

Danfoss Mobile Training Unit North American Tour – Fall 2023

CO₂ Transcritical System Overview

Steve Moss - CO₂ Field Service Engineer

Agenda

Mobile Training Unit Overview

Parallel Compression

CO2 Review

High Pressure Ejectors

AK-PC782B Transcritical Control

Case Controller Overview

Service Tool Software (ST500)

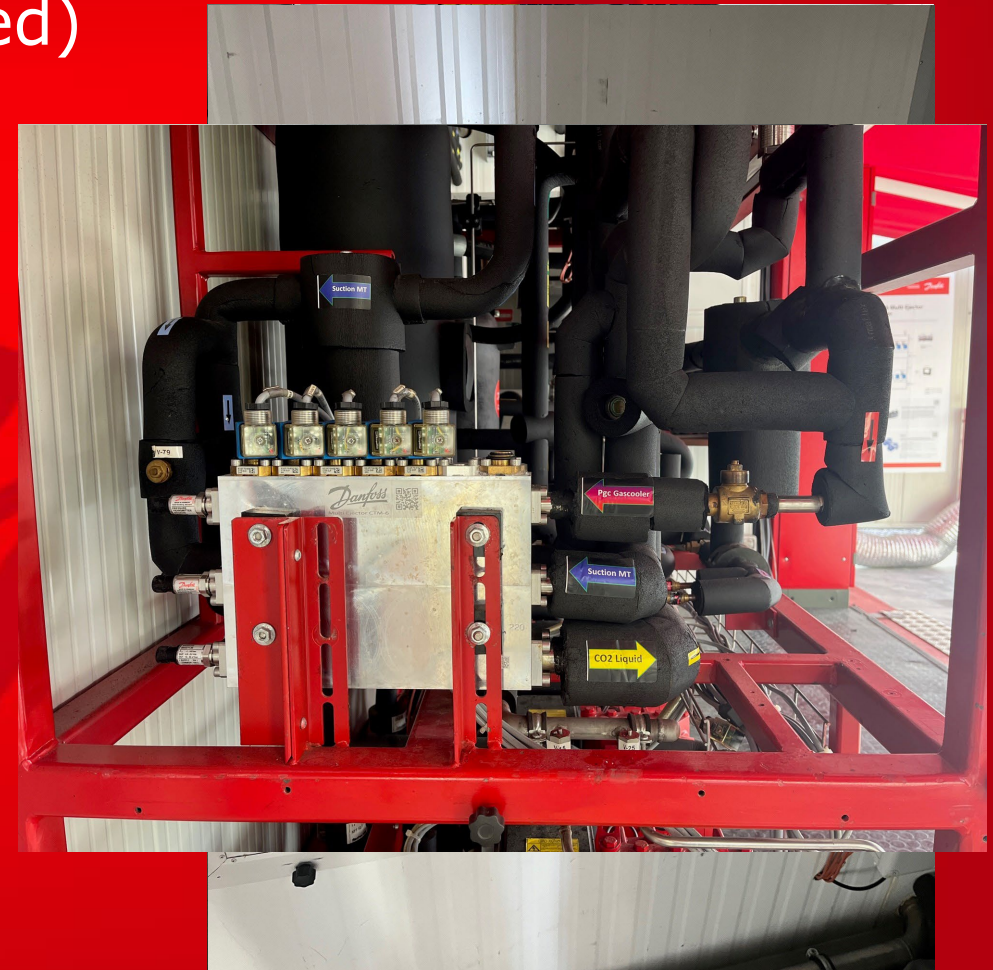
AK-CC55 Connect Mobile App

Mobile Training Unit Overview (aka Big Red)

MT Transcritical CO2 System
Serving Two Evaporators
Gas Cooler (under cooler shelf)

Three Control Modes

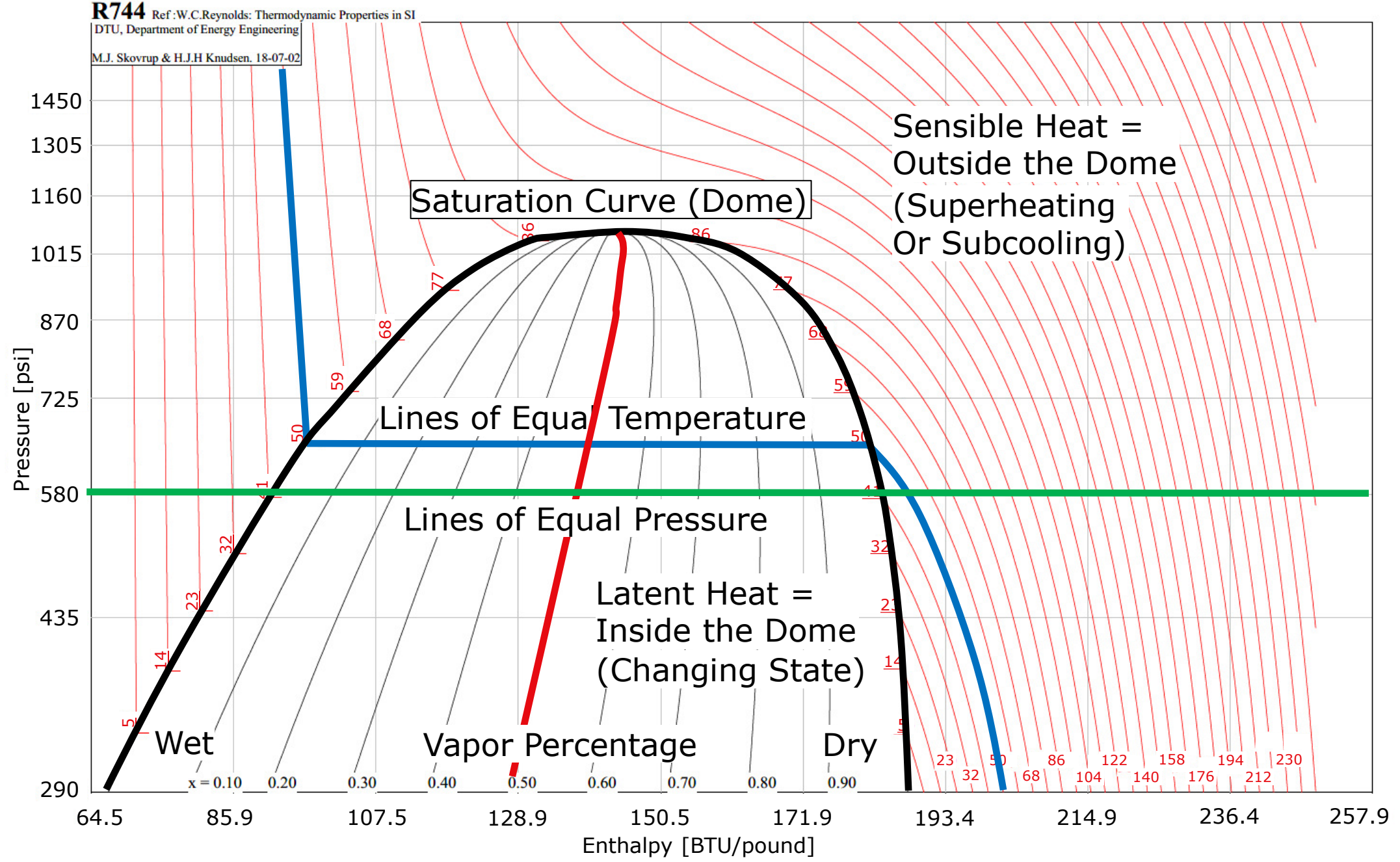
- Medium Temp Transcritical
- MT Transcritical with Parallel Compression
- MT Transcritical with Parallel Compression & High-Pressure Ejectors



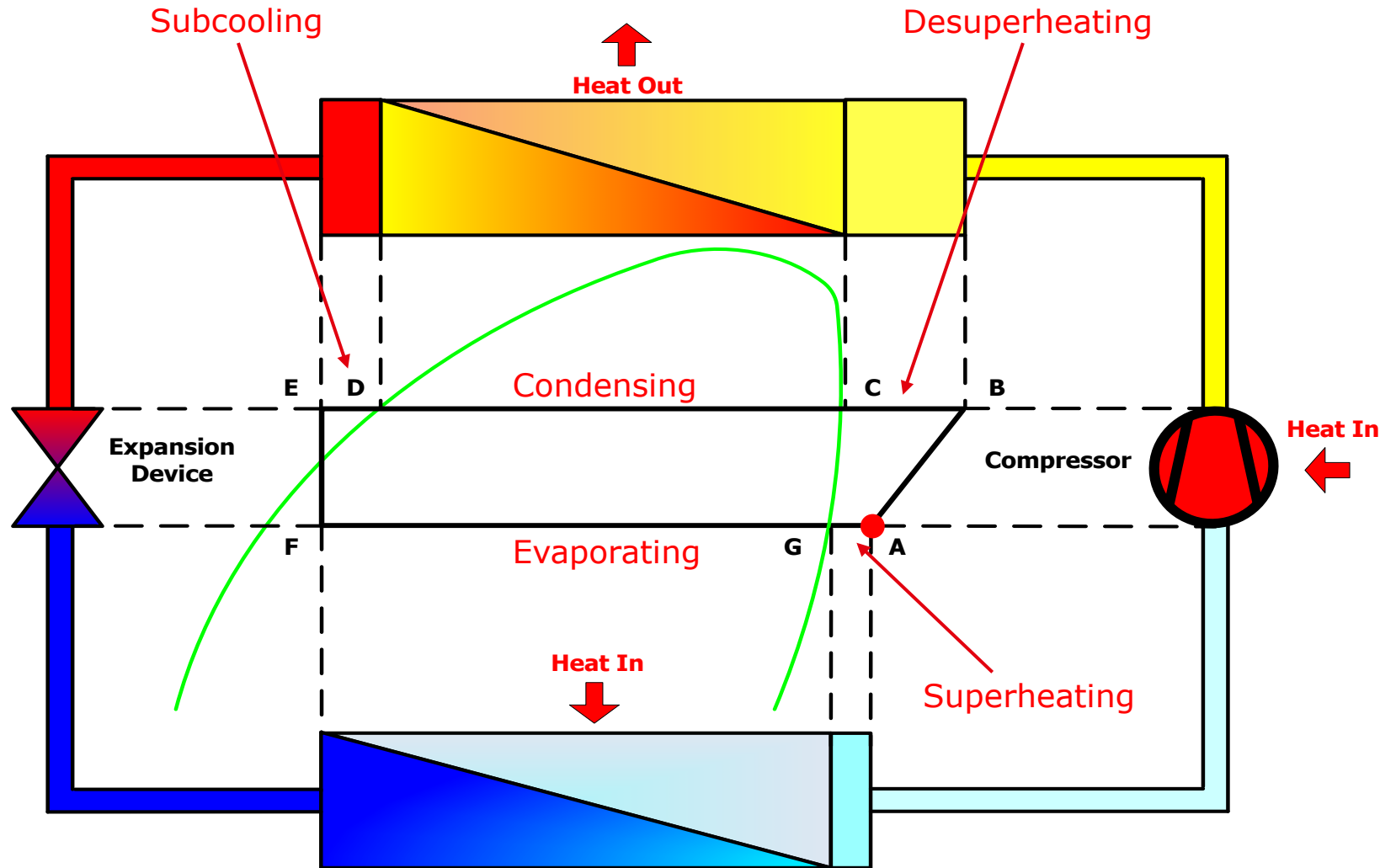
CO₂ Refrigeration Cycle

What is similar to HFC? (Subcritical)

What is different from HFC? (Supercritical)



Basic Refrigeration Cycle – R448a



Point A = Low Temp, Low PSI, SH Vapor

Point B = Hi PSI, Hi Temp, SH Vapor

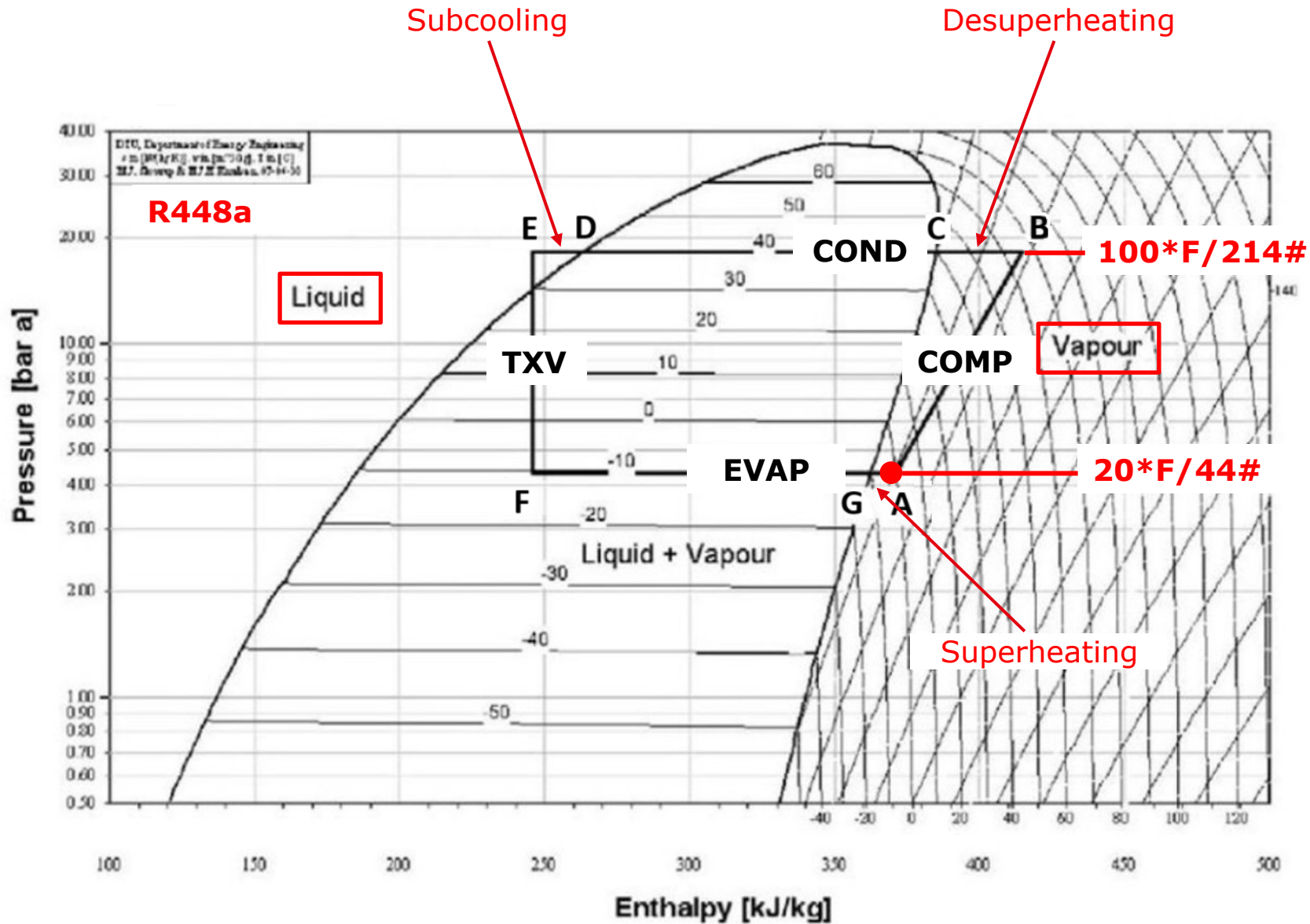
Point C = Hi PSI, Hi Temp Saturated Vapor

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



Point A = Low Temp, Low PSI, SH Vapor

Point B = Hi PSI, Hi Temp, SH Vapor

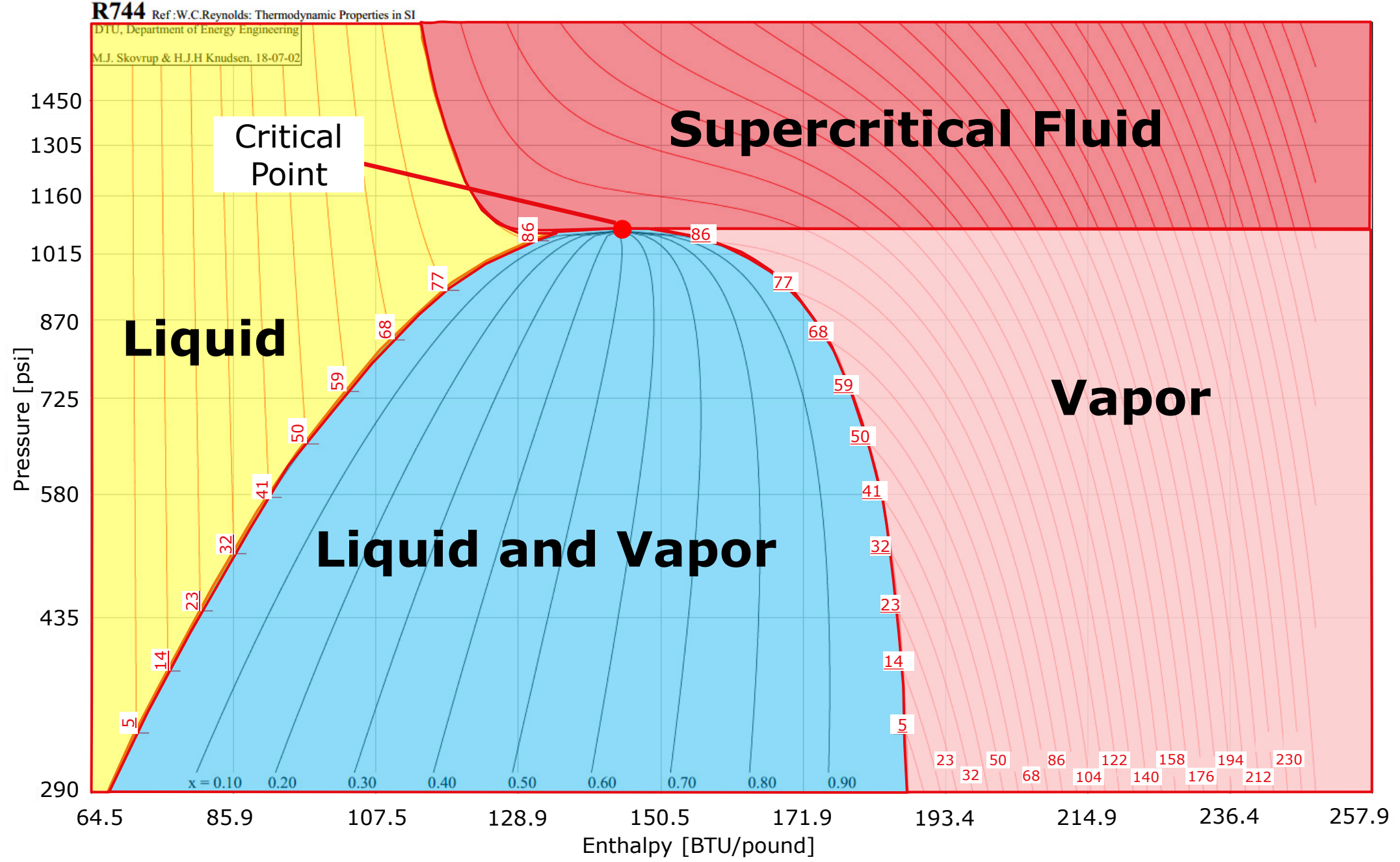
Point C = Hi PSI, Hi Temp Saturated Vapor

Point D = Hi PSI, Hi Temp, Saturated Liquid

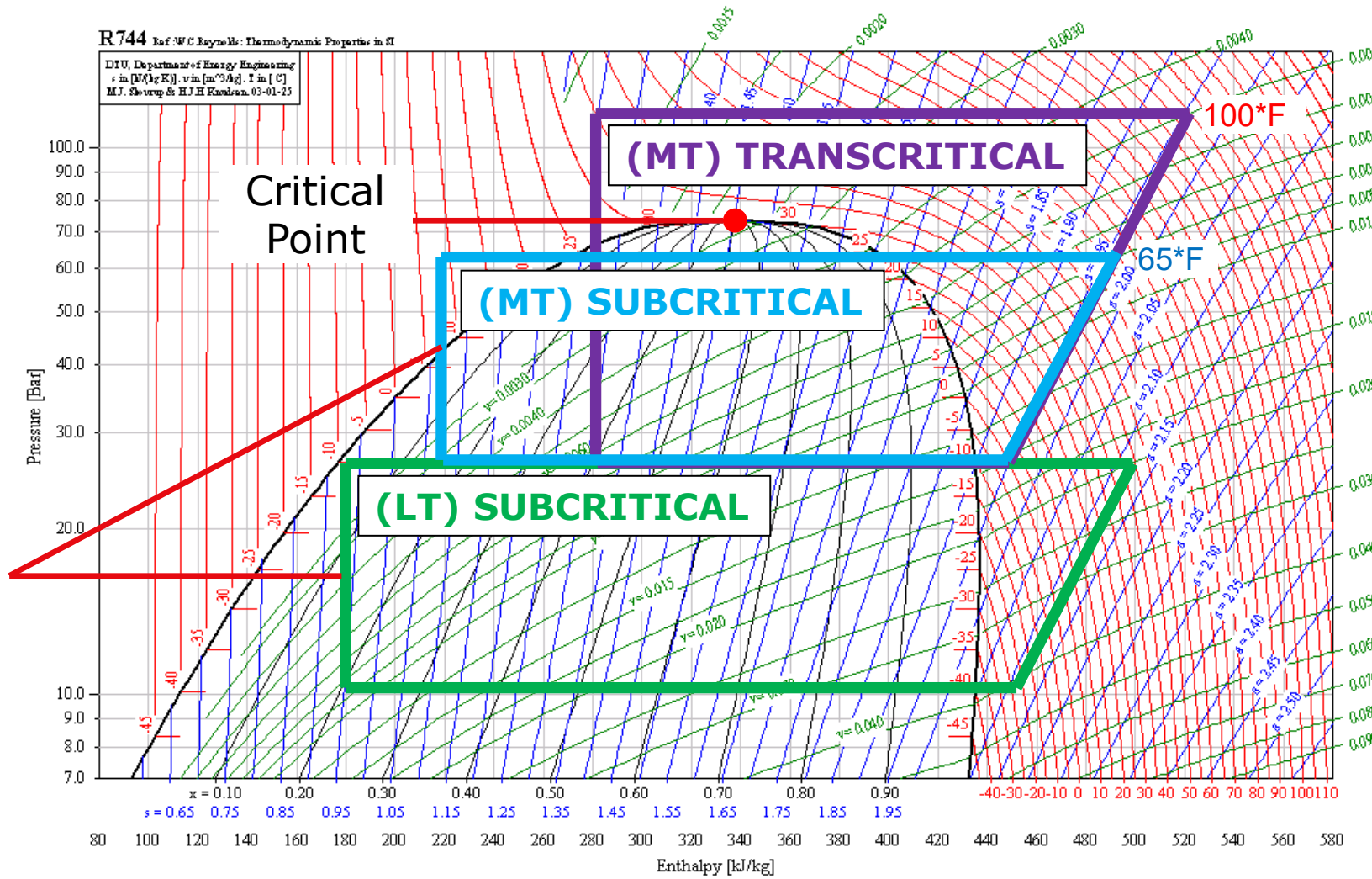
Point E = Hi PSI, Hi Temp, SC Liquid

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

Point G = Low Temp, Low PSI, Saturated Vapor



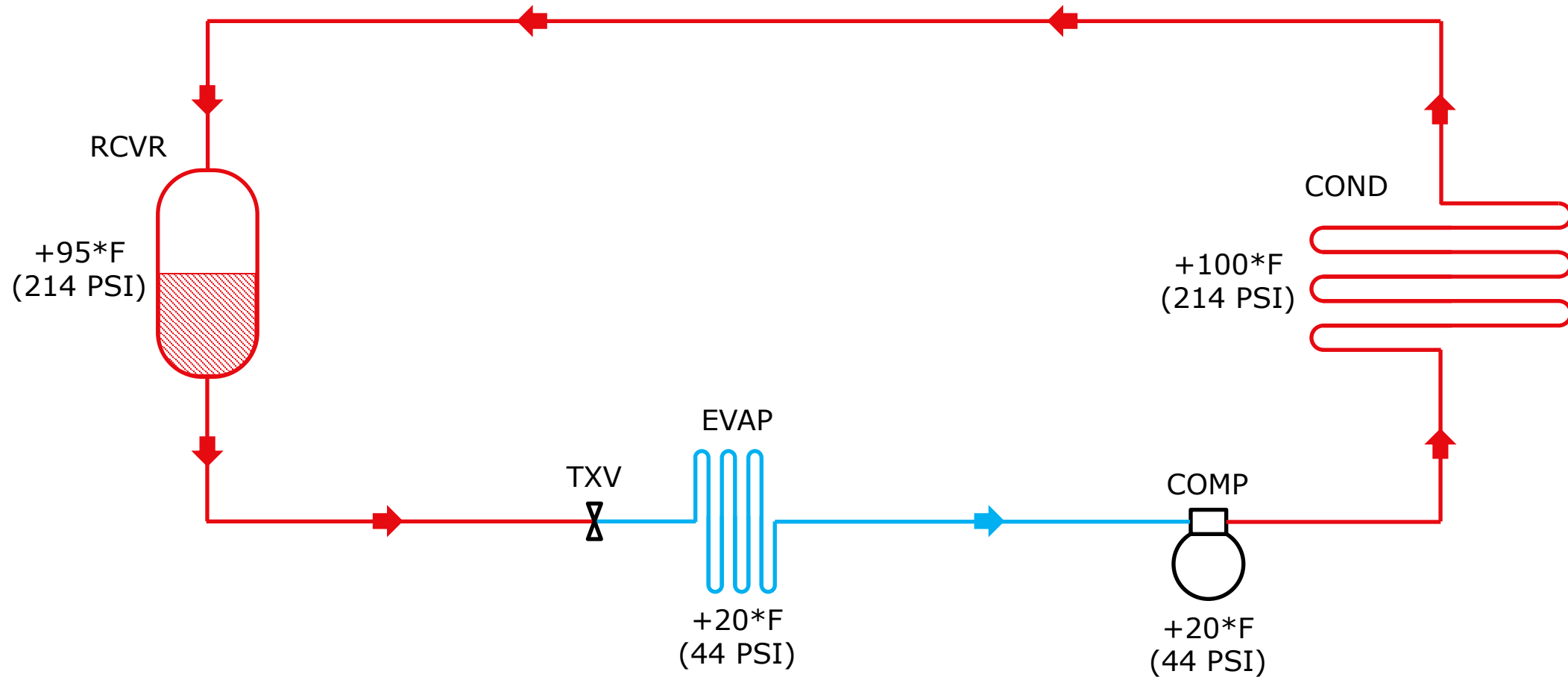
Transcritical & Subcritical Cycles



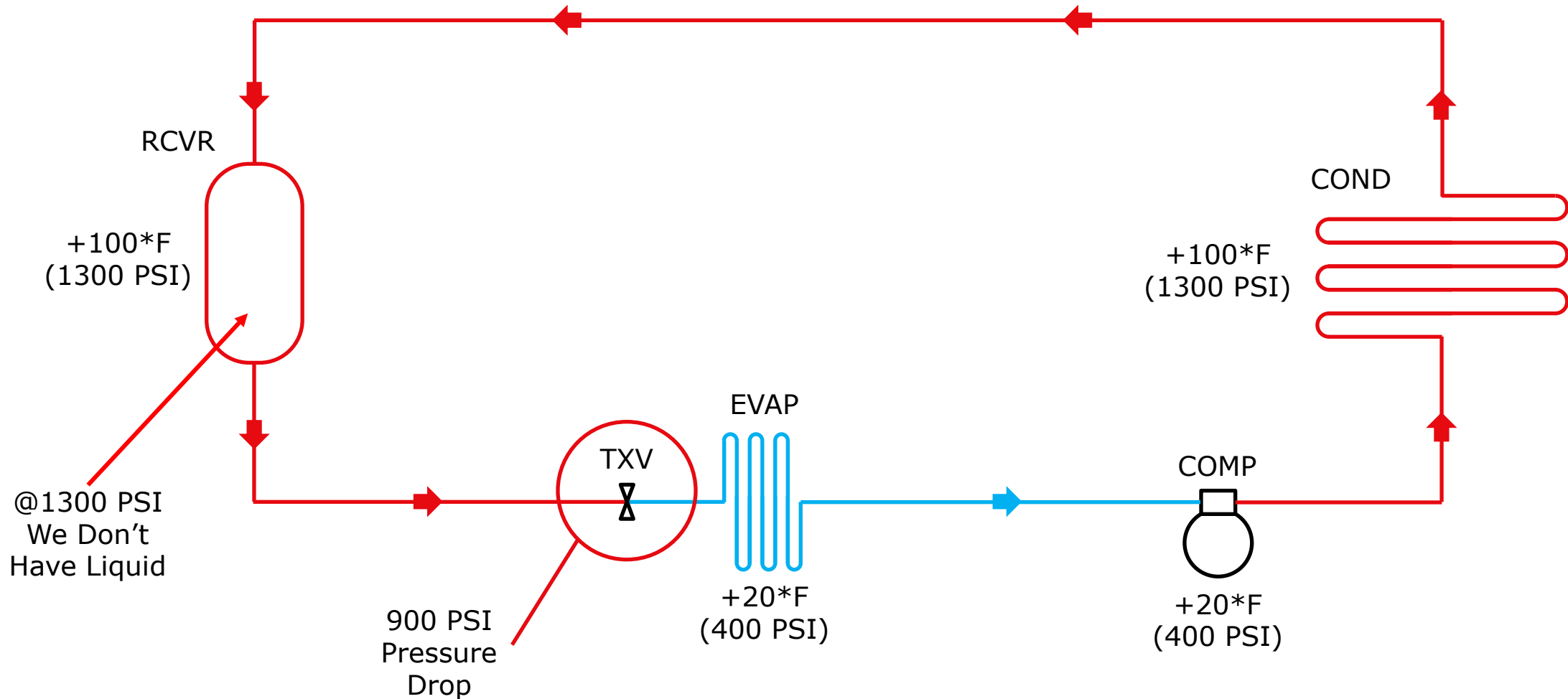
100°F Ambient
 65°F Ambient
 The High Side of the system **Transitions** between Supercritical and Subcritical as gas cooler outlet temp goes above or below the critical point, hence the term **Transcritical**

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

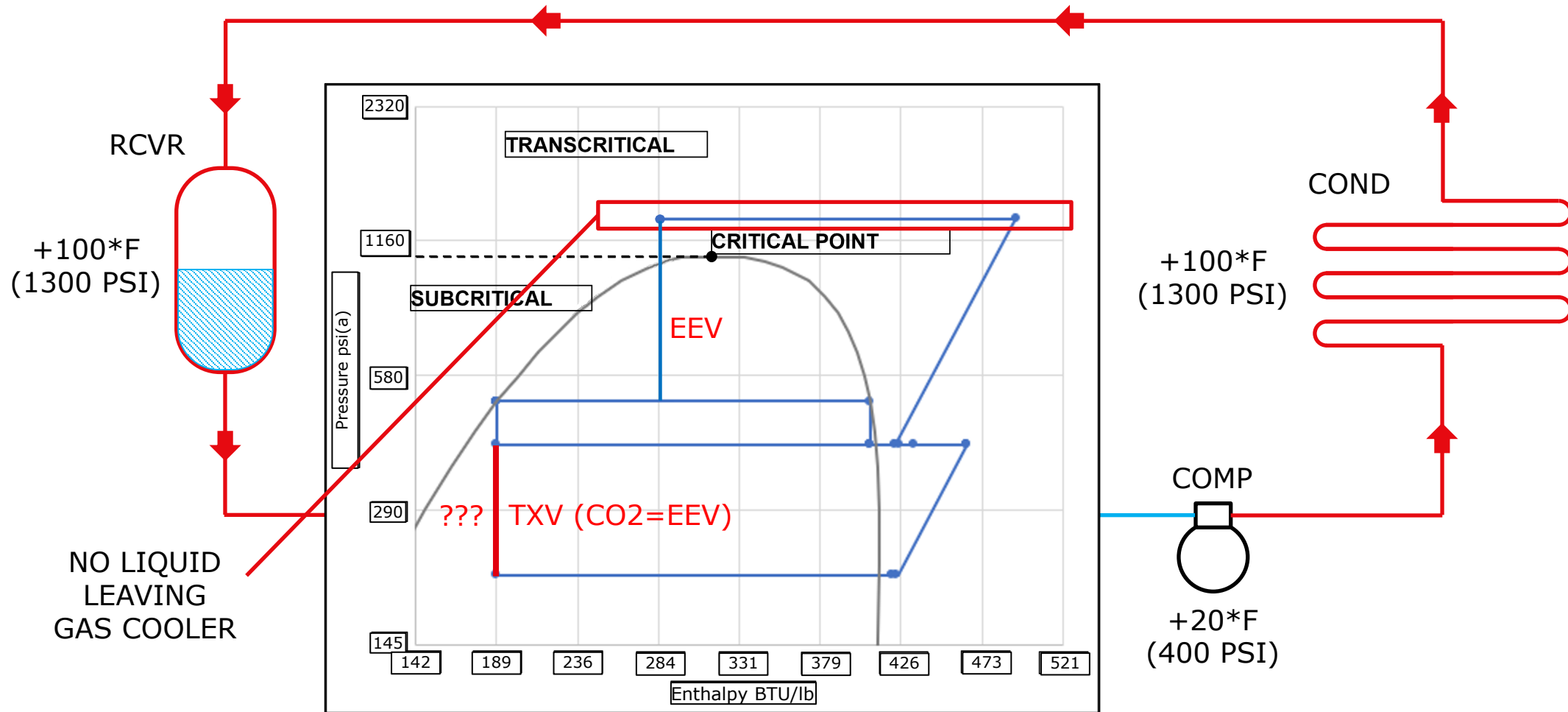
R448A Refrigeration Cycle



R448A Refrigeration Cycle with R744 Pressures

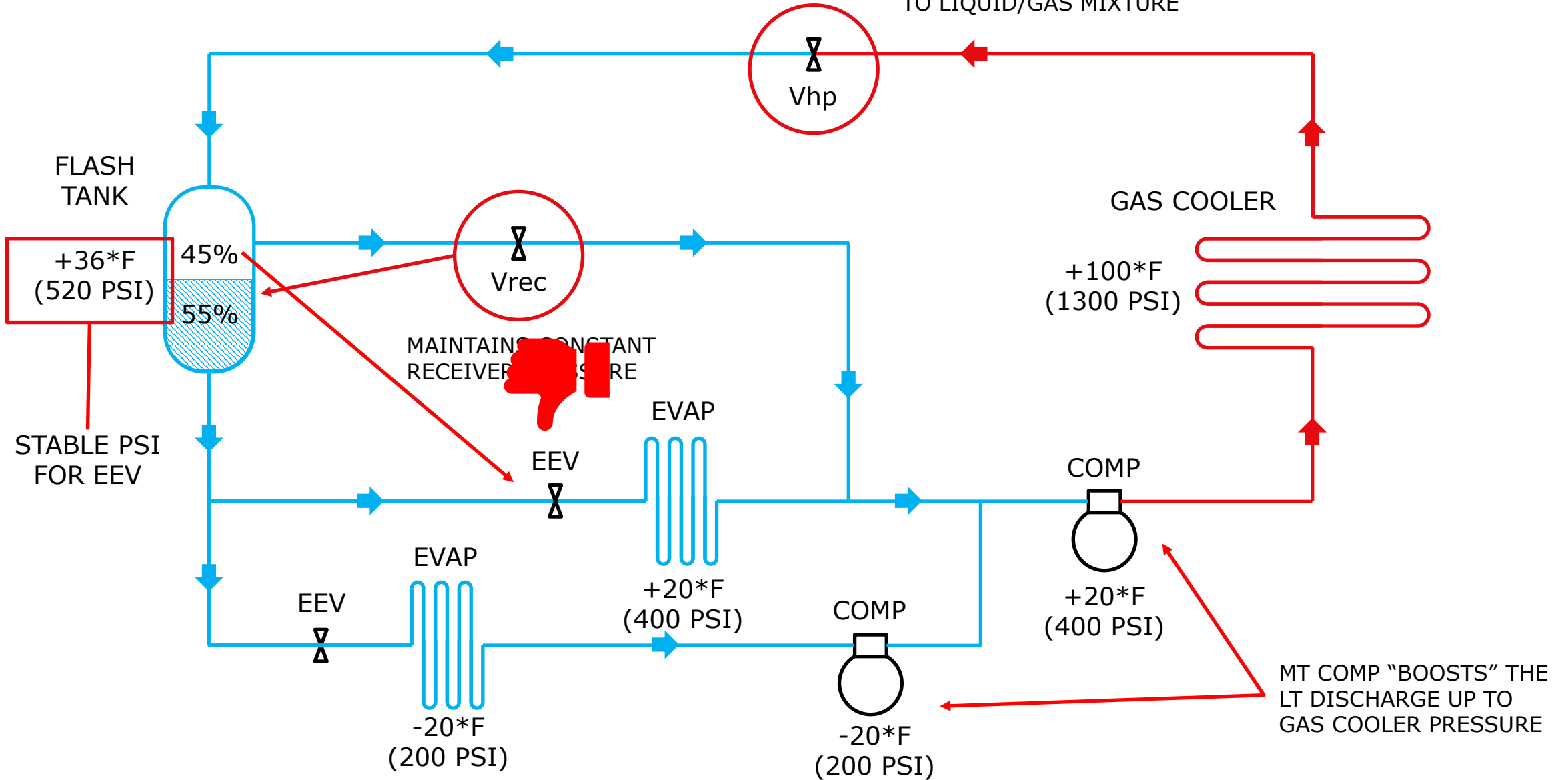


R448A Refrigeration Cycle with R744 Pressures

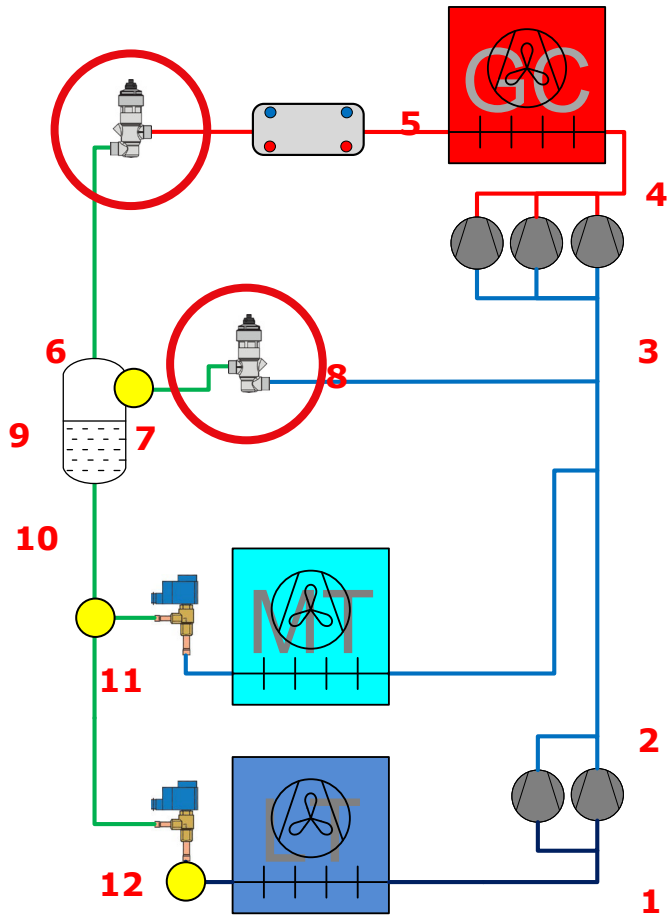


R744 Refrigeration Cycle

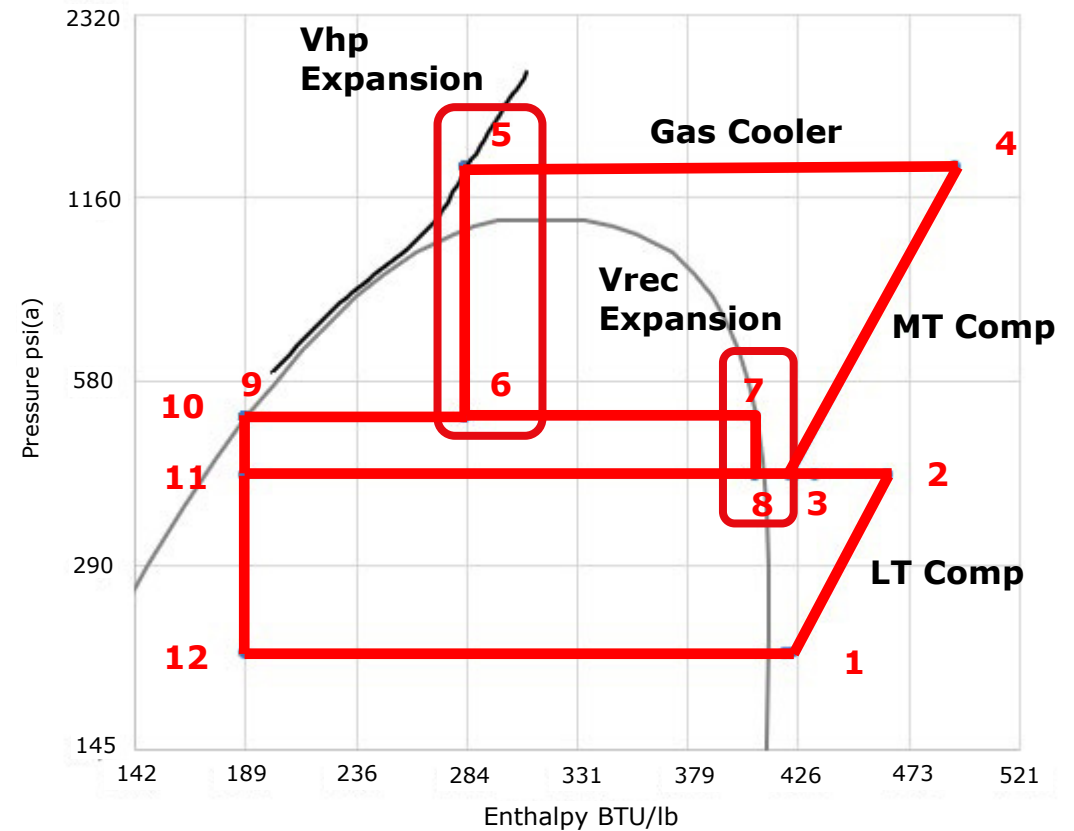
THE PRESSURE DROP ACROSS V_{hp} IS HOW WE CHANGE FROM SC FLUID TO LIQUID/GAS MIXTURE



CO₂ Transcritical Booster system



BOOSTER SYSTEM – 100°F AMBIENT



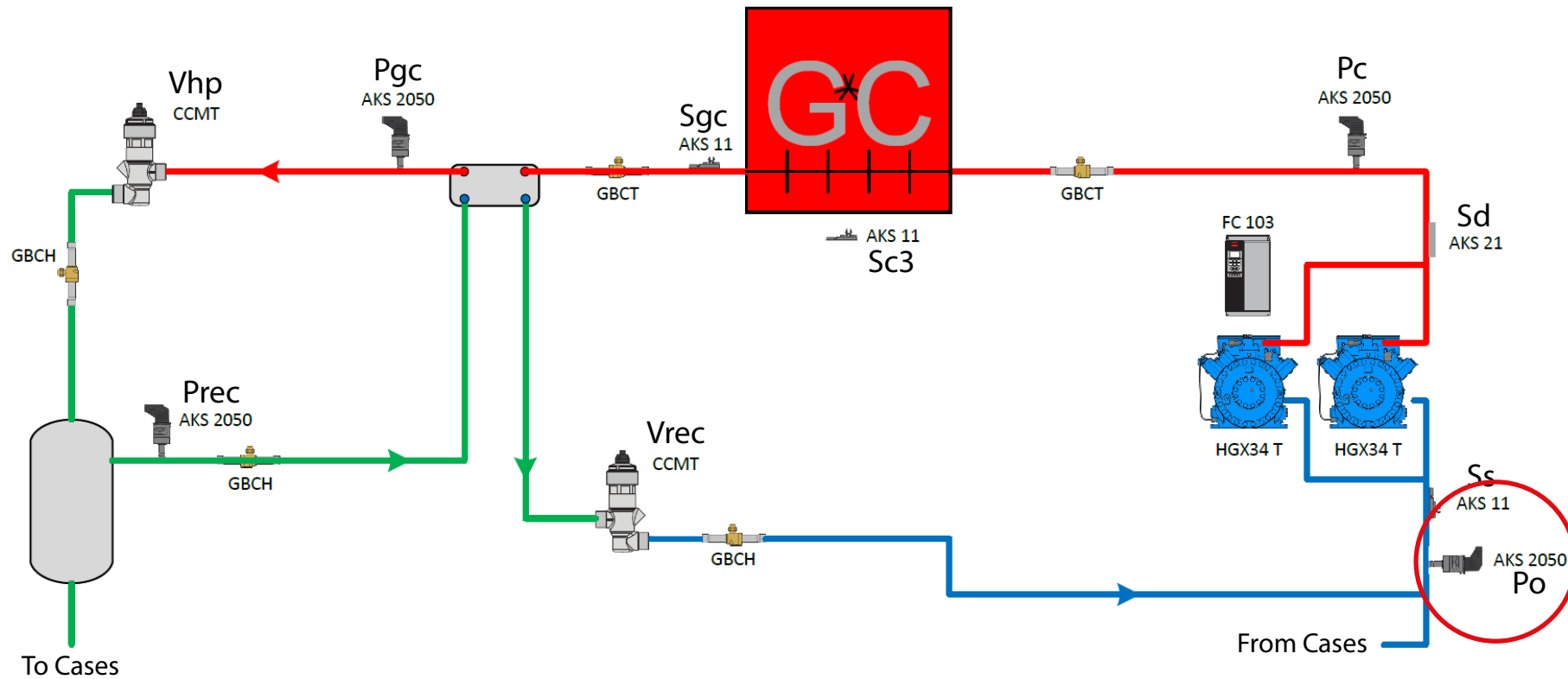
Questions?

AK-PC 782 Control Basics

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



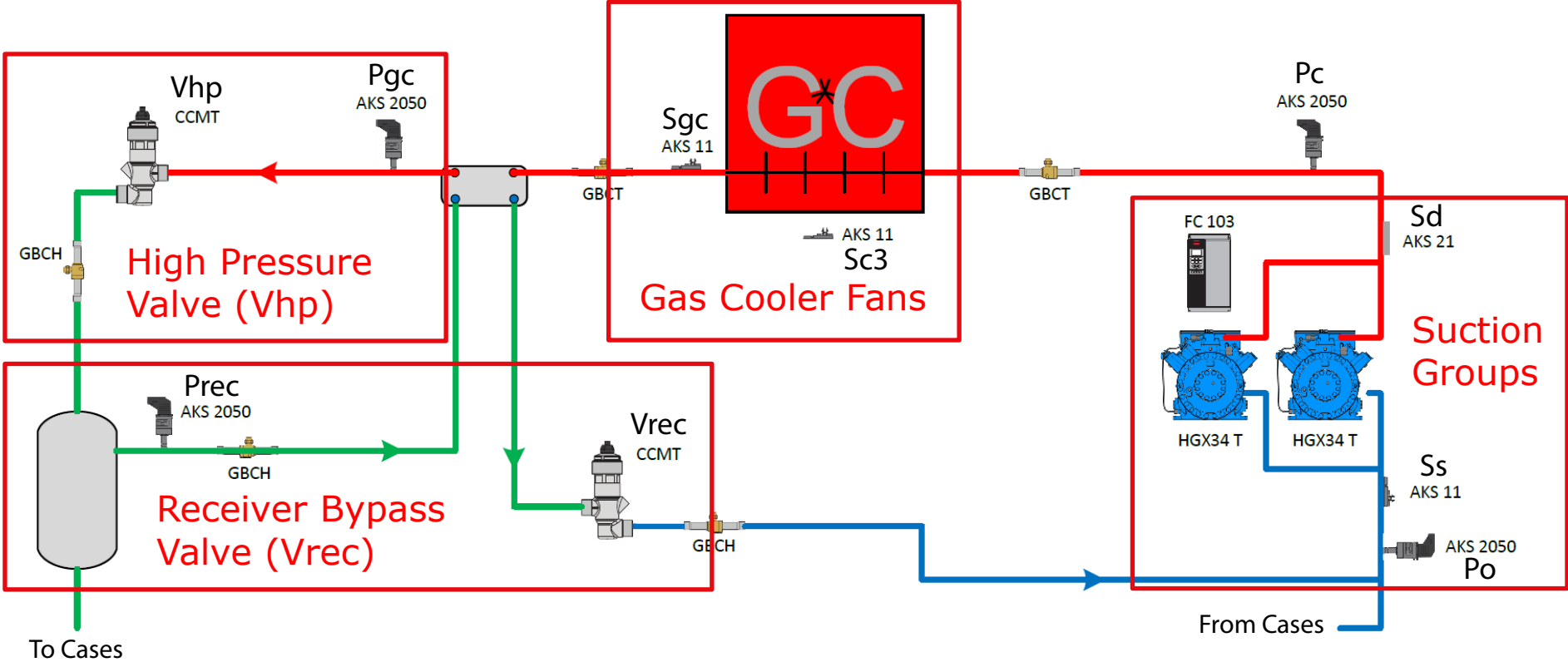
Danfoss Sensor and Device Abbreviations



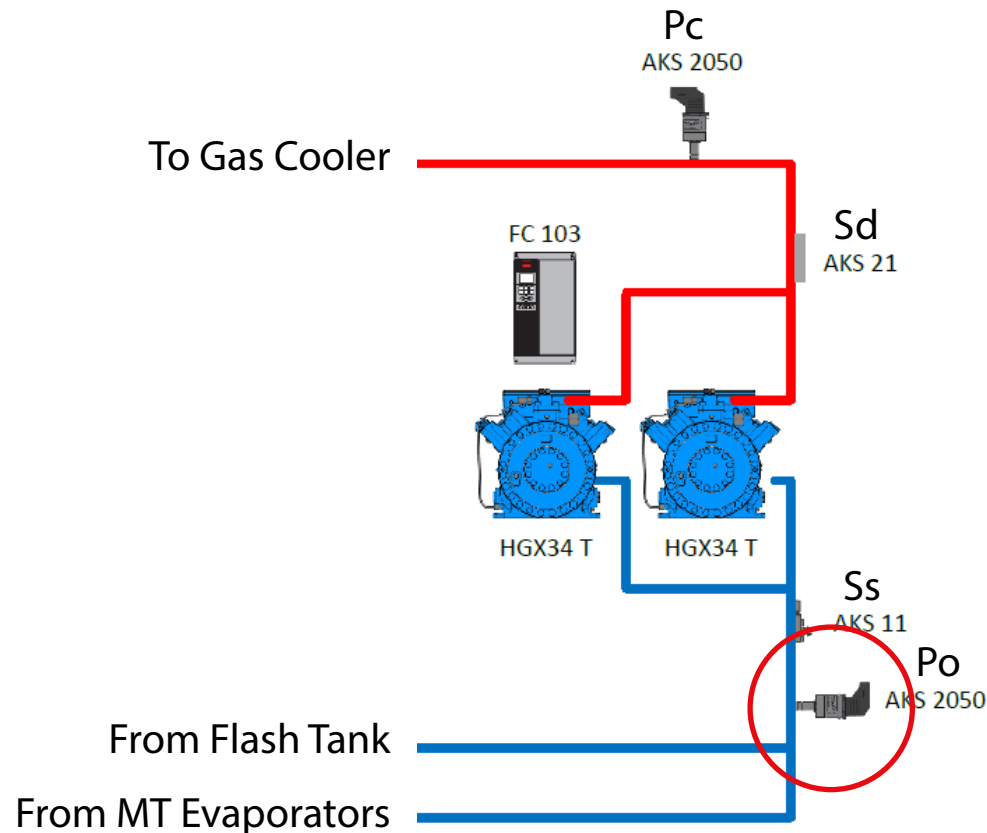
Po = Suction Pressure
 Ss = Suction Temperature
 Sd = Discharge Temperature
 Pc = Condensing Pressure
 Sc3 = Ambient Temperature

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

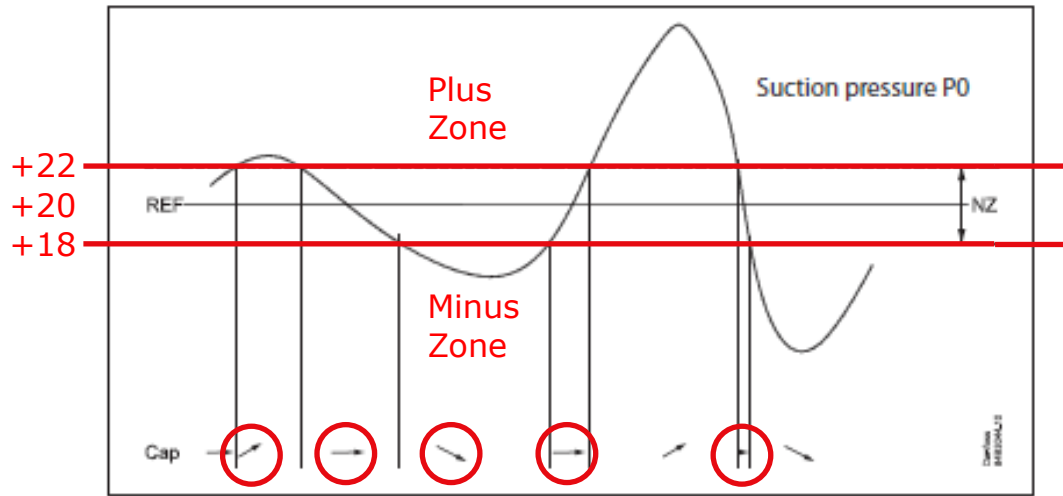
Key Set Points

- 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.

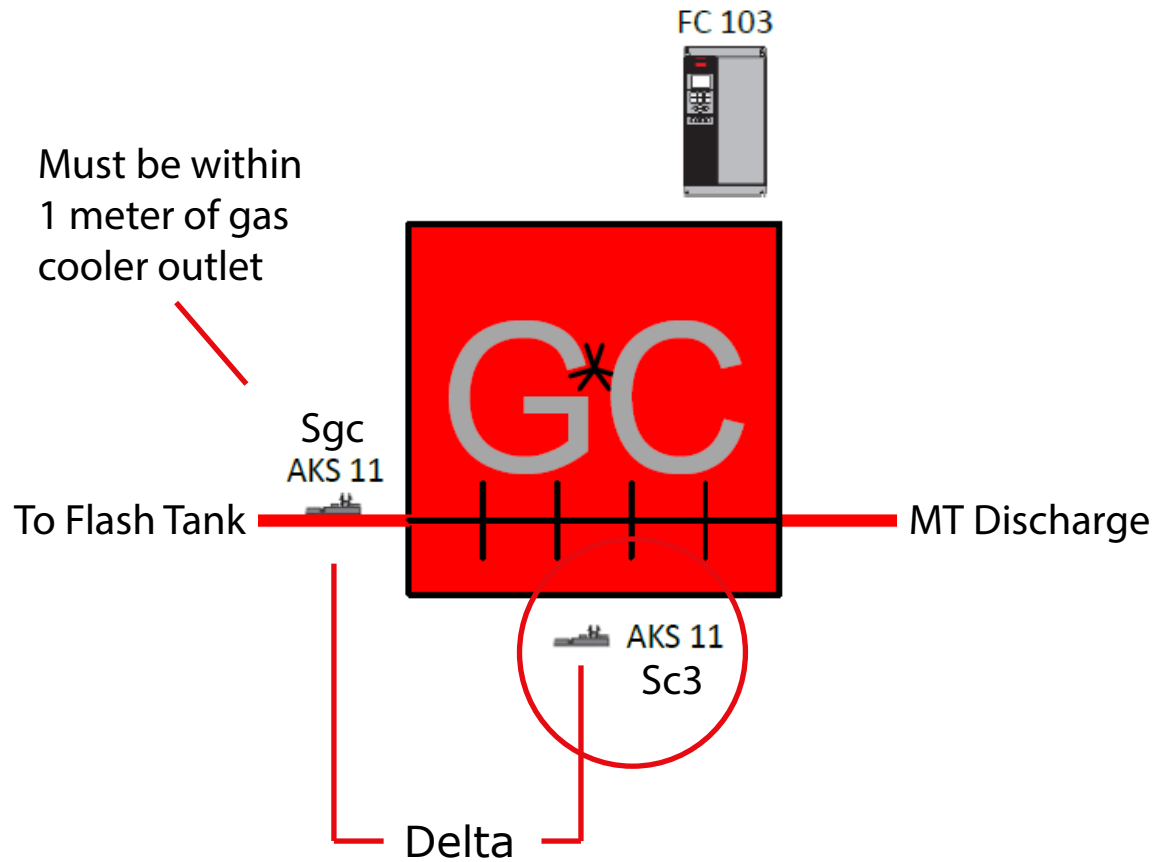
AK-PC782A – Suction Group Neutral Zone



- 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.

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

AK-PC782A – Gas Cooler Fan Control



Sensors

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

Devices

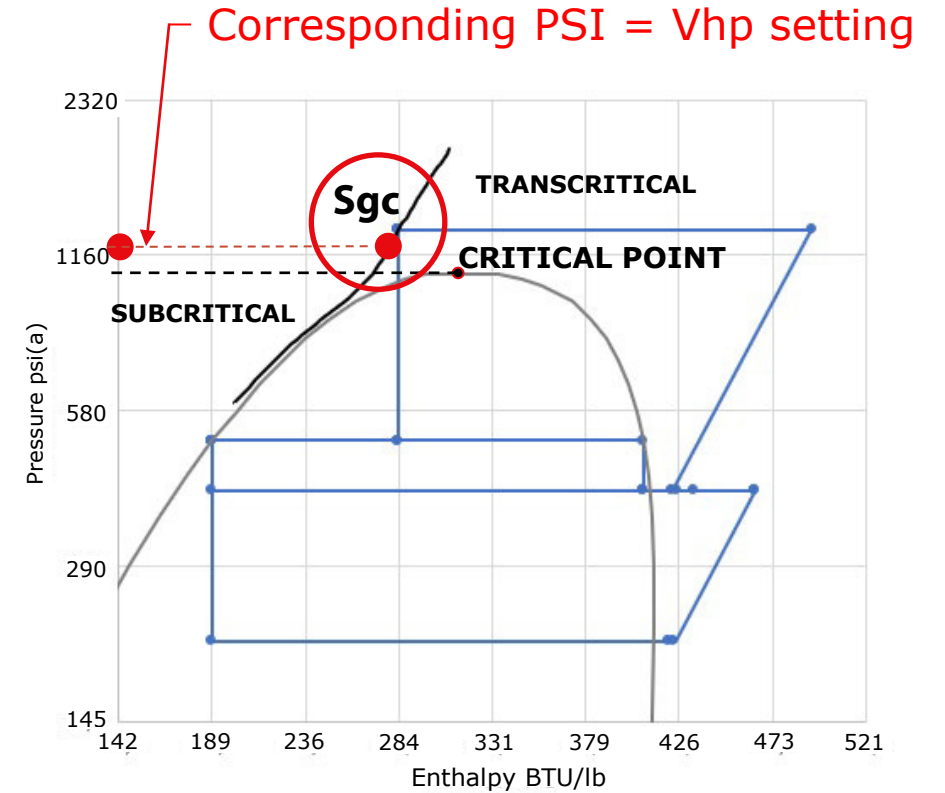
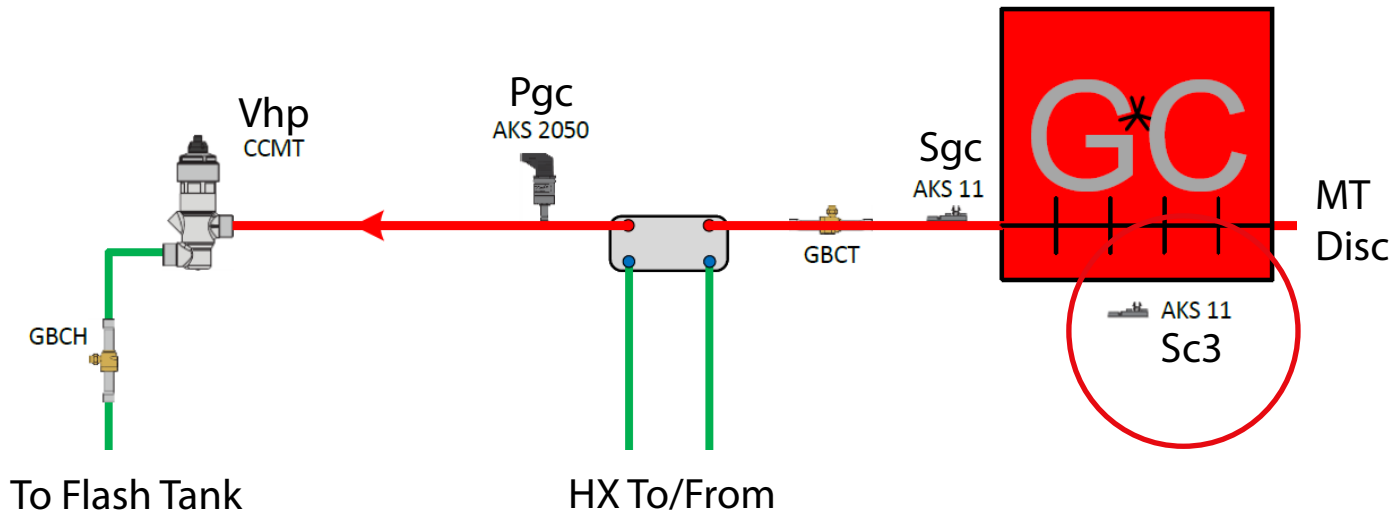
- Inverter/ECM Motors = Analog Output

Key Set Points

- Min. t_m = Minimum average temperature difference between Sc3 and Sgc
- Reference Mode = Use Floating so Min. t_m 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. t_m .

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.

CO₂ 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

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

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

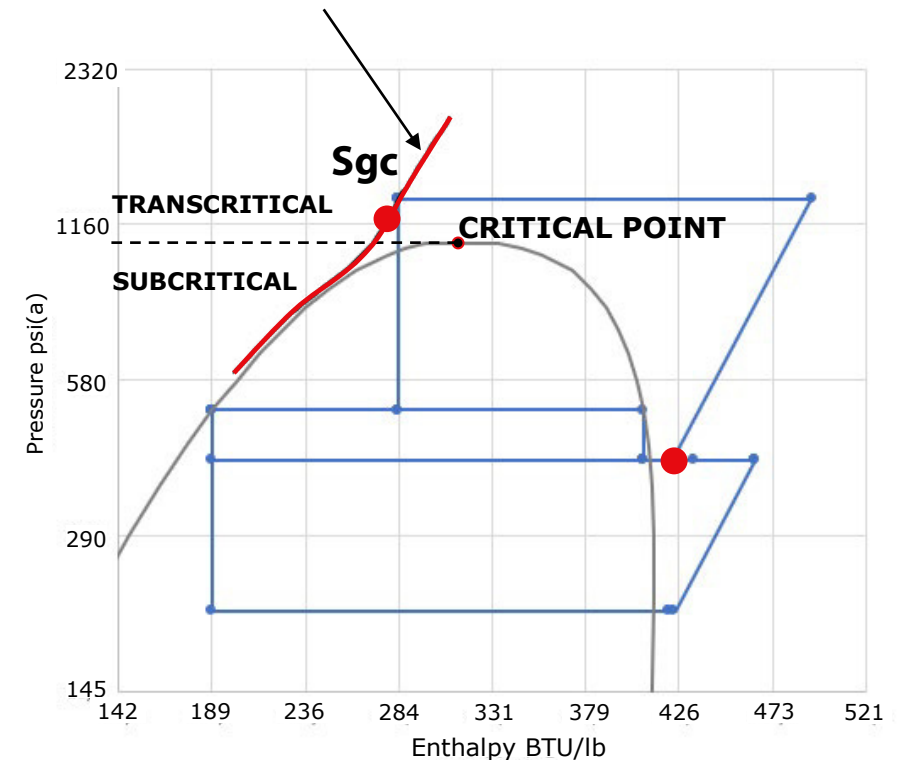
It is seen that, since W is finite, both COP_C and COP_H are less than ∞ . Also, from the first law equation, since $Q_H = Q_L + W$

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

$$COP_H = COP_C + 1$$

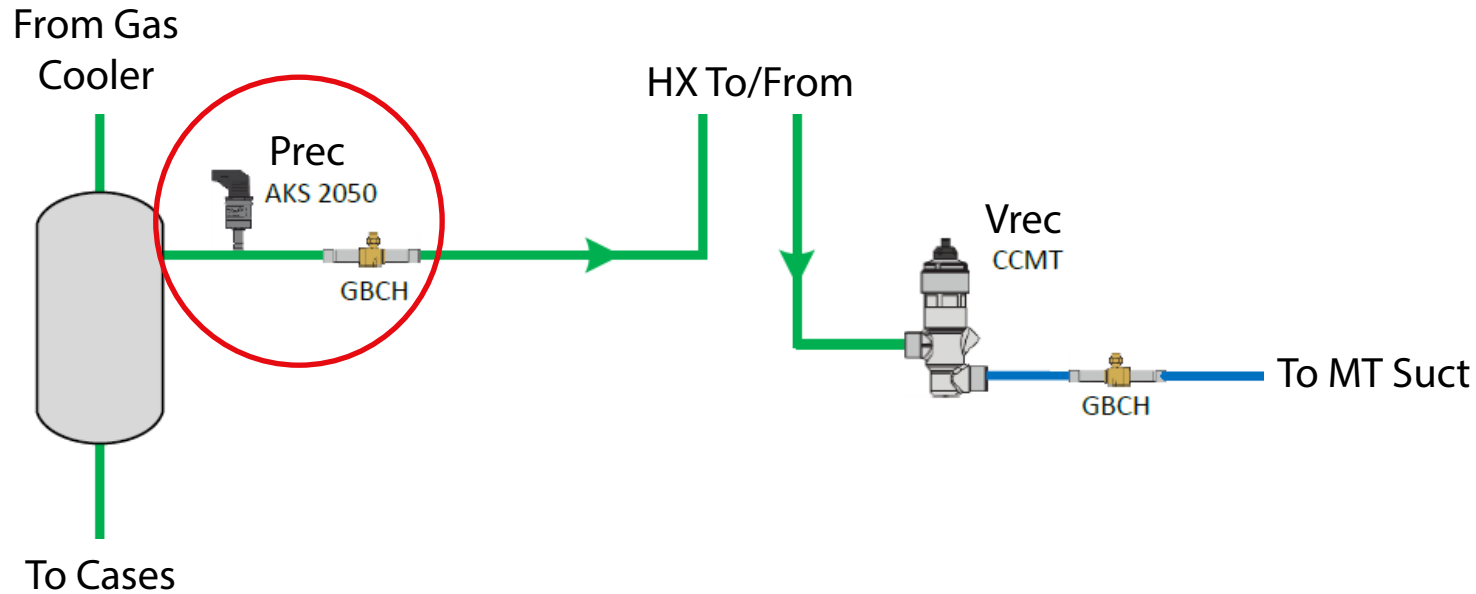
Accordingly, COP_H is always greater than unity. It is so since Q_H is always greater than Q_L by the amount W .

Optimal COP Line



At a given Sc_3 and Sgc , Pgc should be?

AK-PC782A – Receiver Bypass Valve (Vrec)



Sensors

- Prec = Receiver Pressure

Devices

- Vrec = Stepper Valve Output

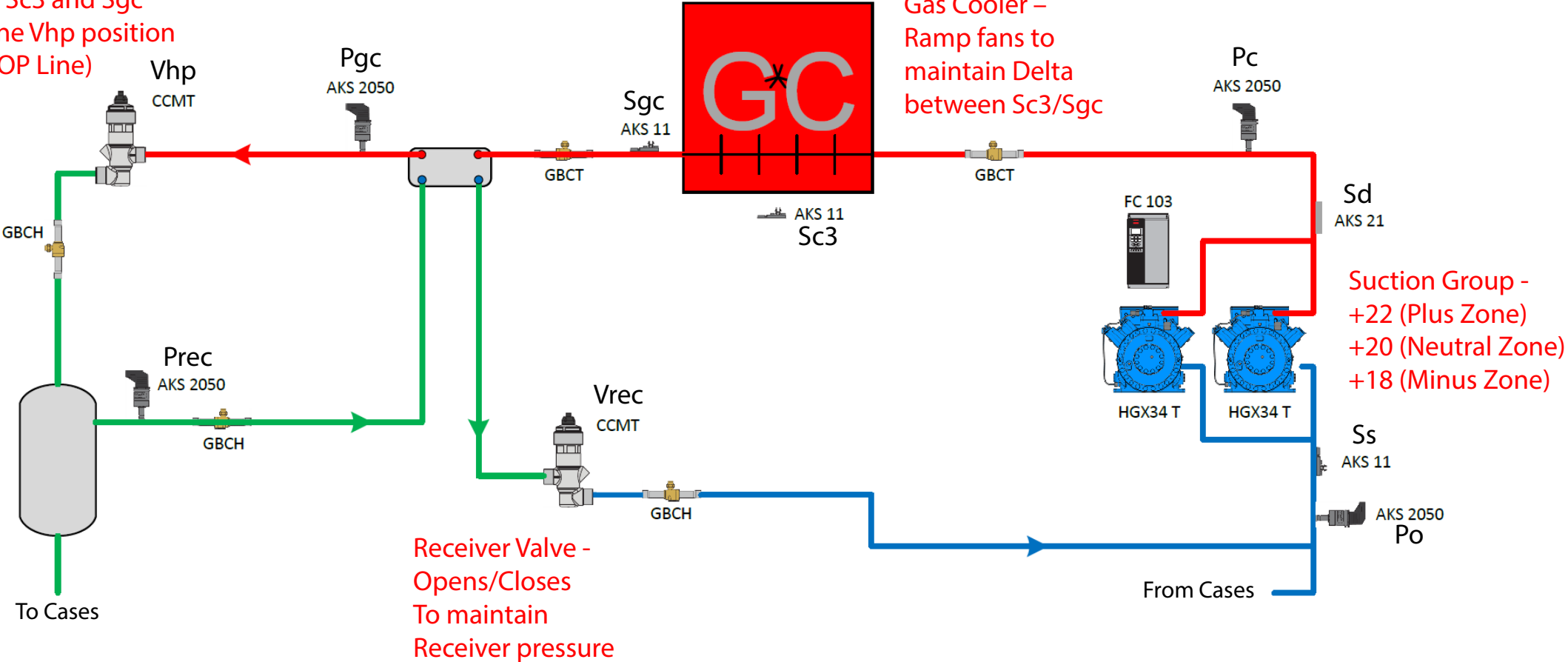
Key Set Points

- 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

High Pressure Valve -
References Sc3 and Sgc
to determine Vhp position
(Optimal COP Line)



Questions?

Service Tool (ST500)

Service Tool AK-ST 500

Main Screen Features

MT Suction Group



LT Suction Group



Gas Cooler Fan



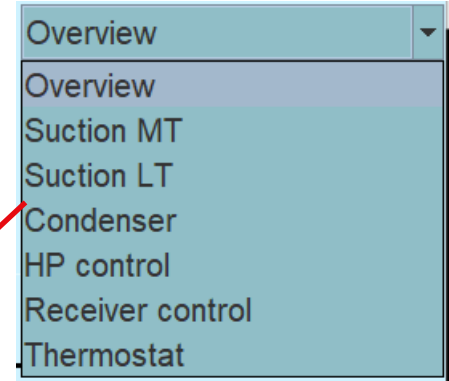
High Pressure Valve



Receiver Bypass Valve



Alarm	value	Ref.	Act.%	Status
	28.6 °F	18.0 °F	65	Alarm comp.
	-12.0 °F	-22.0 °F	45	Alarm comp.
	7.3 °F	56.5 °F	0	Standby
	935.1 psi	725.2 psi	100	Normal
	35.0 °F	36.0 °F	0	Normal ctrl.



Ref. = Set Point

Value = Actual

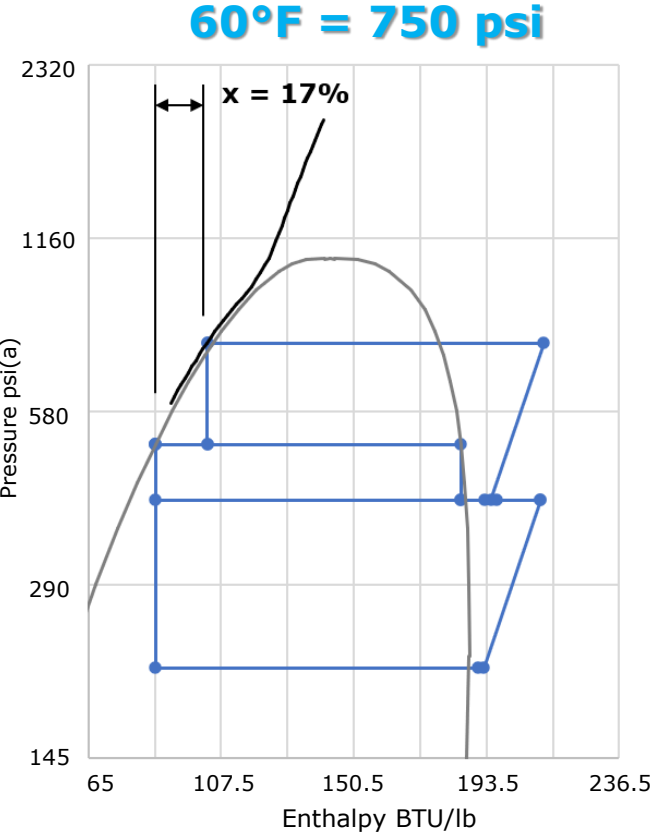
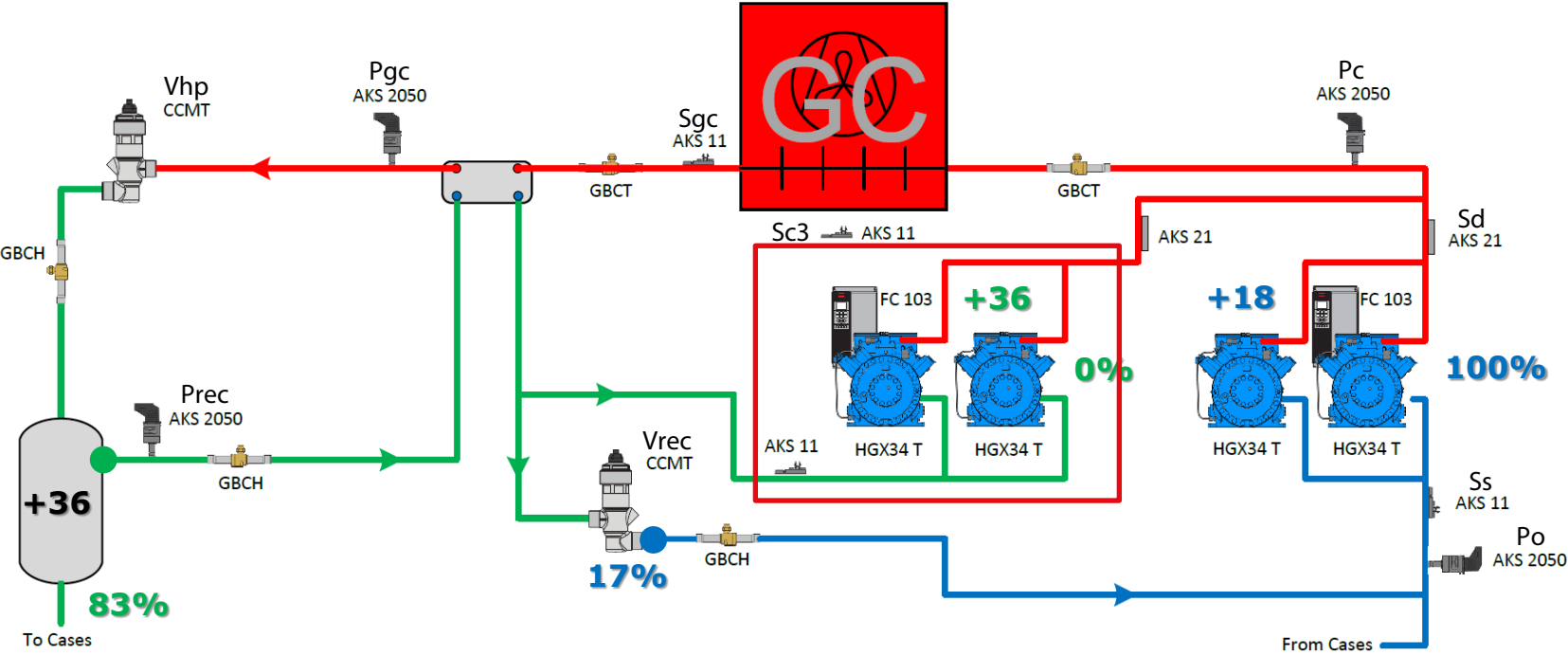
Act.% = Active Capacity

Status = Condition

Alarm = Problem

Parallel Compression Overview

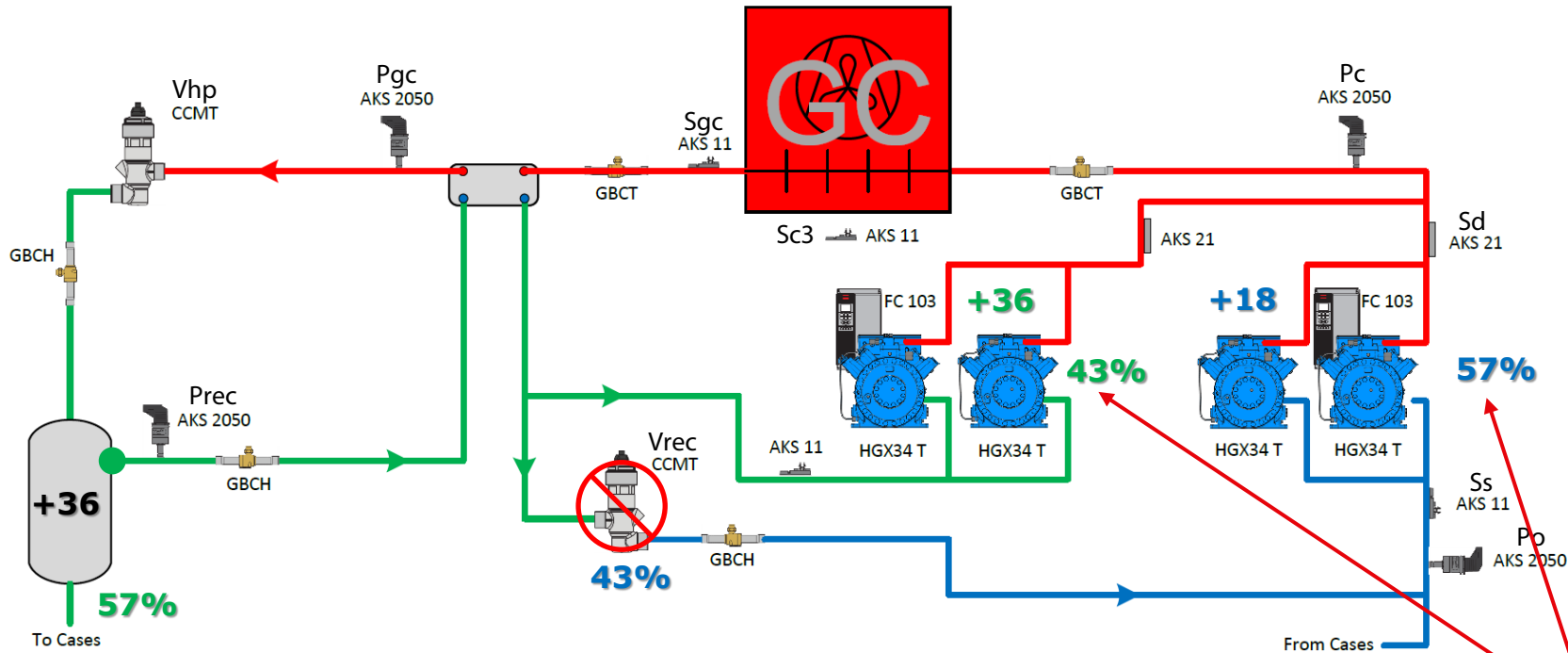
Mode 2 – Parallel Compression – Cold Ambient



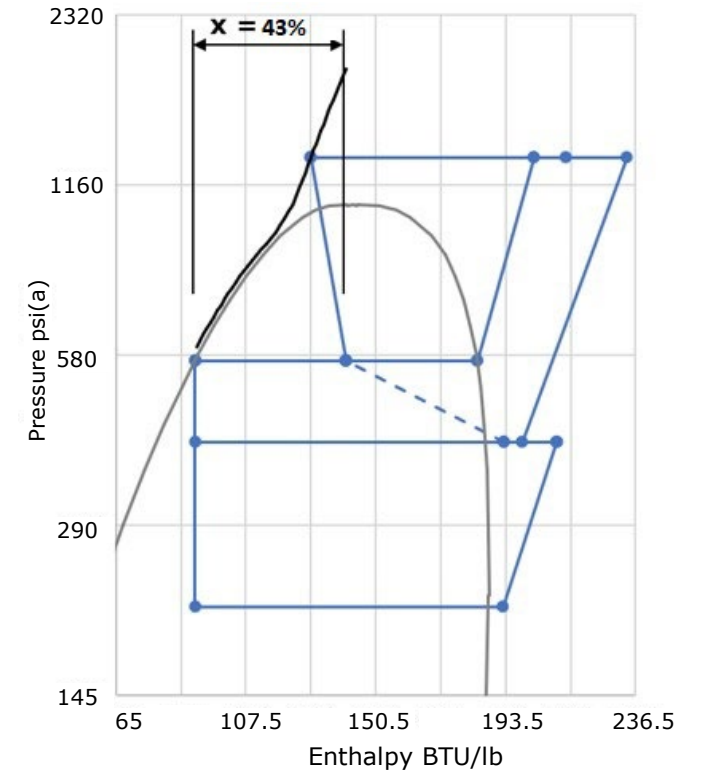
Parallel Compressors are an optimal solution for addressing the flash gas in the receiver

- 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



100°F = 1300 psi



- 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%)

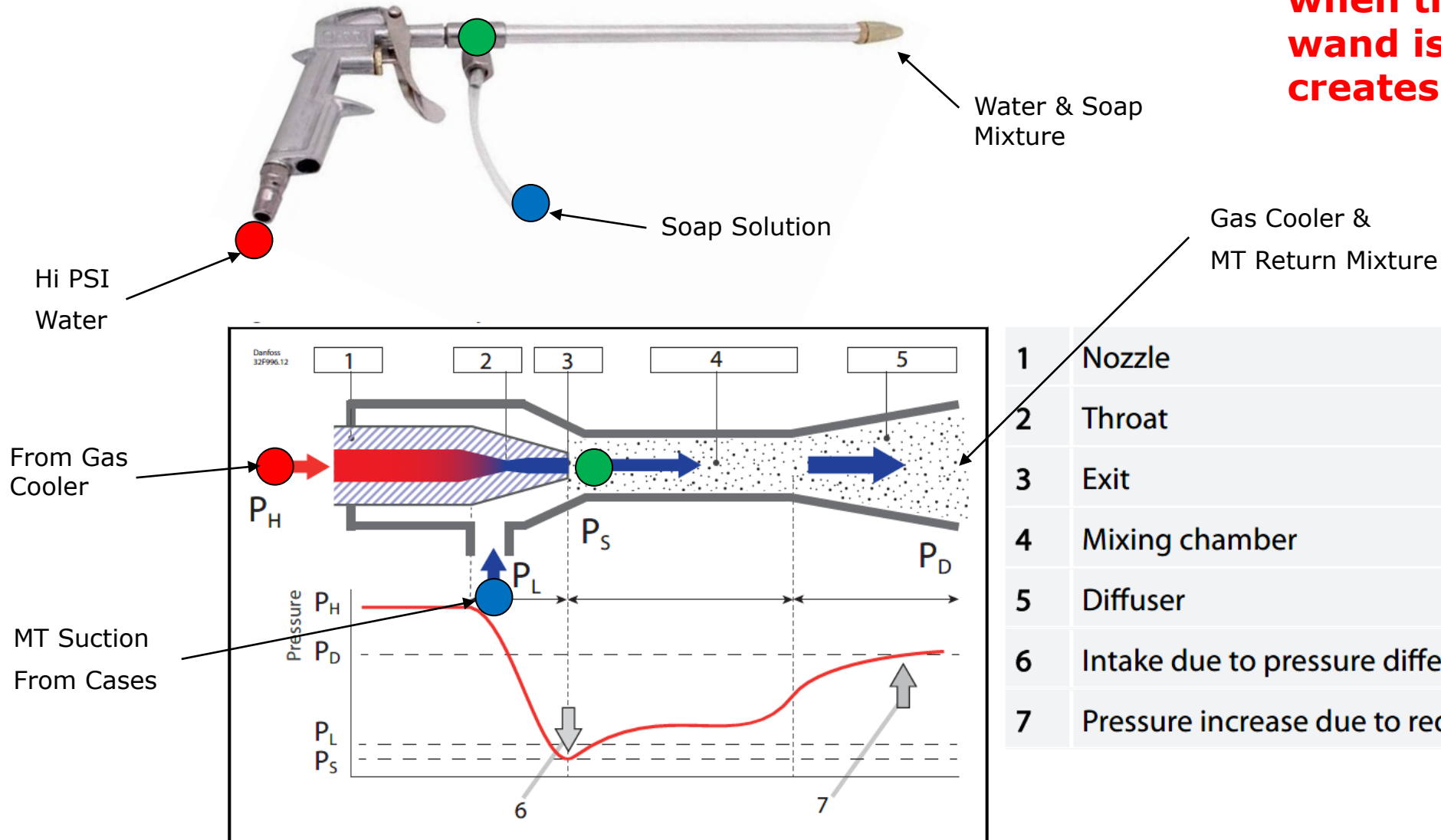
Questions?

Ejector Overview



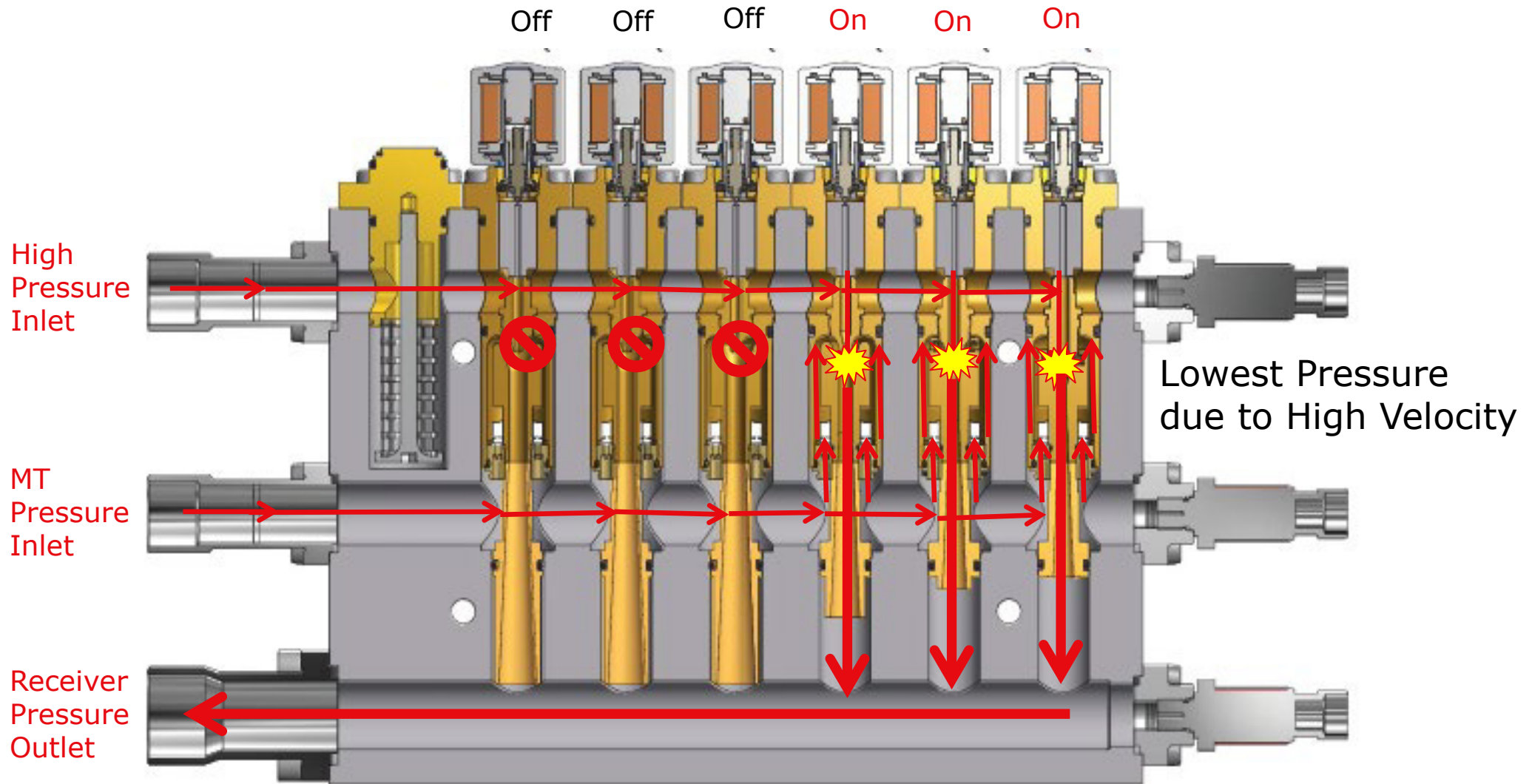
Working Principal of the Multi-Ejector

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



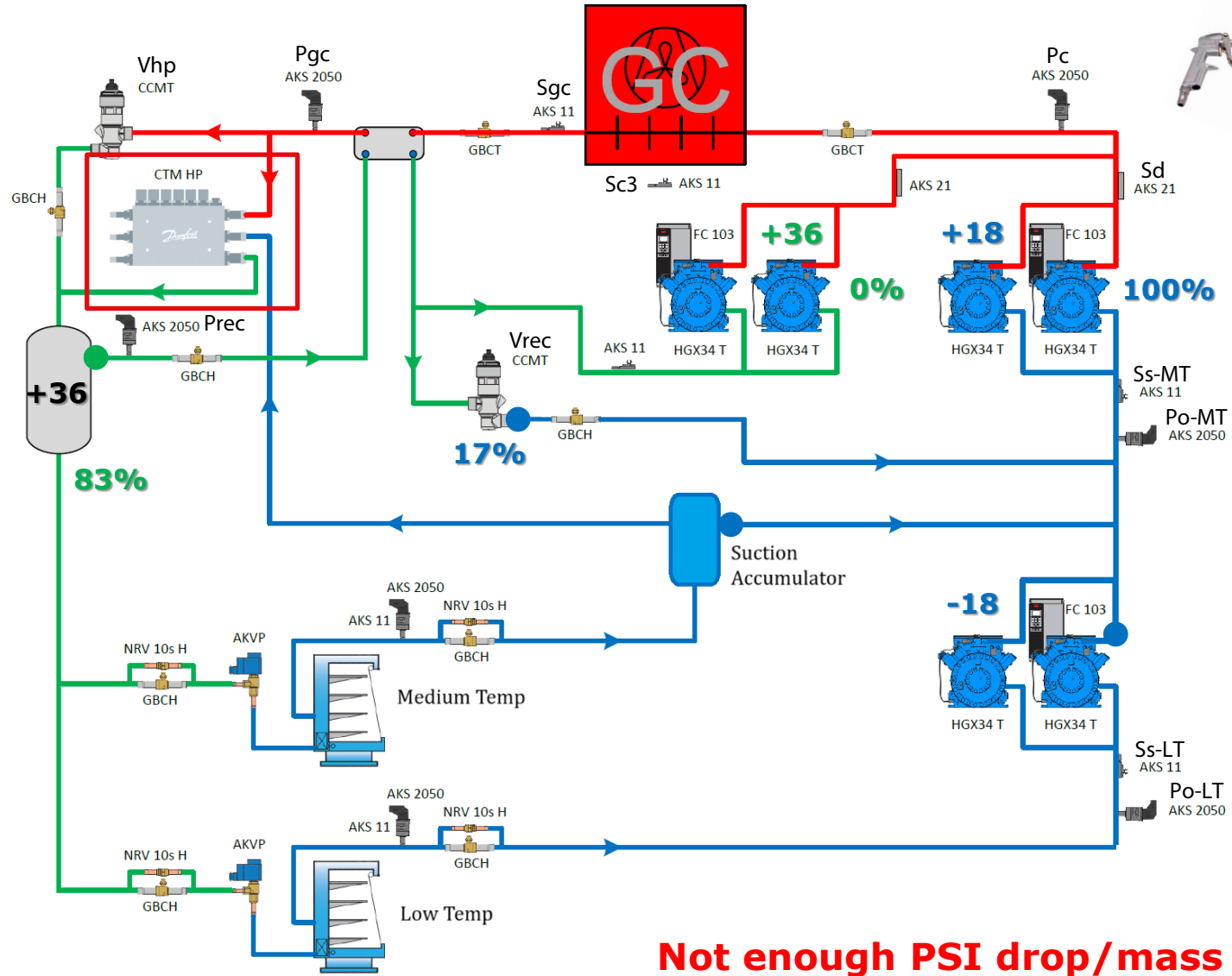
1	Nozzle
2	Throat
3	Exit
4	Mixing chamber
5	Diffuser
6	Intake due to pressure differential
7	Pressure increase due to reducing flow velocity

How does the Multi-Ejector work?

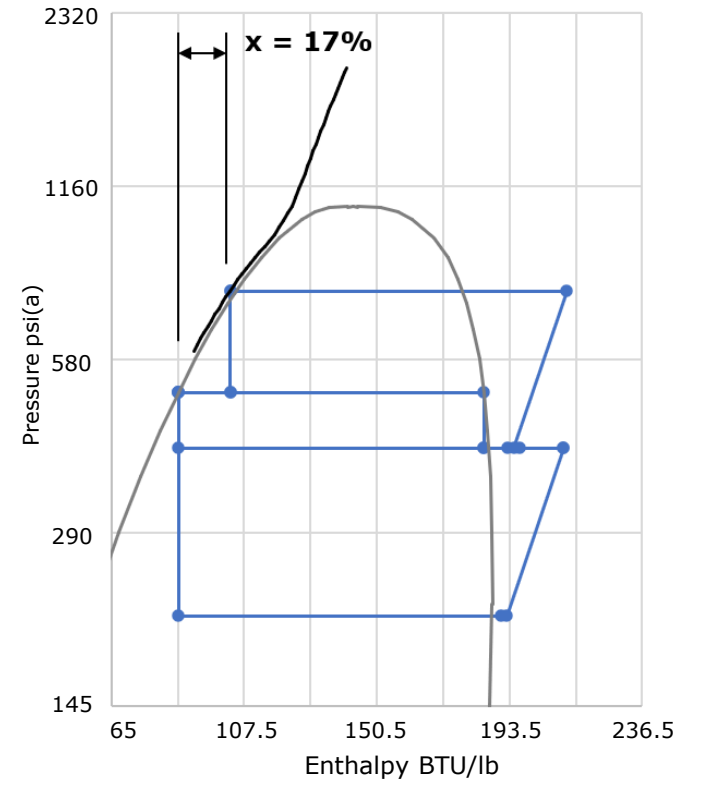


Mode 3 – HP Ejectors – Cold Ambient

We haven't pulled the trigger on the wand



60°F = 750 psi

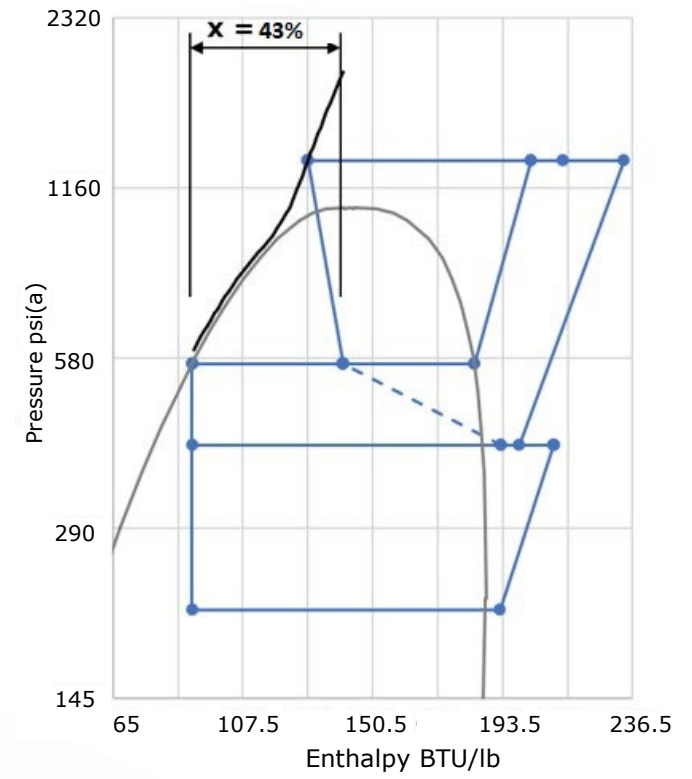
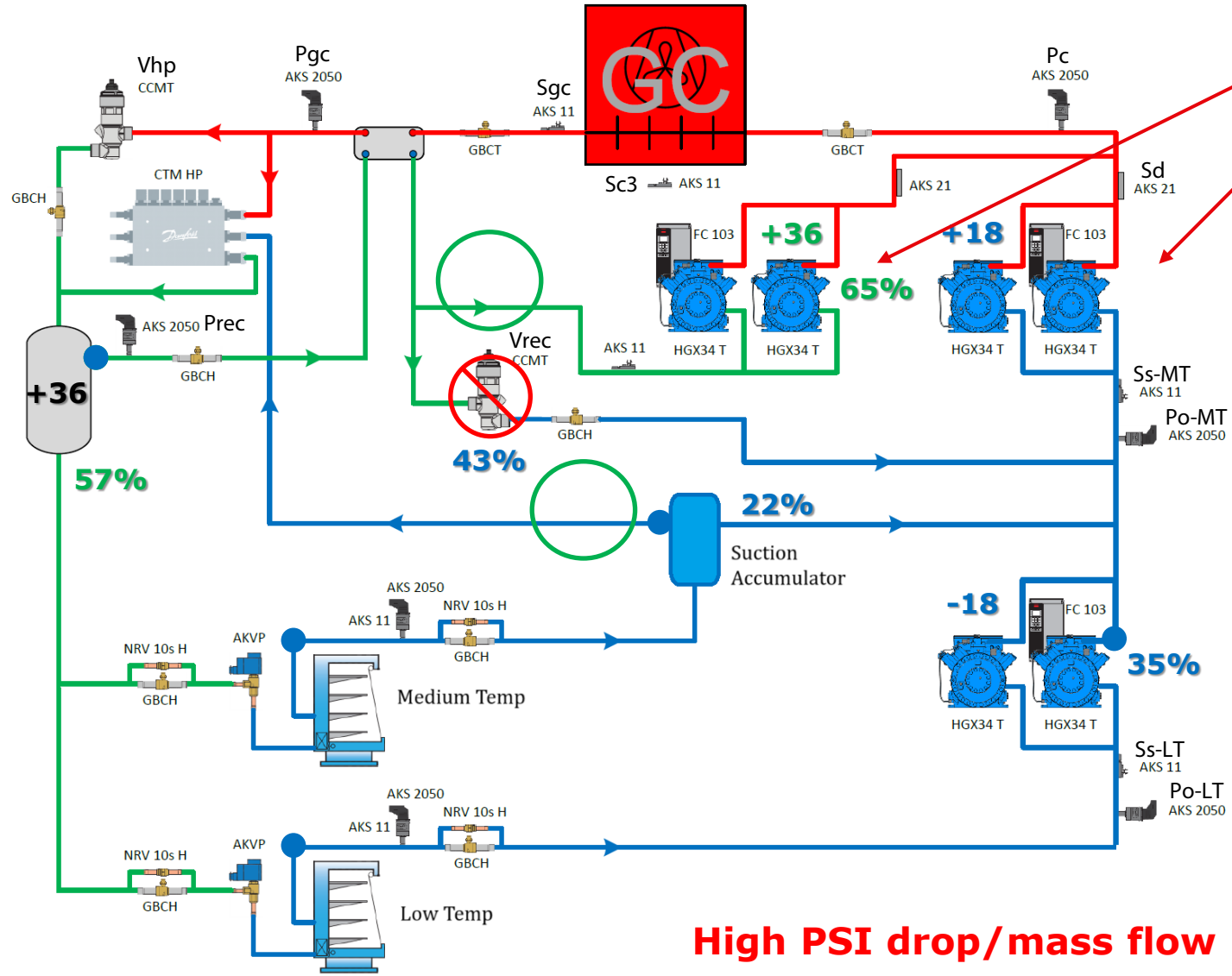


Not enough PSI drop/mass flow to create venturi effect

Mode 3 - HP Ejectors - Warm Ambient

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

100°F = 1300 psi

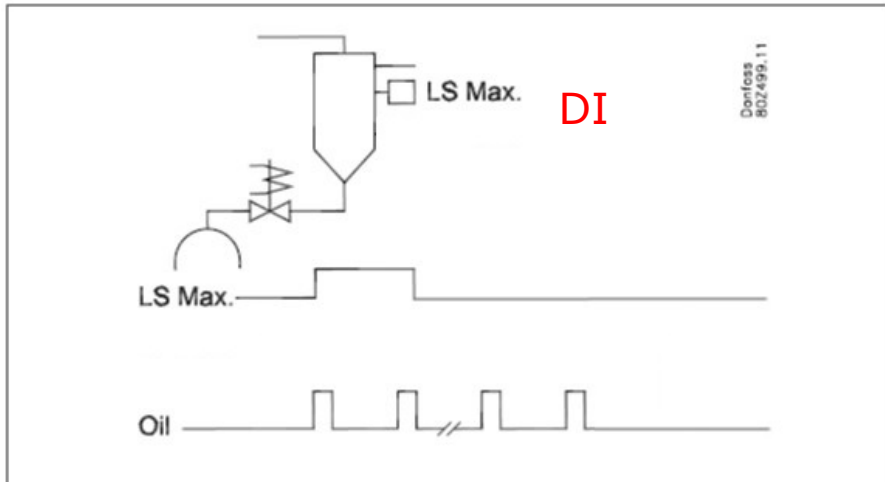


High PSI drop/mass flow = Trigger has been pulled

Questions?

Next Lesson

AK-PC782A – Oil System with One Level Switch



SSRO

Systems with one level switch

Full sequence:

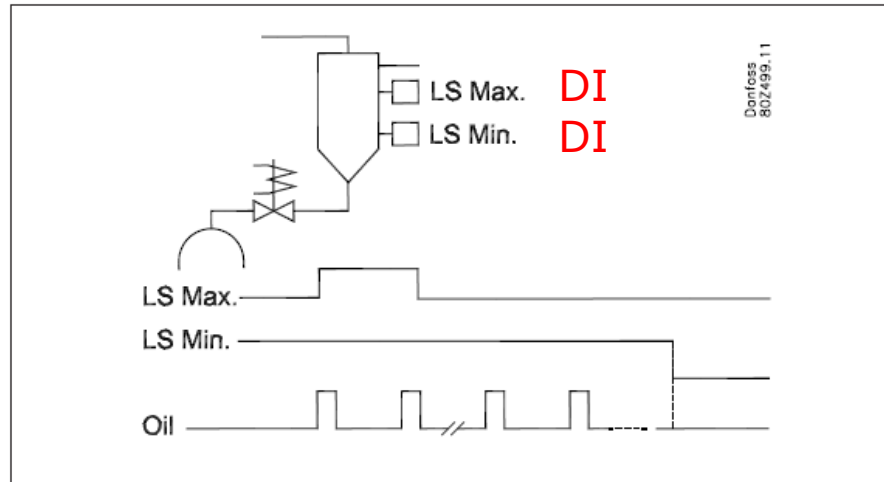
- When the level switch registers oil, the oil is emptied into the receiver running all periods. Users define the pulse length, period time between pulses and number of periods.

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

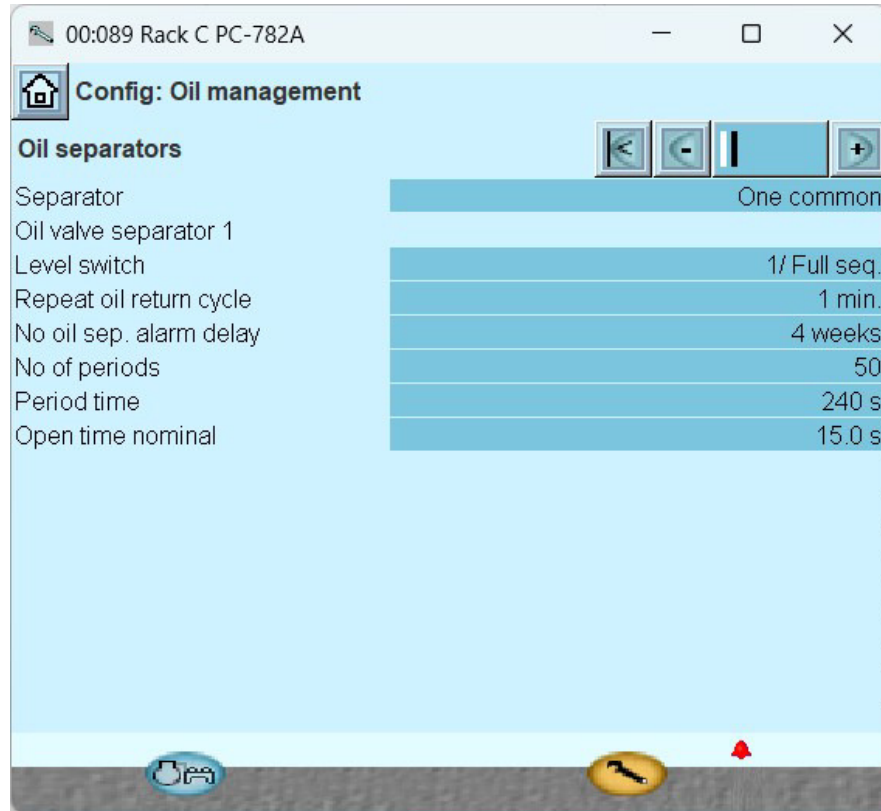


SSRO

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 FOUR MINUTES