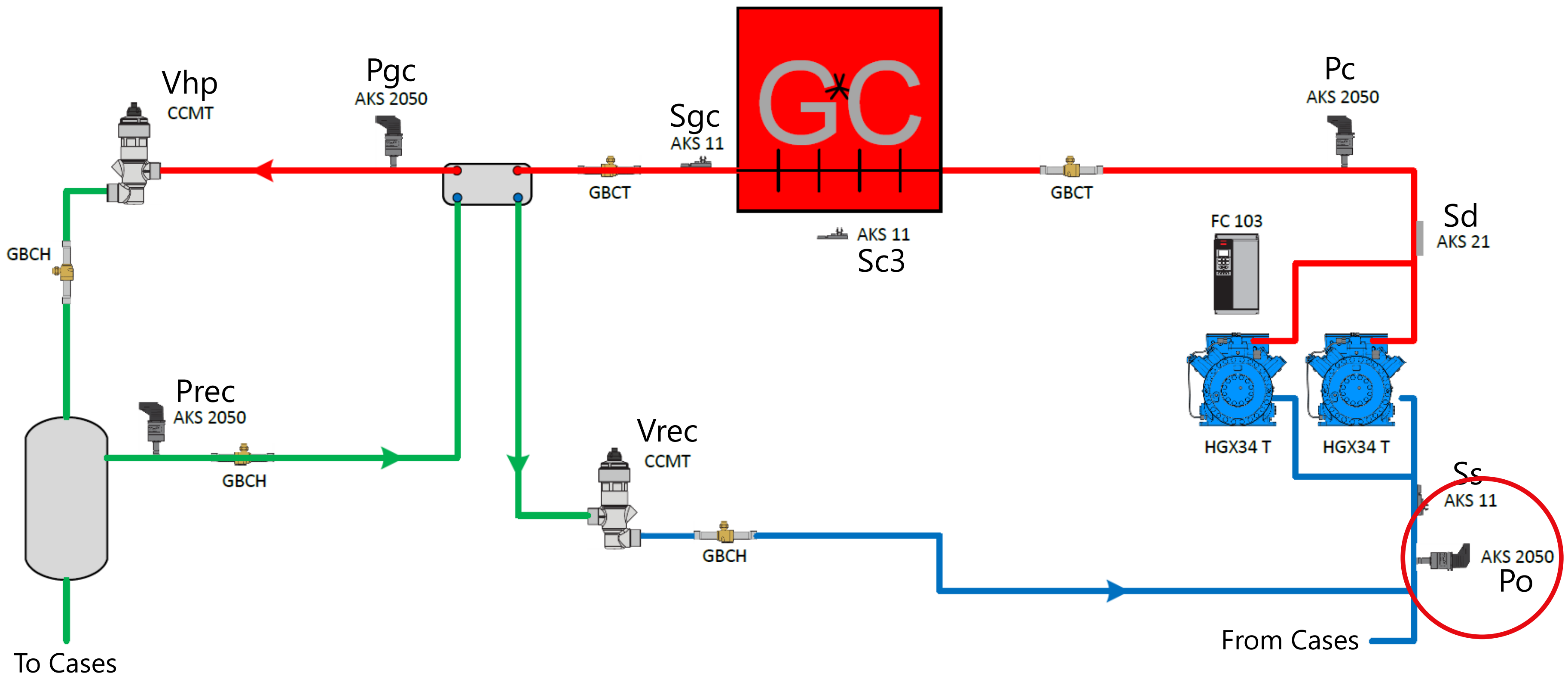
AK-PC 782 Control Basics

- Sensor Abbreviations
- Suction Groups
- Gas Cooler
- High Pressure Valve (Vhp)
- Receiver Bypass Valve (Vrec)

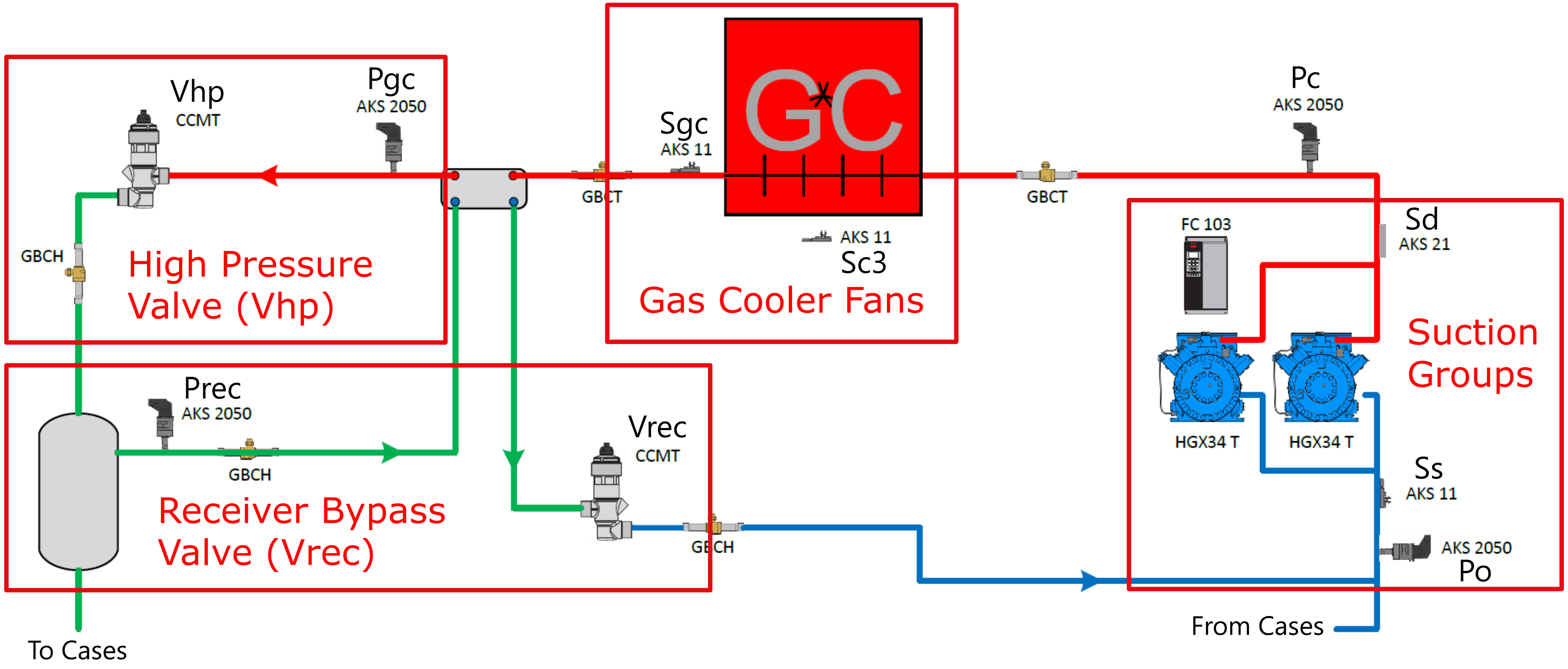
Danfoss Sensor and Device Abbreviations



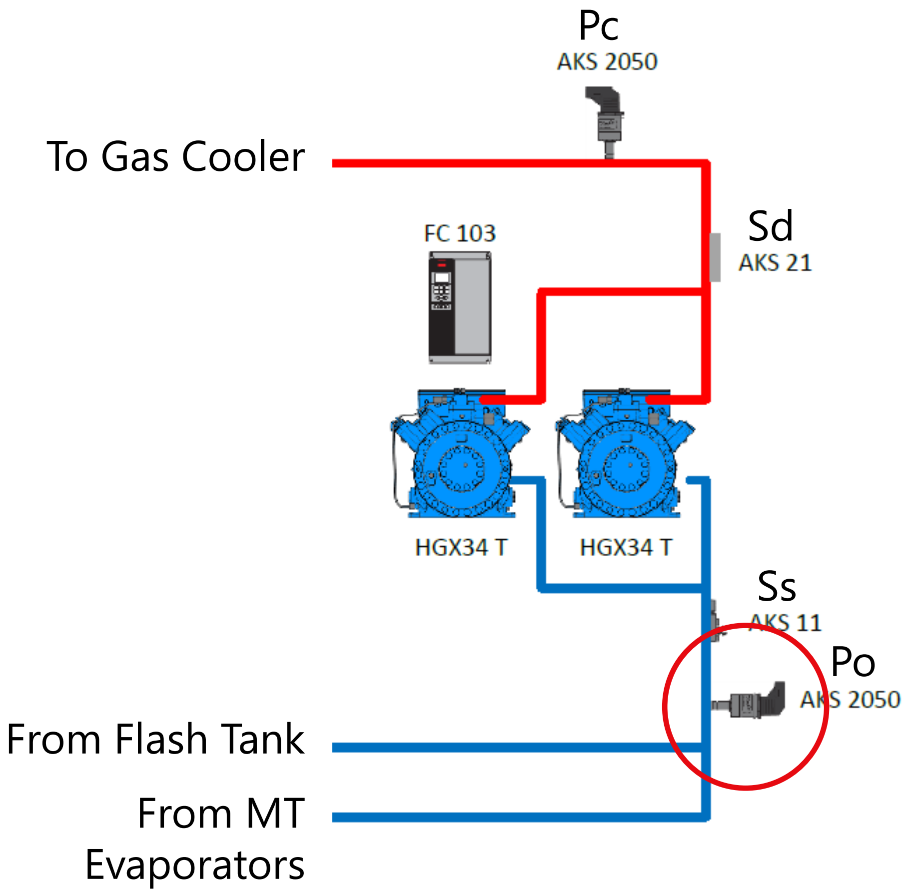
Po = Suction Pressure
Ss = Suction Temperature
Sd = Discharge Temperature
Pc = Condensing Pressure
Sc3 = Ambient Temperature

Sgc = Gas Cooler Outlet Temperature
Pgc = Gas Cooler Outlet Pressure
Vhp = High Pressure Valve
Prec = Receiver Pressure
Vrec = Receiver Gas Bypass Valve

Big Red Mode 1 - CO2 MT Transcritical System



AK-PC782A – Suction Group Control



Sensors
- Po = Evaporator Outlet Pressure
- Ss = Suction Line Temperature
- Sd = Discharge Temperature
- Pc = Discharge Pressure

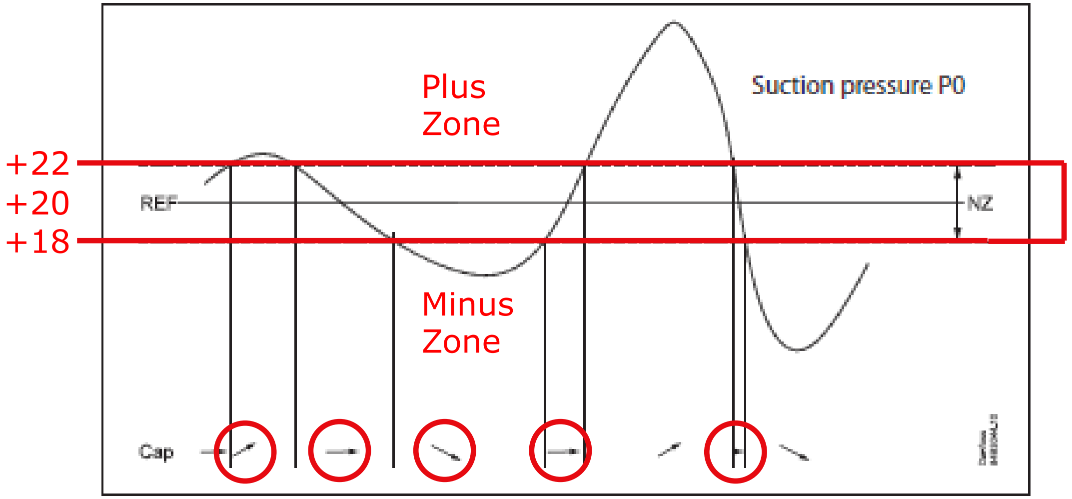
Devices
- Compressors = Relay Outputs
- Inverter = Analog Output

Key Set Points
- To setpoint = Calculated temperature target
- Neutral Zone = Limits above/below set point prior to adding/reducing capacity

"To" represents the evaporator outlet pressure
converted to a temperature.

The user defines the desired evaporator temperature as the set point.

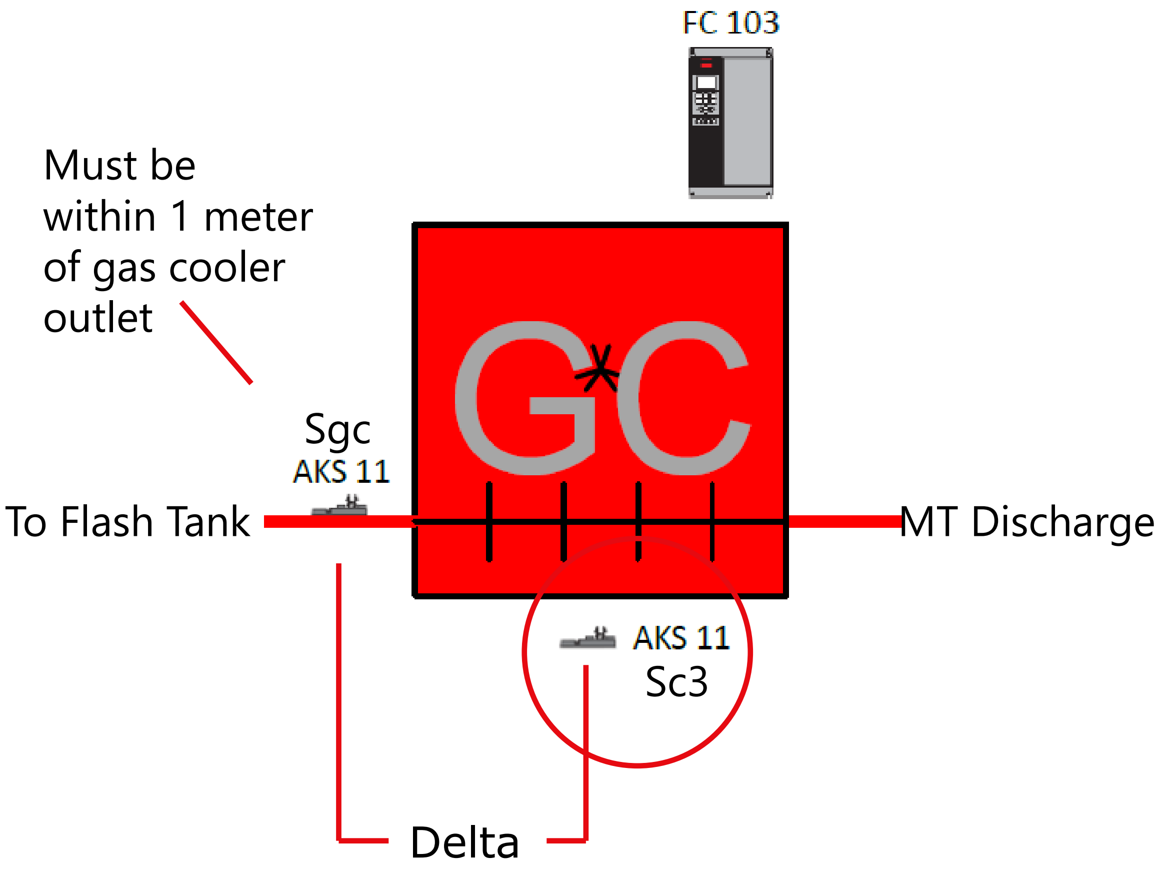
AK-PC782A – Suction Group Neutral Zone



*Example: Set point of +20*F, NZ set to 4*F

- When the pressure is higher than the “reference + a half neutral zone”, cut-in of the next compressor (arrow up) is permitted.
- When the pressure is lower than the “reference - a half neutral zone”, cut-out of a compressor (arrow down) is permitted.
- When the pressure is within the neutral zone, the process will continue with the currently activated compressors. The VFD ramps to keep the pressure at set point.

AK-PC782A – Gas Cooler Fan Control



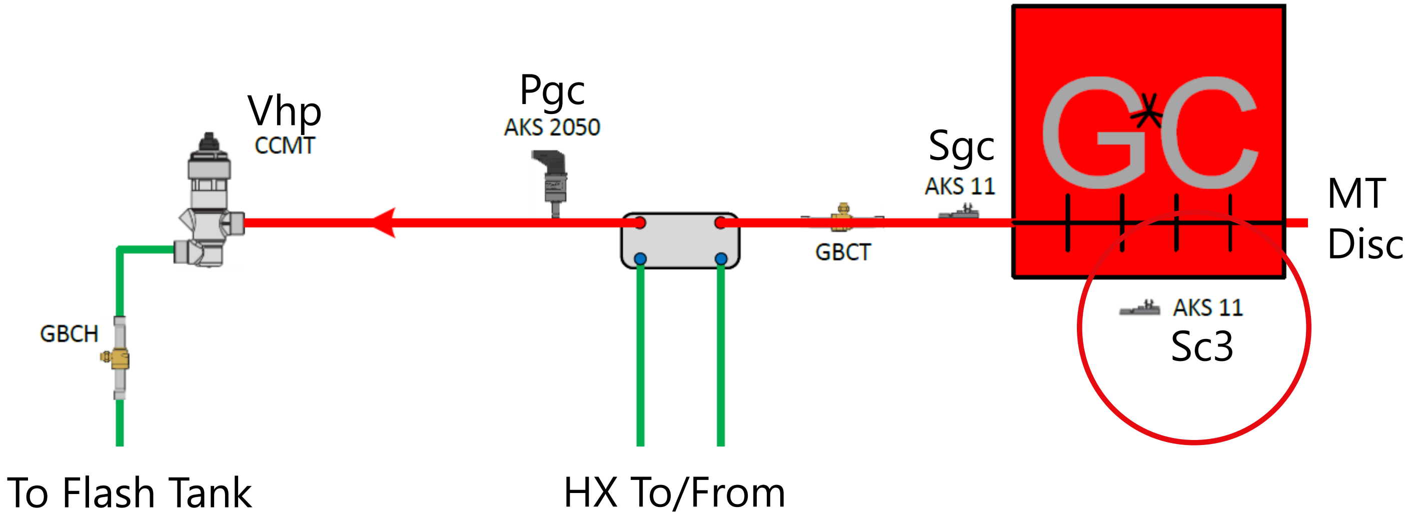
Sensors
- Sc3 = Ambient Temperature
- Sgc = Gas Cooler Outlet Temperature

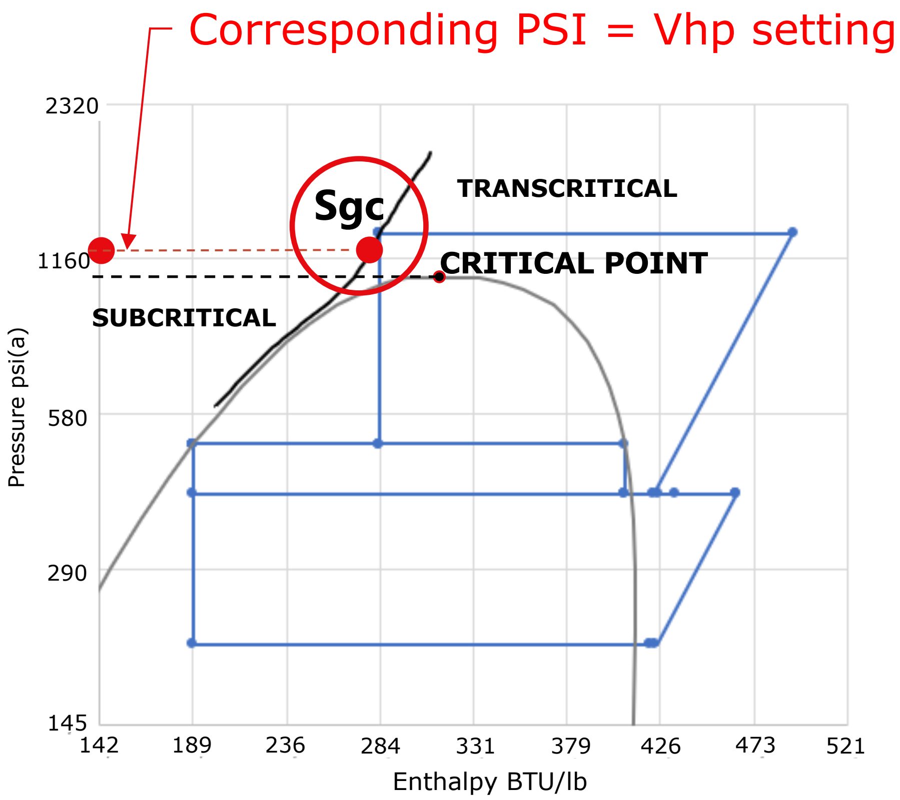
Devices
- Inverter/ECM Motors = Analog Output

Key Set Points
- Min. tm = Minimum average temperature difference between Sc3 and Sgc
- Reference Mode = Use Floating so Min. tm follows ambient conditions
- Sgc max reference = Maximum allowed gas cooler outlet temperature (Max float)
- Sgc Absolute Max Sgc = Force fans to 100% (Adjustable)

The pack controller ramps the fans up/down to maintain user-defined temp Delta Min. tm.

AK-PC782A – High Pressure Valve (Vhp)





Sensors

- Sc3 = Ambient Temperature
- Sgc = Gas Cooler Outlet Temperature
- Pgc = Gas Cooler Pressure

Devices

- Vhp = Stepper Valve Output

Key Set Points

- Pgc Min. = Valve Closing (Min Gas Cooler Pressure)
- Pgc Max. = Valve Opening (Max Gas Cooler Pressure)

The pack controller monitors Sc3 to determine Sgc and Pgc locations on Optimal COP line.

Vhp position will be adjusted to keep Sgc on the Optimal COP line.

CO_2 System COP – What Is It?

Coefficient of Performance of a Refrigerator and a Heat Pump

The coefficient of performance for cooling of a refrigerator, and for heating of a heat pump can now be expressed as

$$COP_C = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1}$$

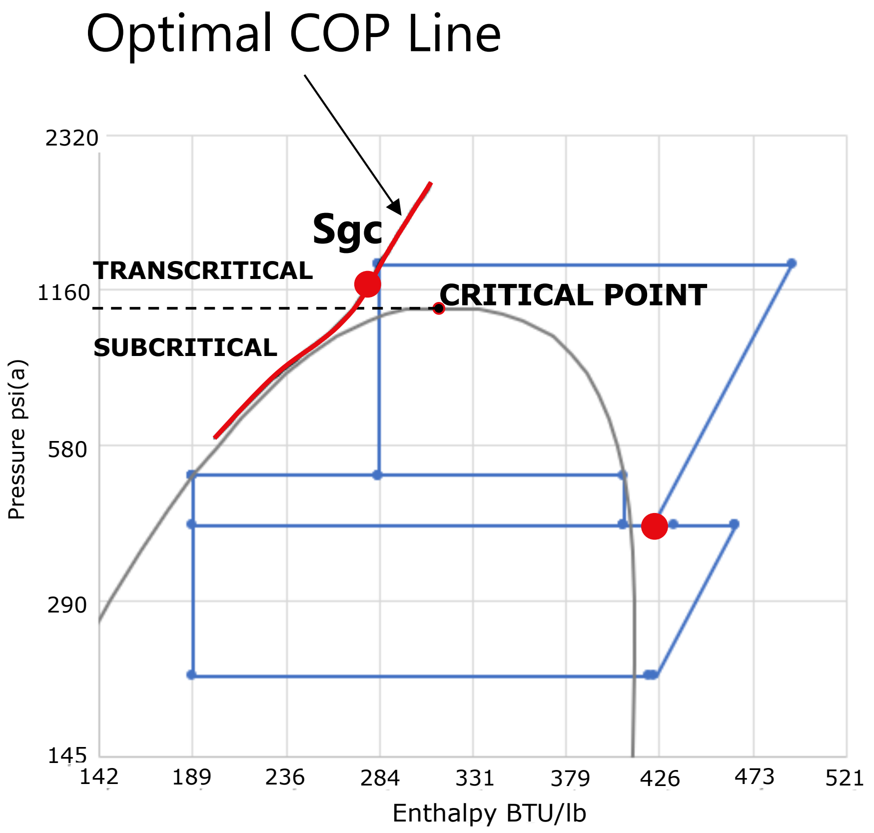
$$COP_H = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

It is seen that, since W is finite, both COP_C and COP_H are less than ∞. Also, from the first law equation, since $Q_H = Q_L + W$

$$\frac{Q_H}{W} = \frac{Q_L}{W} + 1$$

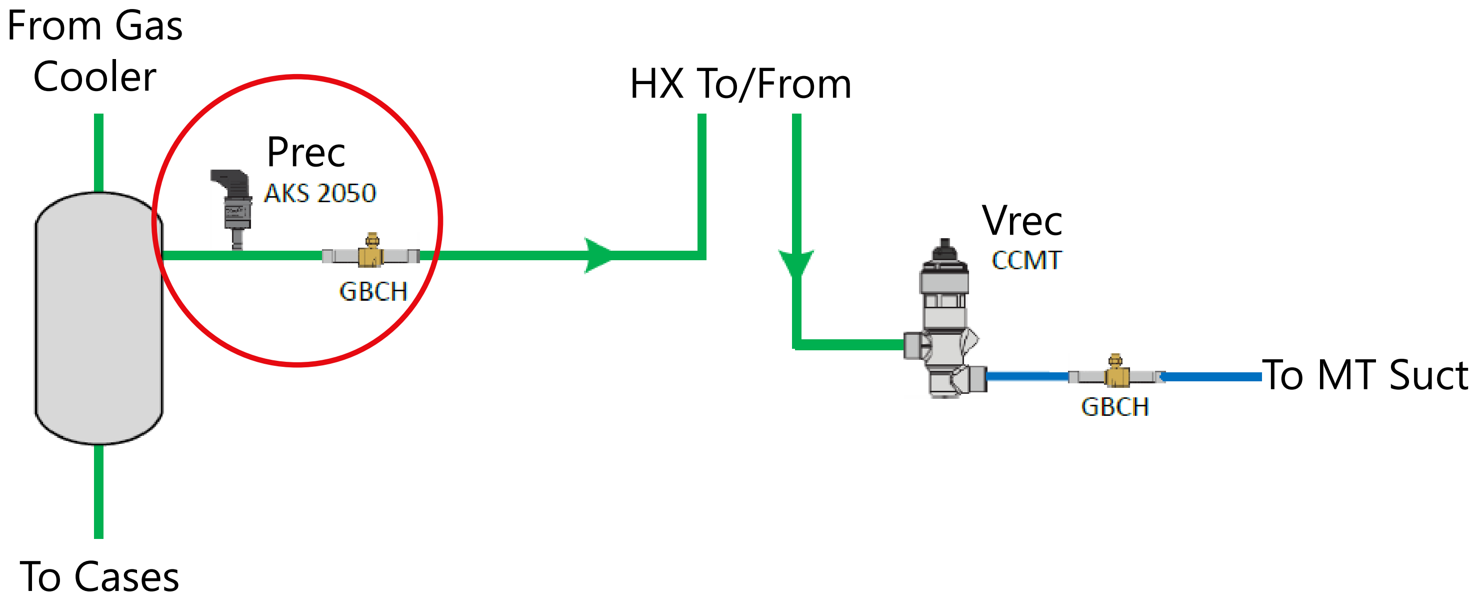
$$COP_H = COP_C + 1$$

Accordingly, COP_H is always greater than unity. It is so since Q_H is always greater than Q_L by the amount W.



At a given Sc3 and Sgc, Pgc should be?

AK-PC782A – Receiver Bypass Valve (Vrec)



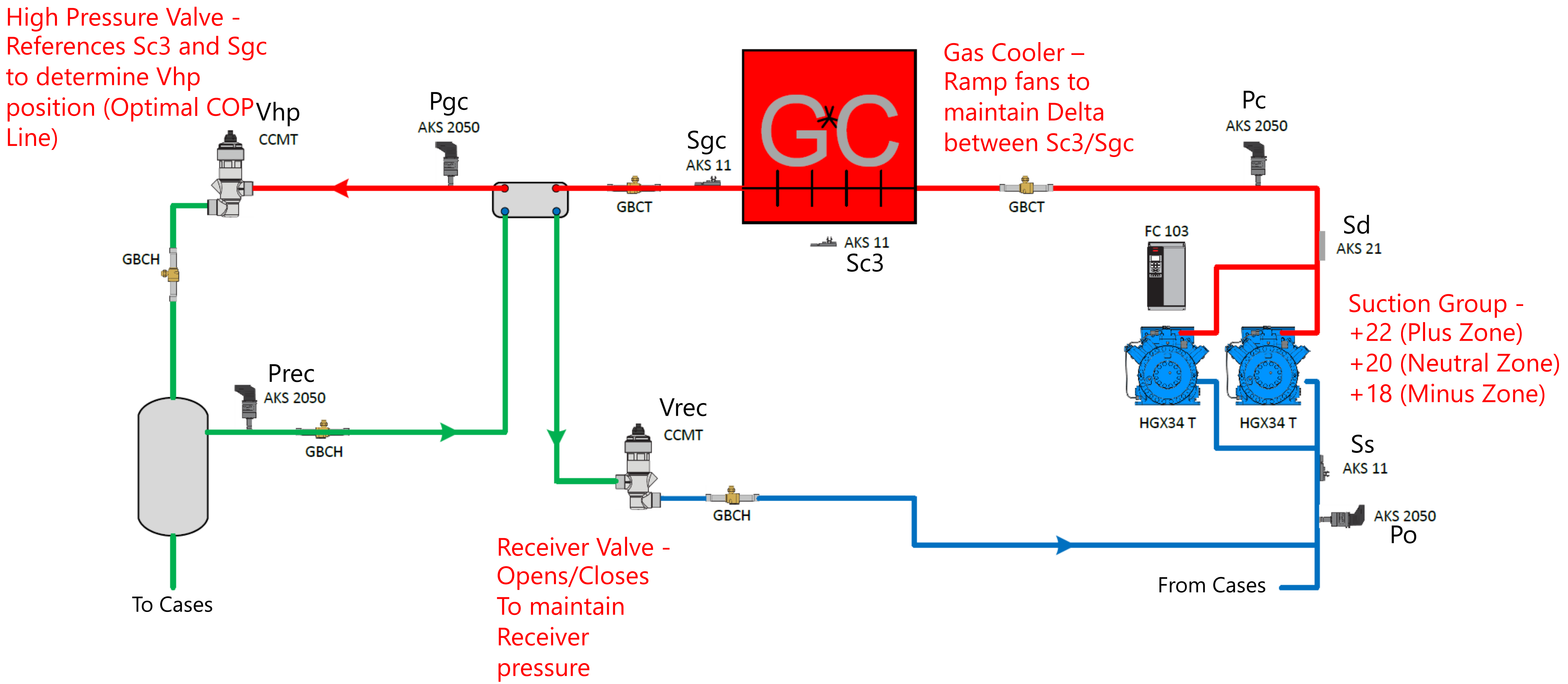
Sensors
- Prec = Receiver Pressure

Devices
- Vrec = Stepper Valve Output

Key Set Points
- Prec setpoint = Regulation PSI Setting
- Prec min. = Valve position at 0%
- Prec max. = Valve position at 100%

The pack controller references Prec, then opens/closes Vrec to maintain Prec setpoint.

CO2 MT Transcritical System – Control Recap



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Questions?

Service Tool (ST500)

Service Tool AK-ST 500
Main Screen Features

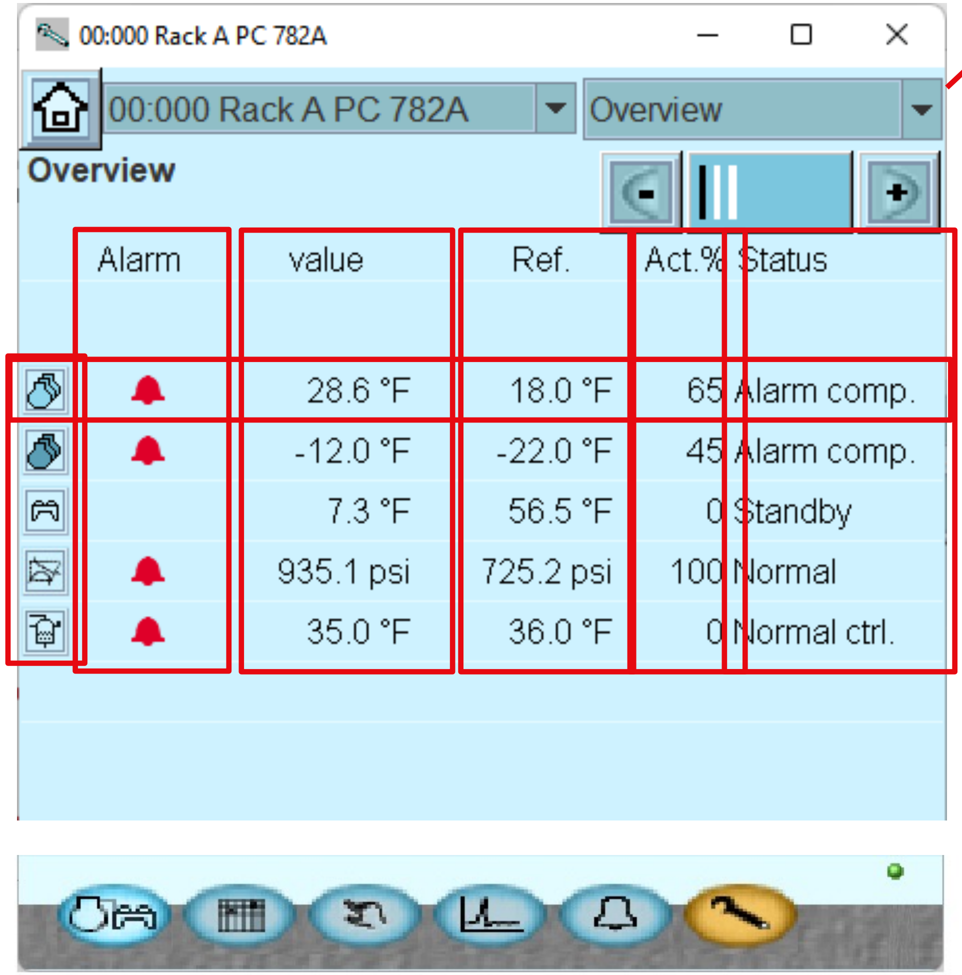
MT Suction Group

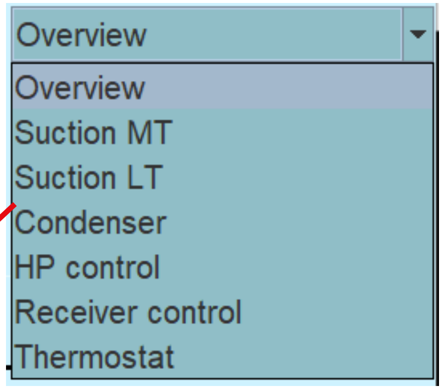
LT Suction Group

Gas Cooler Fan

High Pressure Valve

Receiver Bypass Valve





Ref. = Set Point

Value = Actual

Act.% = Active Capacity

Status = Condition

Alarm = Problem

Parallel Compression Overview

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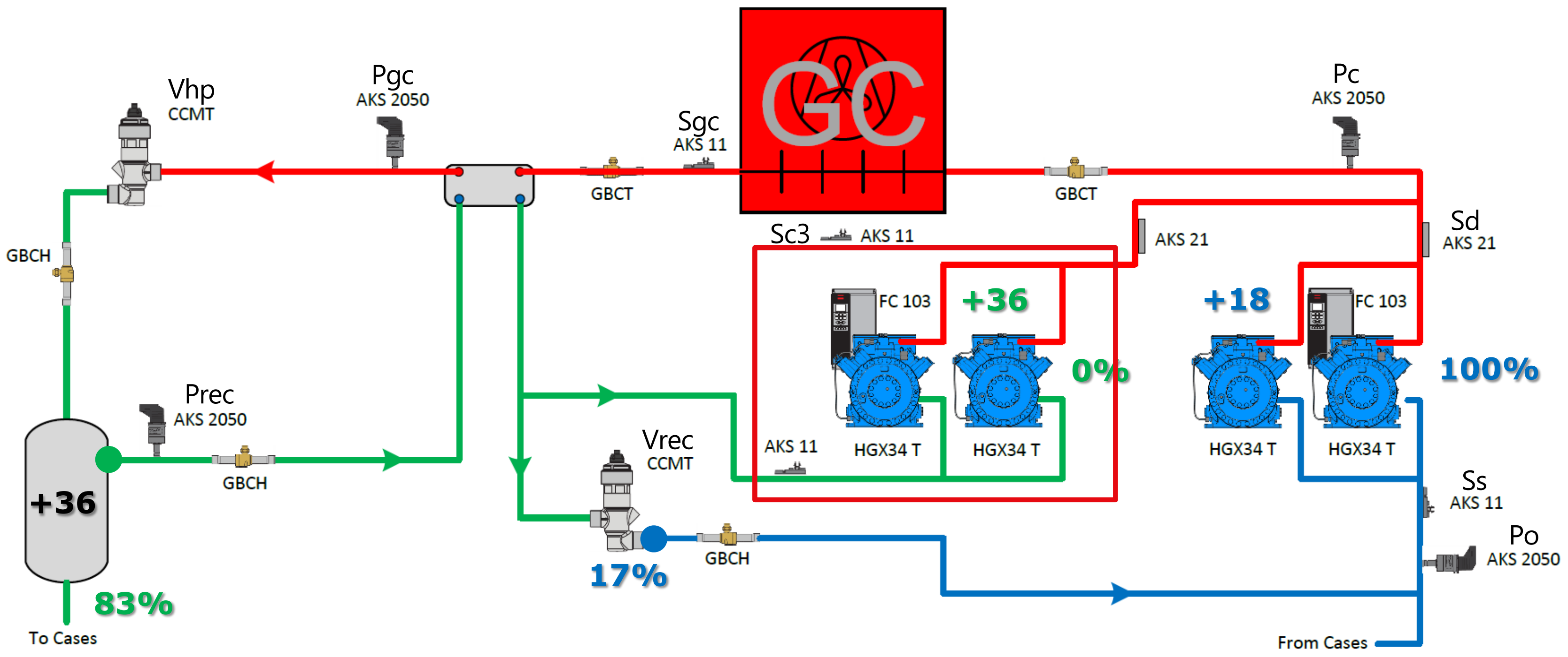
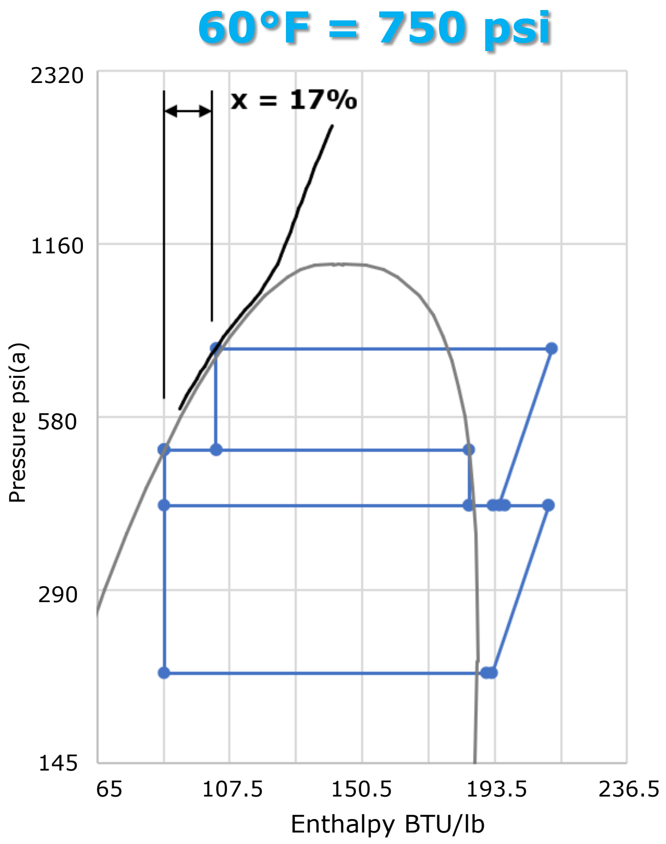
Mode 2 – Parallel Compression – Cold Ambient

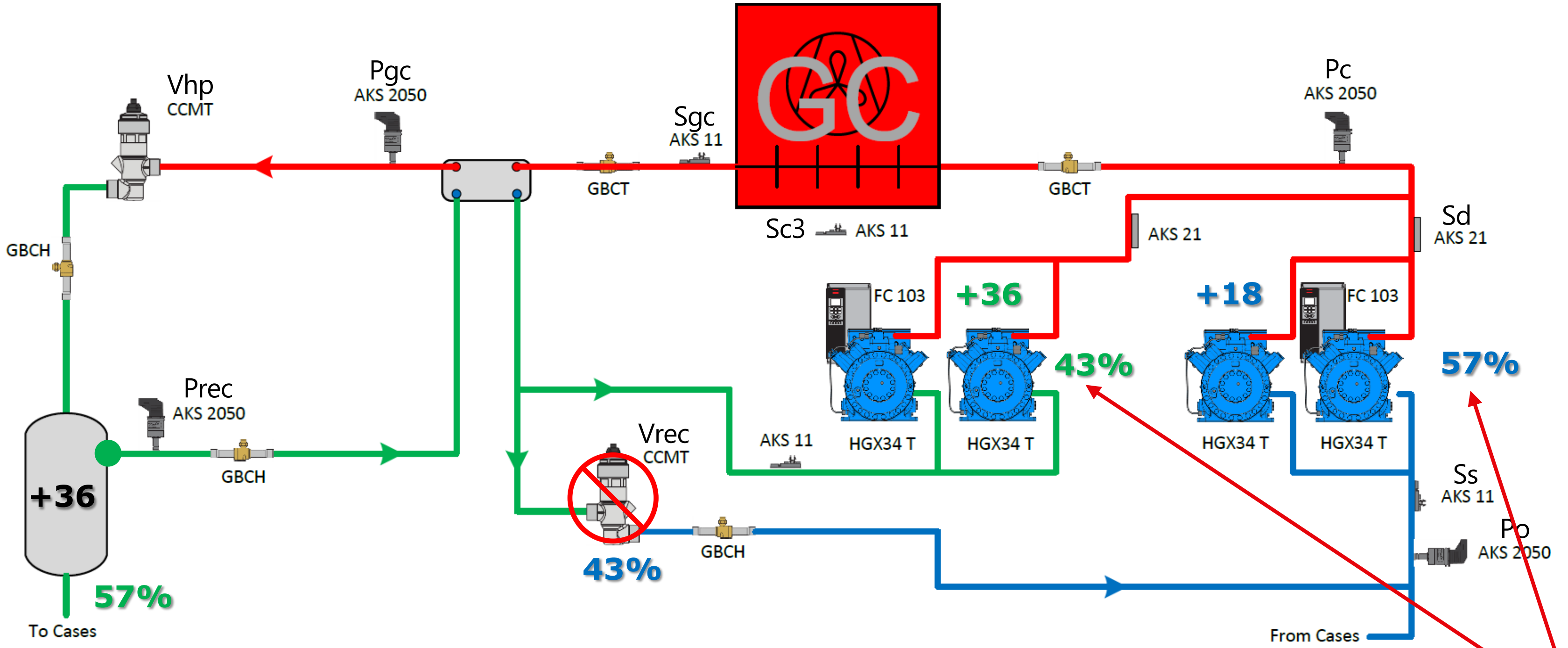


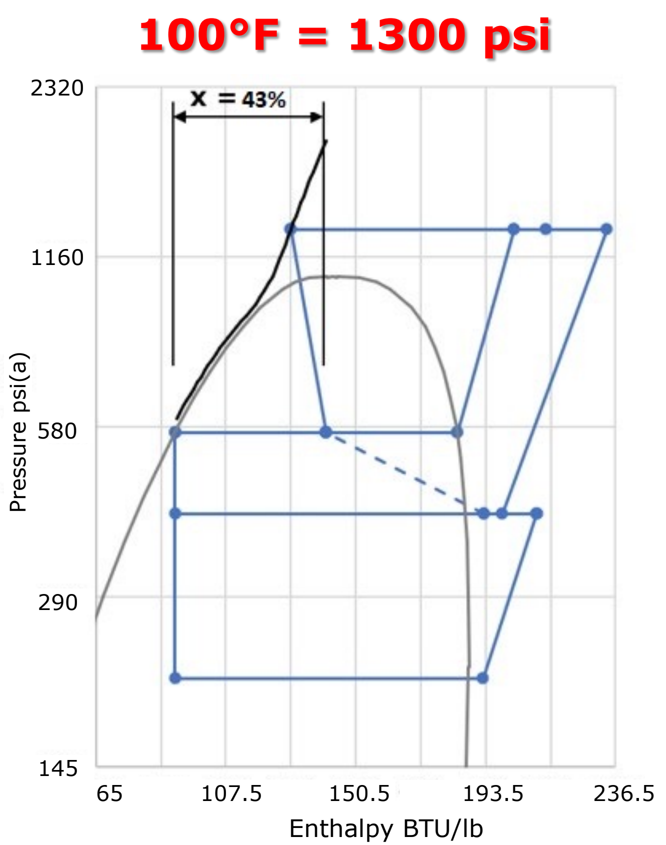


Parallel Compressors are an optimal solution for addressing the flash gas in the receiver

- In colder ambient conditions the gas bypass valve controls pressure in the receiver by releasing flash gas to the MT compressors

Mode 2 – Parallel Compression – Warm Ambient





- In warmer ambient conditions the gas bypass valve closes which diverts the flash gas to the IT compressors
- When Vrec = ??% open, close Vrec to activate Parallel Compressors

1.5% Energy Savings per/*F Suction Temp (18*F Increase = 27%)

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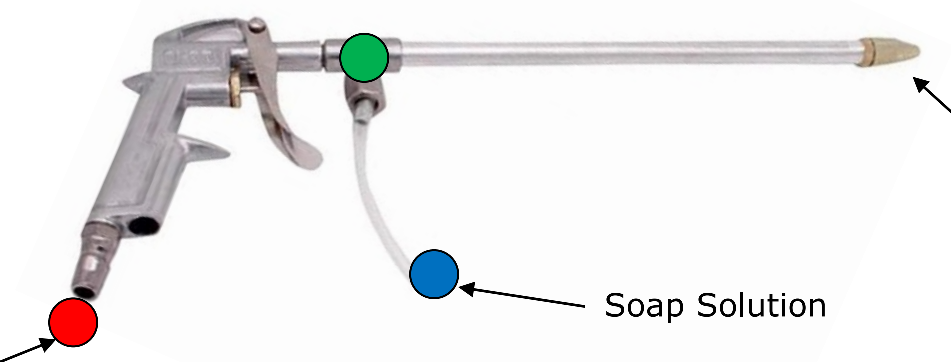
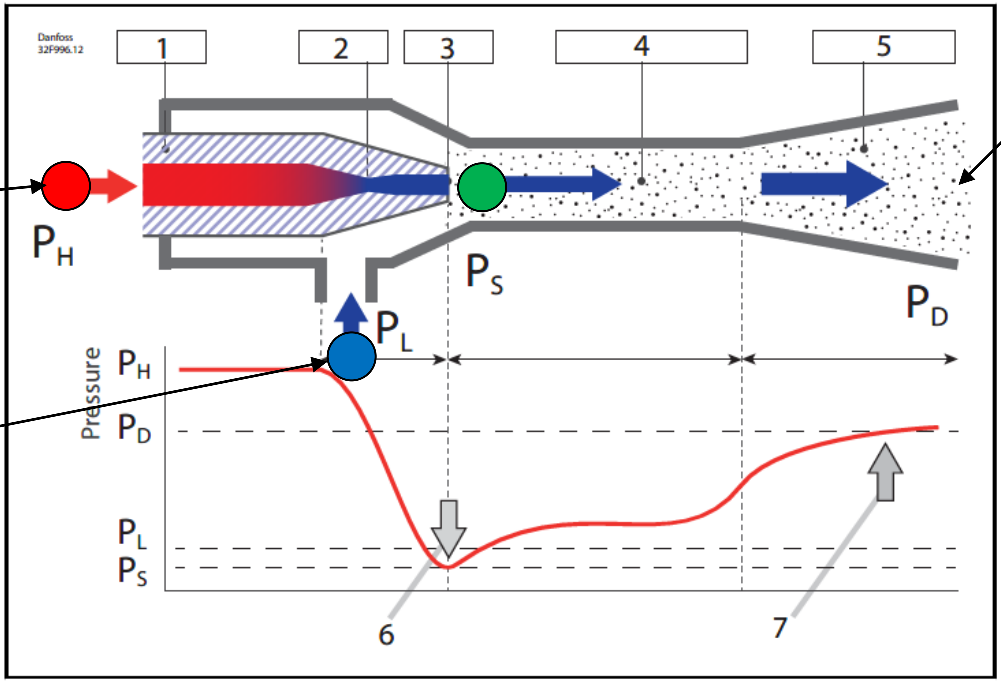
Questions?

Ejector Overview

Working Principal of the Multi-Ejector

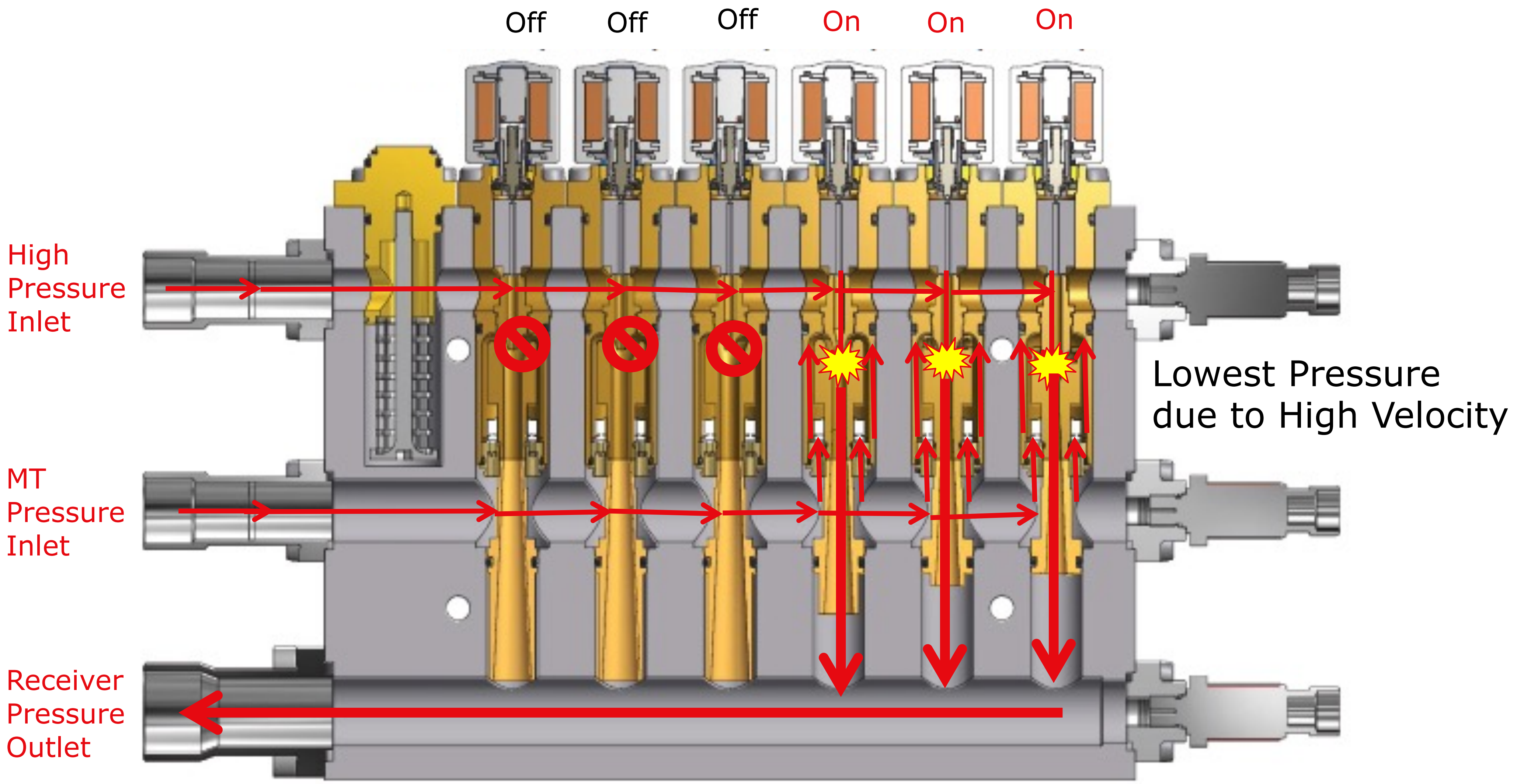
We only get the mixture when the trigger on the wand is pulled which creates a Venturi effect





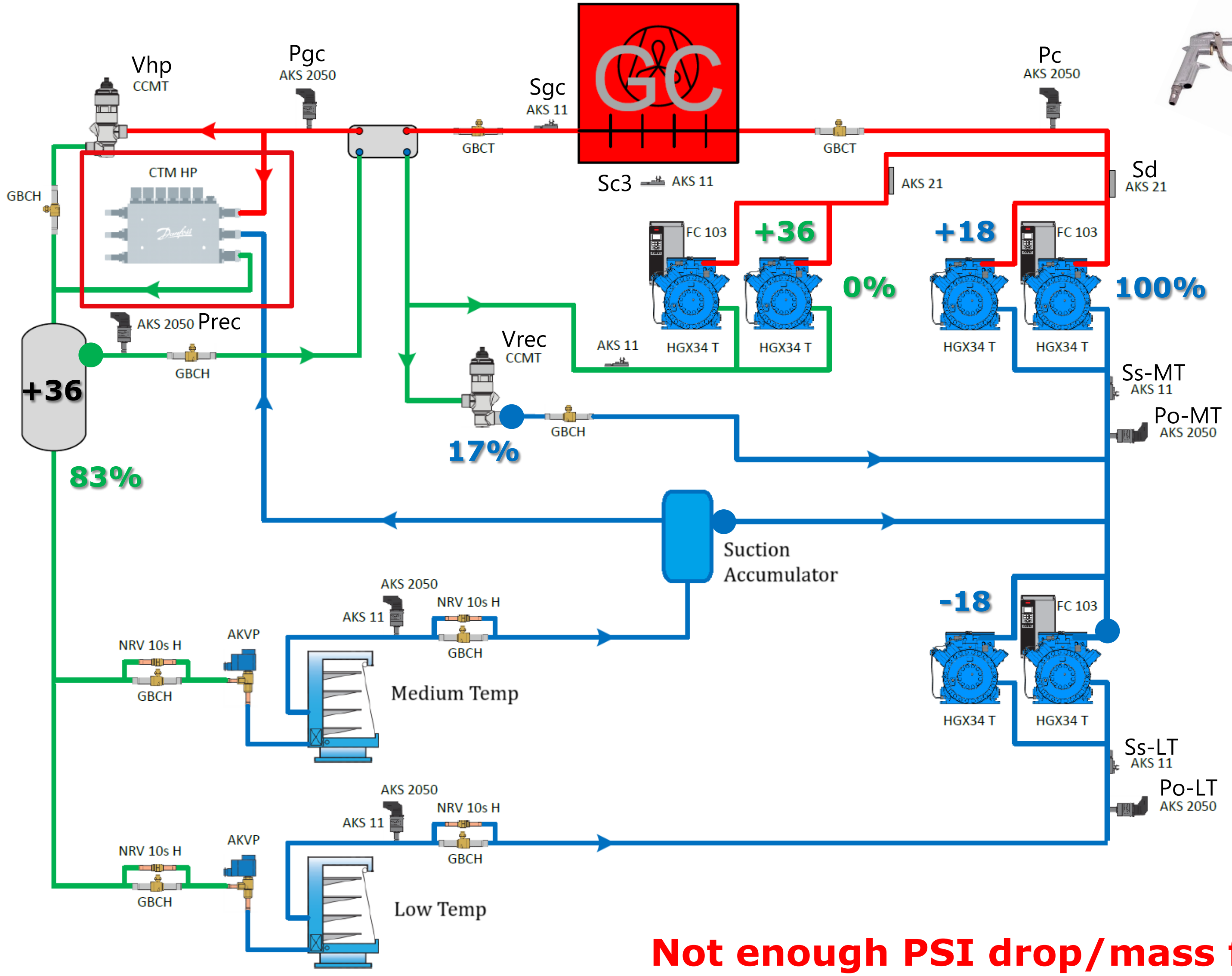
1	Nozzle
2	Throat
3	Exit
4	Mixing chamber
5	Diffuser
6	Intake due to pressure differential
7	Pressure increase due to reducing flow velocity

How does the Multi-Ejector work?

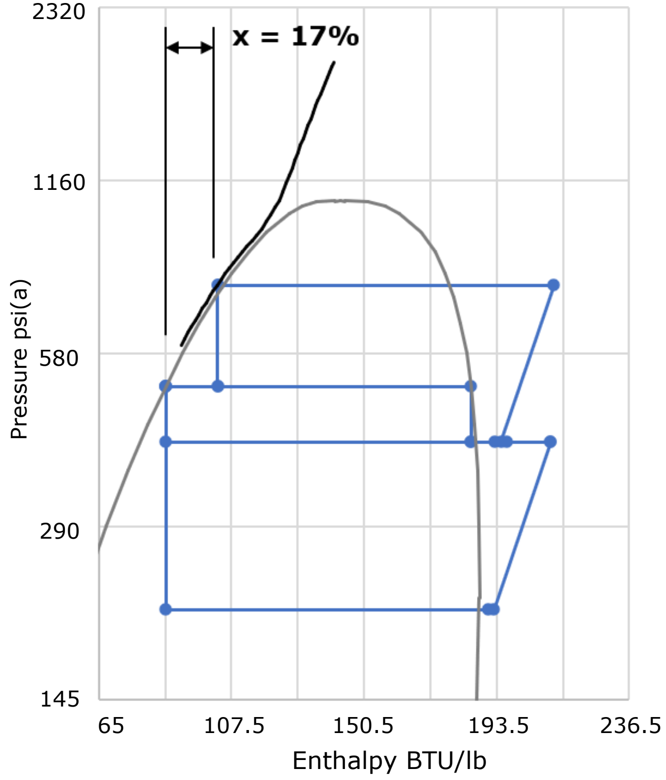


Mode 3 – HP Ejectors – Cold Ambient

We haven't pulled the trigger on the wand



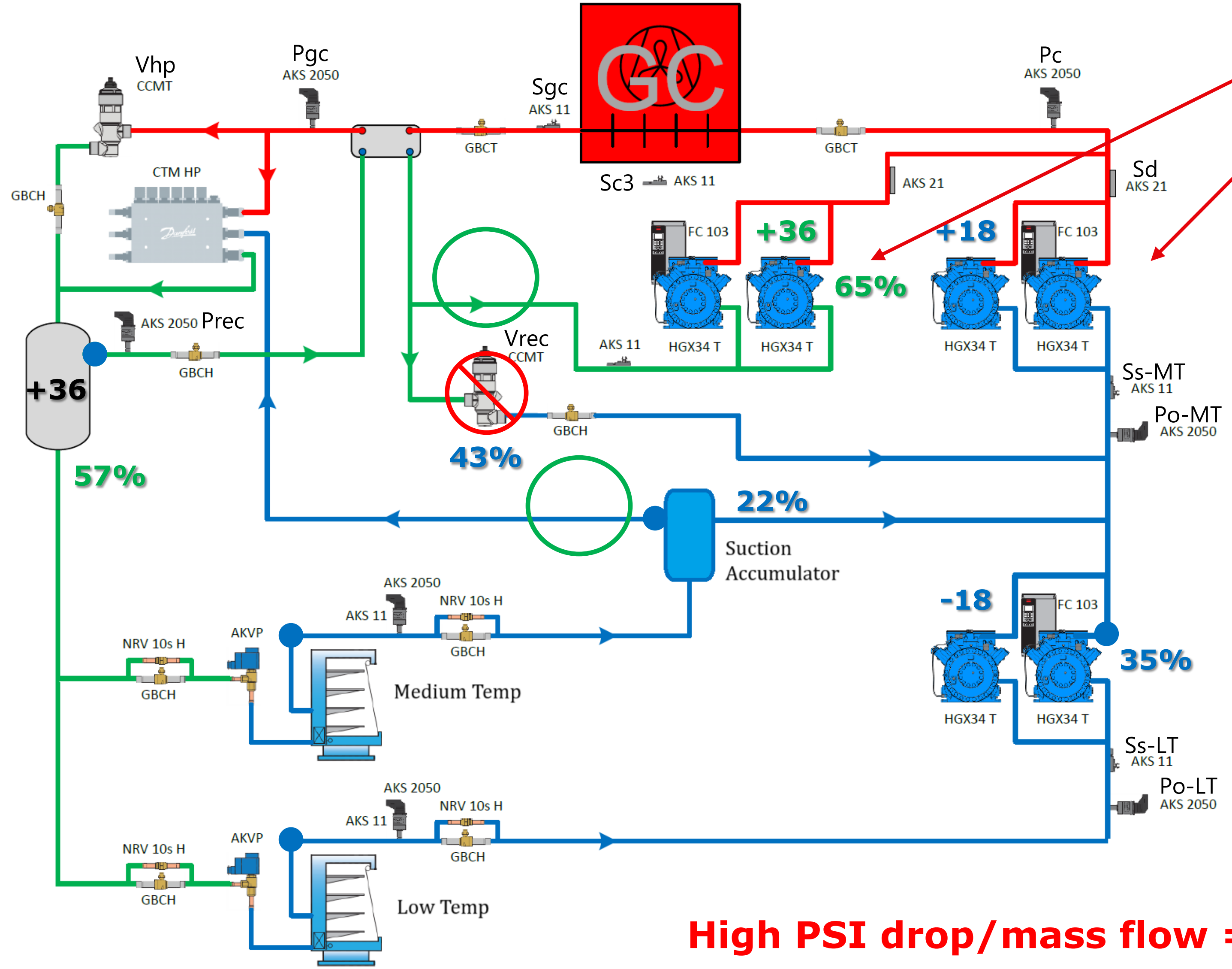
60°F = 750 psi



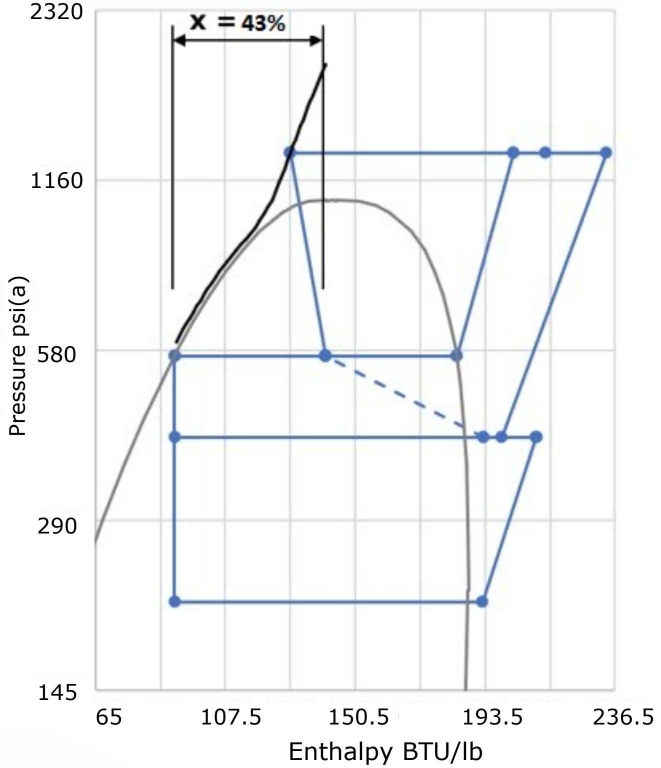
Not enough PSI drop/mass flow to create venturi effect

Mode 3 – HP Ejectors – Warm Ambient

1.5% Energy Savings
per/*F Suction Temp
(18*F Increase = 27%)



100°F = 1300 psi



High PSI drop/mass flow = Trigger has been pulled

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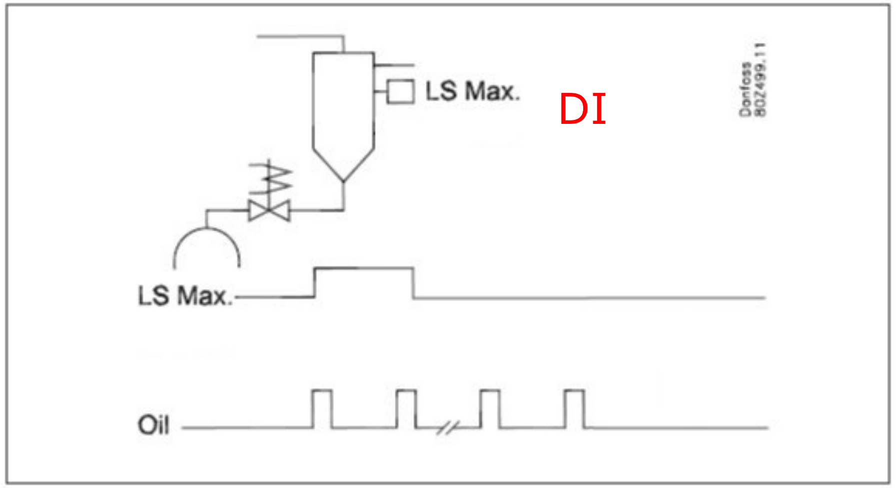
Questions?

AK-PC782A – Oil System with One Level Switch



SSRO

Systems with one level switch

Full sequence:

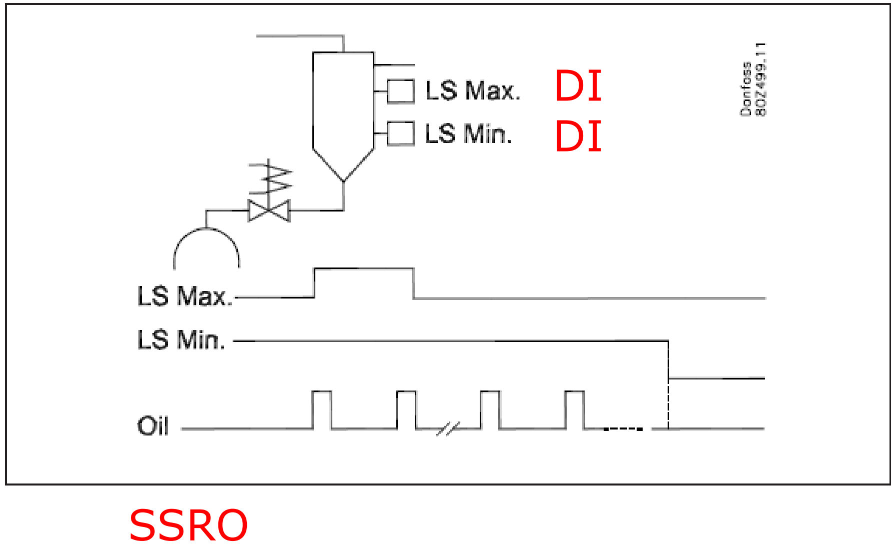
- When the level switch registers oil, the oil is emptied into the receiver running all periods. Users define the pulse length, period time between pulses and number of periods.

To level:

- Here the pulse sequence starts at activation of the switch, but the sequence stops immediately once the oil level falls below the level switch.

For both, If the level switch is still registering oil after the total number of periods has finished, an alarm is given for high oil level in the separator.

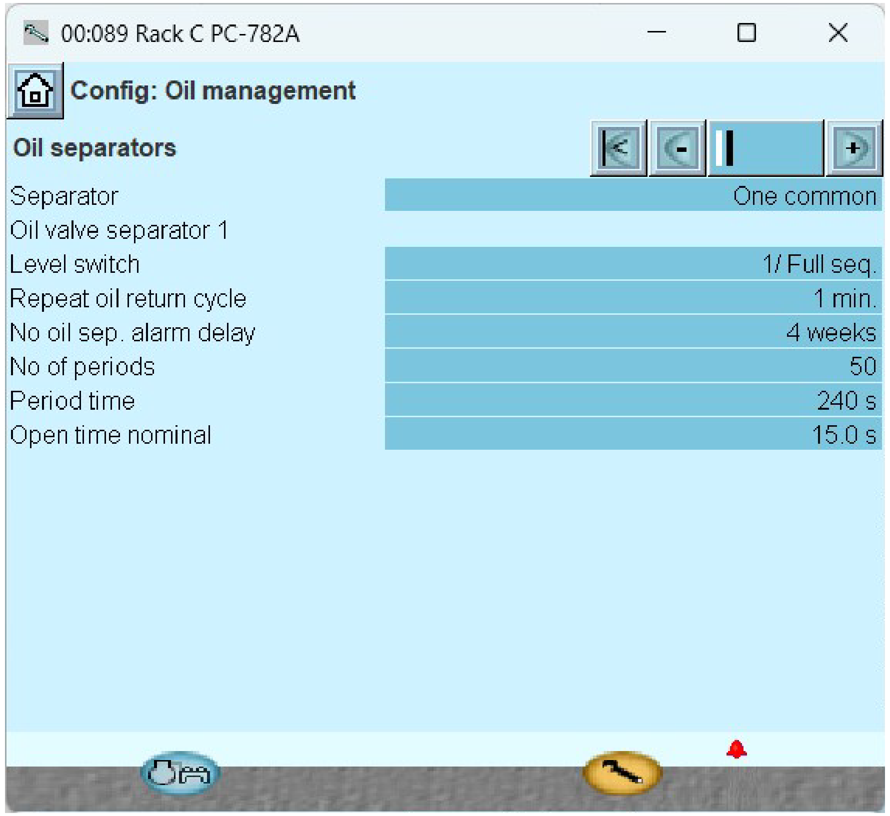
AK-PC782A – Oil System with Two Level Switches



Systems with two level switches

- Here, the high-level switch will start the pulse sequence, and the low-level switch will stop the pulse sequence.
- If the high-level switch is still registering oil after the total number of pulses has finished, an alarm is given for high oil level in the separator.
- If the low-level switch is still registering oil after the total number of pulses is finished, an alarm is given for remaining oil in the separator.

AK-PC782A – Oil Separator/Reservoir Settings



Separator = SELECT THE NUMBER OF OIL RESERVOIRS

Level switch = 1 /Full seq. IS USED FOR BOTH None and Only High. Low & high IS SELECTED ON SYSTEMS WITH BOTH A HIGH- AND LOW-LEVEL SWITCH ON THE OIL RESERVOIR

Repeat oil return cycle = TIME BETWEEN EMPTYING SEQUENCES

No oil sep. alarm delay = ALARM DELAY IF HIGH-LEVEL NEVER ACTIVATES

No of periods = TIMES OIL PULSE VALVE SHOULD OPEN DURING EMPTYING SEQUENCE

Period time = TIME BETWEEN VALVE OPENINGS

Open time nominal = TIME VALVE IS OPEN DURING THE PERIOD

(EXAMPLE): BASED ON THE SETTINGS ABOVE, WHEN THE EMPTYING SEQUENCE STARTS IT WILL PULSE THE OIL RESERVOIR DUMP VALVE FOR 15 SECONDS EVERY FIVE MINUTES