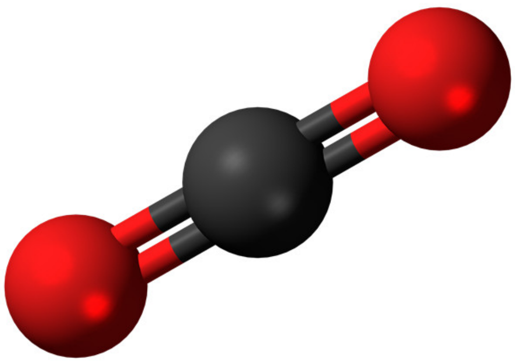

CO2 Refrigeration and Heat Pumping

ASHRAE Puget Sound

November 14, 2017

Greg Scrivener - greg.scrivener@colddynamics.com

COLD DYNAMICS

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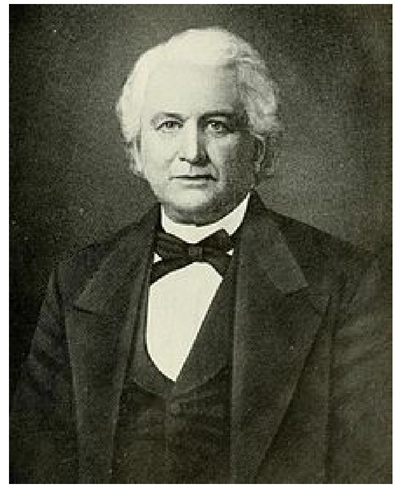
Objectives

- Why is CO_2 refrigerant is being used as a “new” technology?
- What type of applications are using CO_2 as a refrigerant? Why?
- Are there code and safety implications of using CO2?

History

- Alexander Twinning patented a CO2 refrigeration system in 1850.
- By the 1930s CO2 had largely fallen from favour to ammonia and other refrigerants.

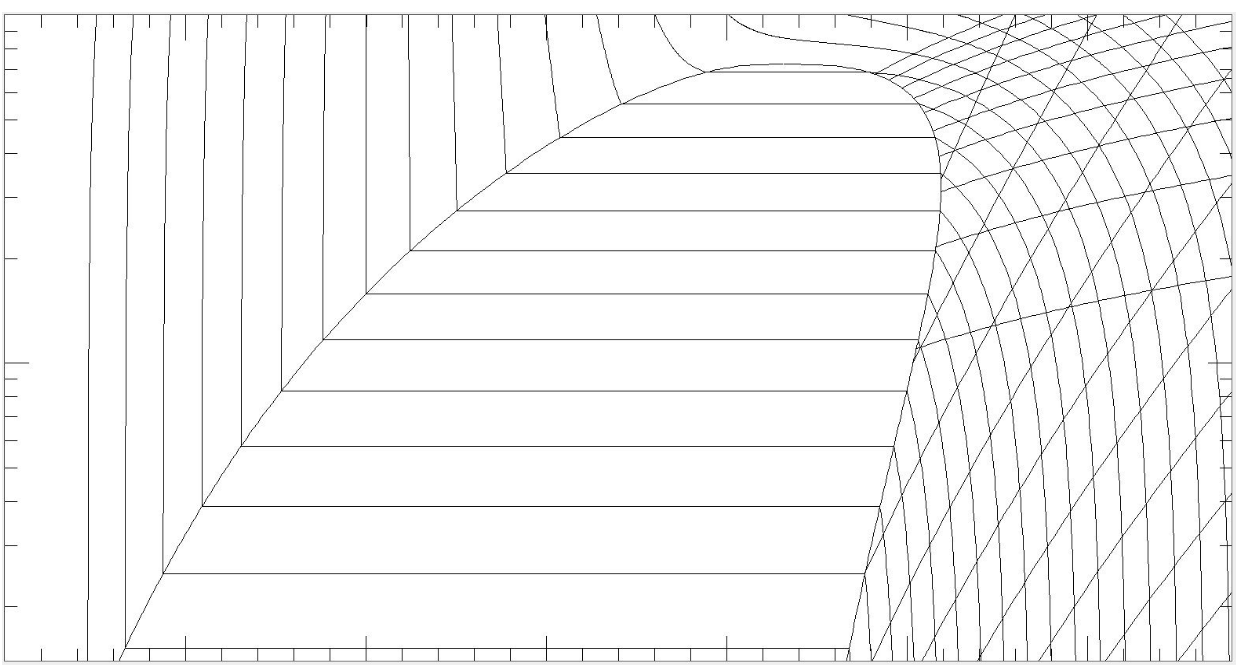


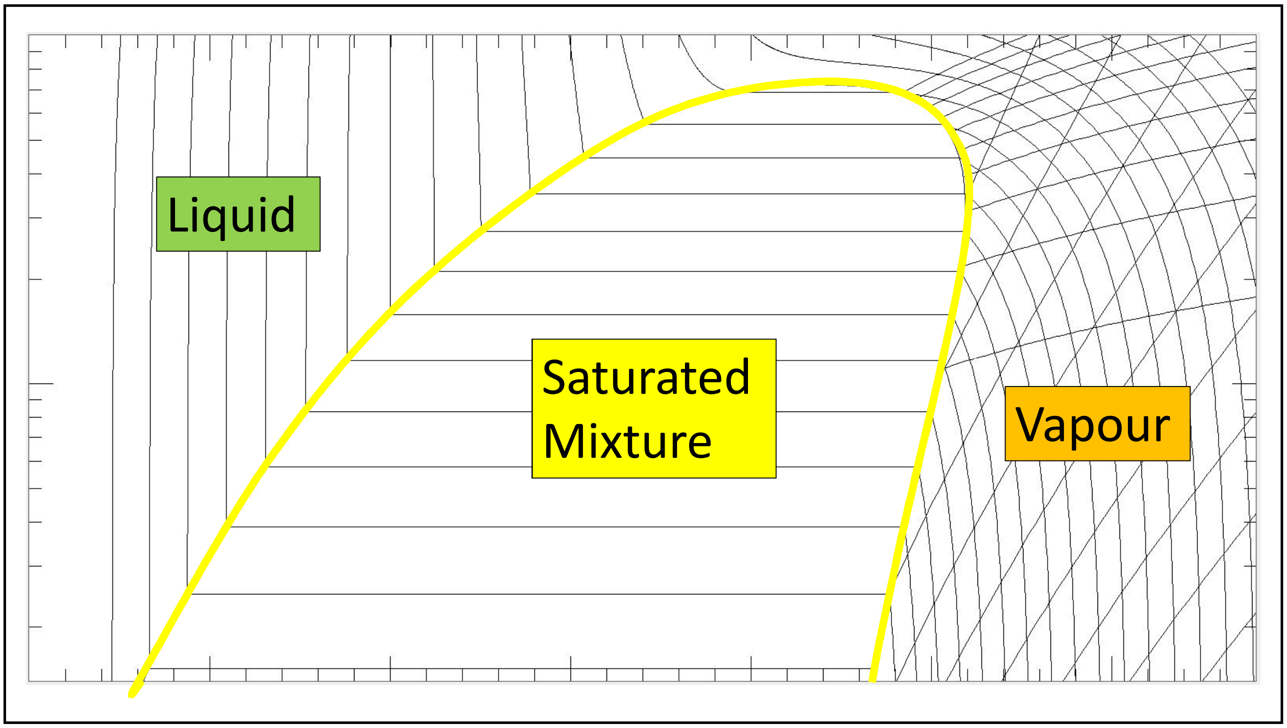
Going back to CO_2

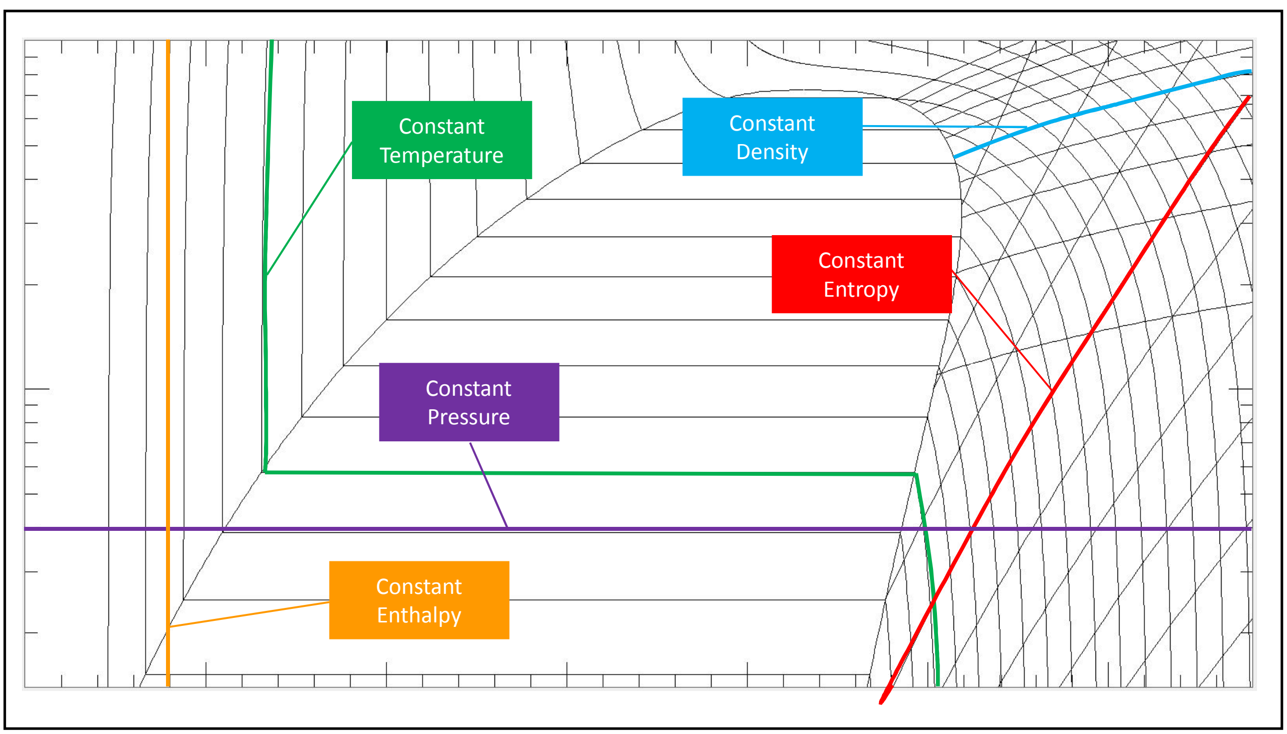
Refrigerant	Ozone Depleting Potential	Global Warming Potential	Safety Classification
R12	1.0	10,900	A1
R22	0.055	1810	A1
R502	0.334	4657	A1
R134A	0	1430	A1
R404A	0	3922	A1
R410A	0	2088	A1
R32	0	675	A2L
R290	0	6	A3
R1234YF	0	4*	A2L
R717	0	0	B2L
R744	0	1	A1

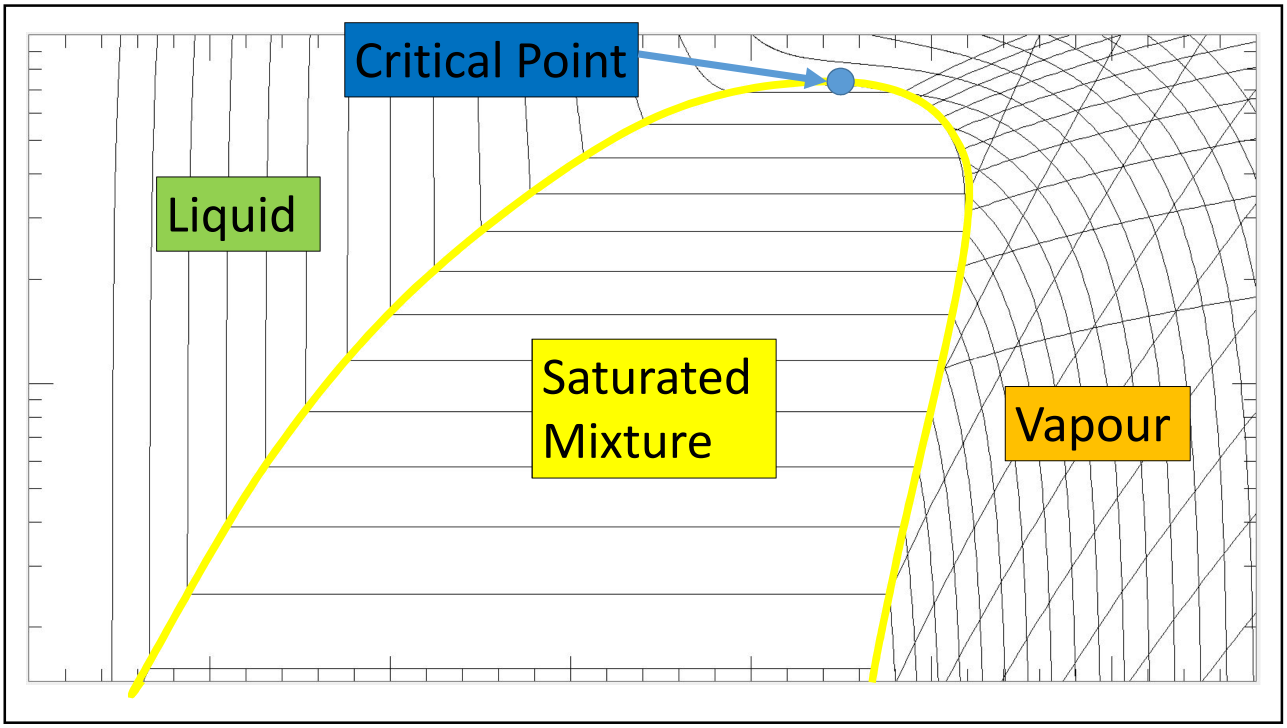
So what's the problem?

- Low critical point!
- Narrow range of operating temperatures?
- High operating pressure!
- It turns solid!



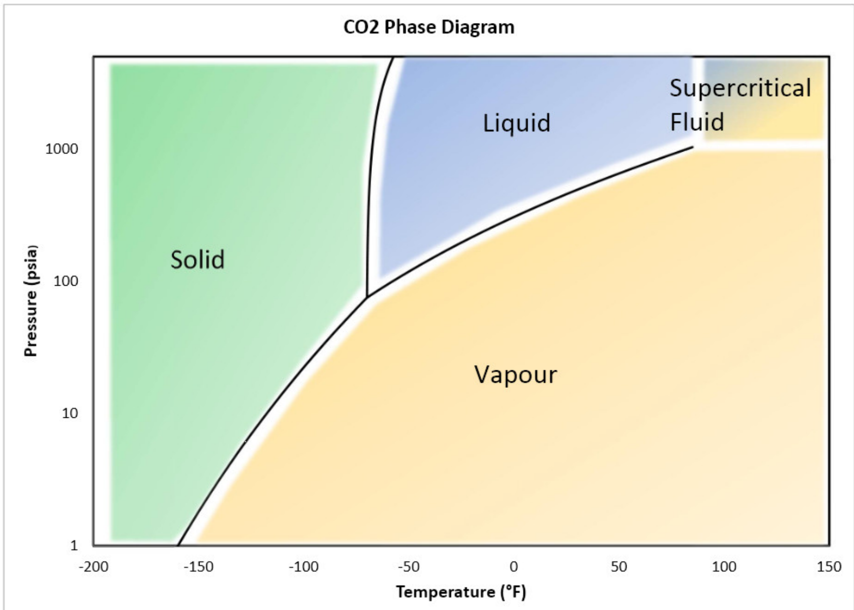

Liquid
Saturated Mixture
Vapour

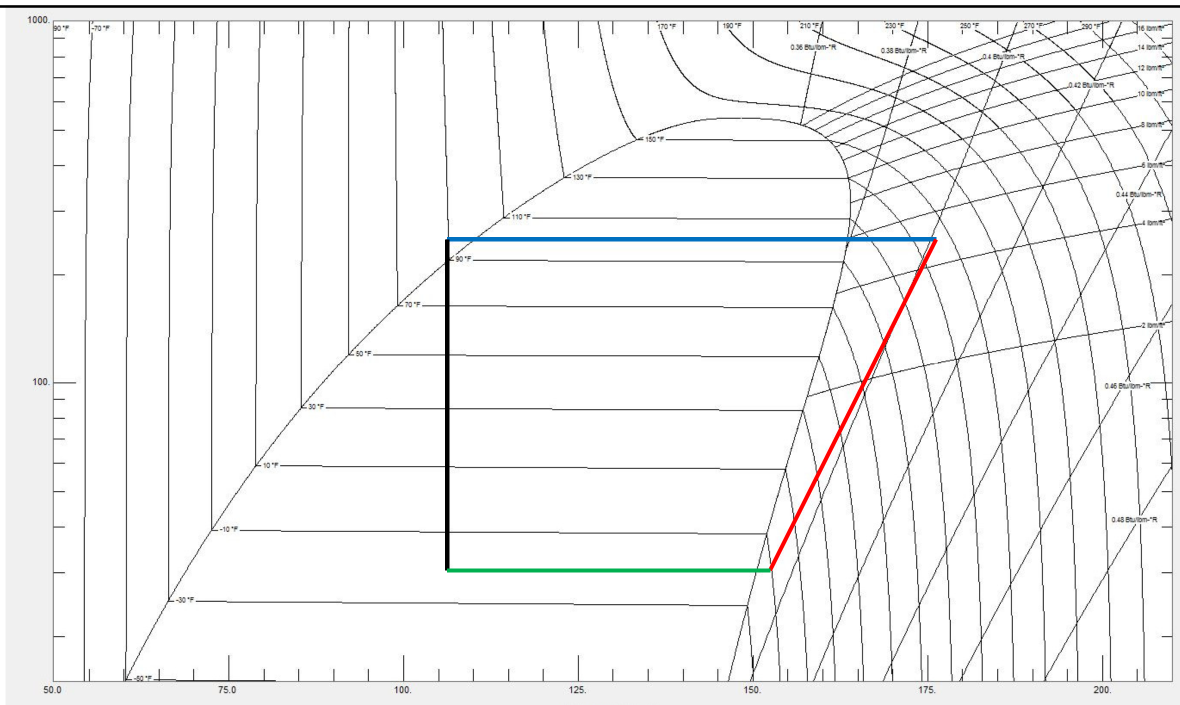

Constant Temperature
Constant Density
Constant Entropy
Constant Pressure
Constant Enthalpy

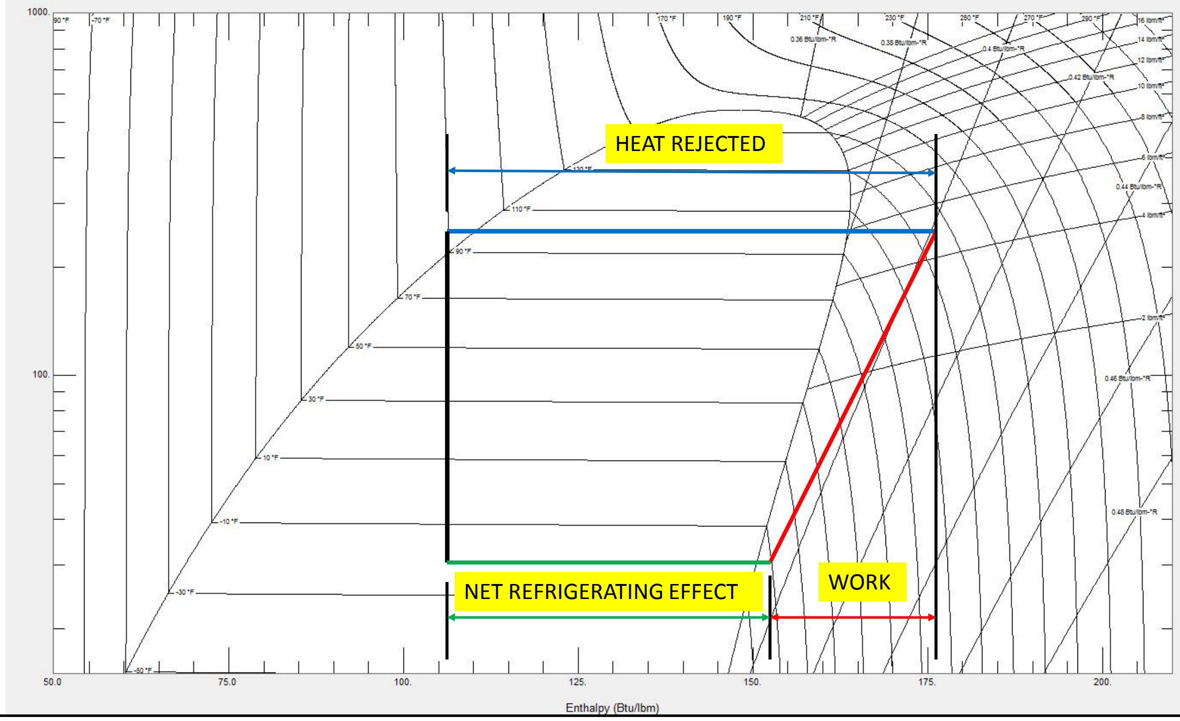


Critical Temperature and Pressure

- Critical Temperature – The temperature above which it is impossible to liquefy a vapour using only a change in pressure
- Critical Pressure – the pressure required to liquefy a gas at its critical temperature


CO2 Phase Diagram
Solid
Liquid
Supercritical
Fluid
Vapour
Pressure (psia)
1000
100
10
1
-200
-150
-100
-50
0
50
100
150
Temperature (°F)


1000.
100.
50.0
75.0
100.
125.
150.
175.
200.
Enthalpy (Btu/lbm)



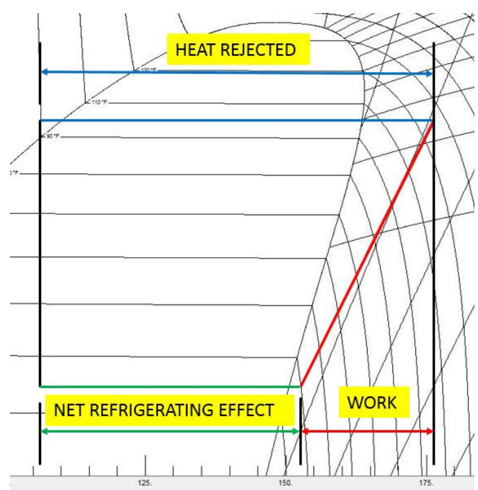
Coefficient of Performance

- $COP_{Cooling} = \frac{Net\ Refrigerating\ Effect}{Work\ Input}$

- $COP_{Heating} = \frac{Heat\ Rejected}{Work\ Input}$

- Maximum theoretical efficiency depends only on the temperature (Carnot Efficiency)

- $COP_{Max} = \frac{T_{cold}}{T_{hot} - T_{cold}}$



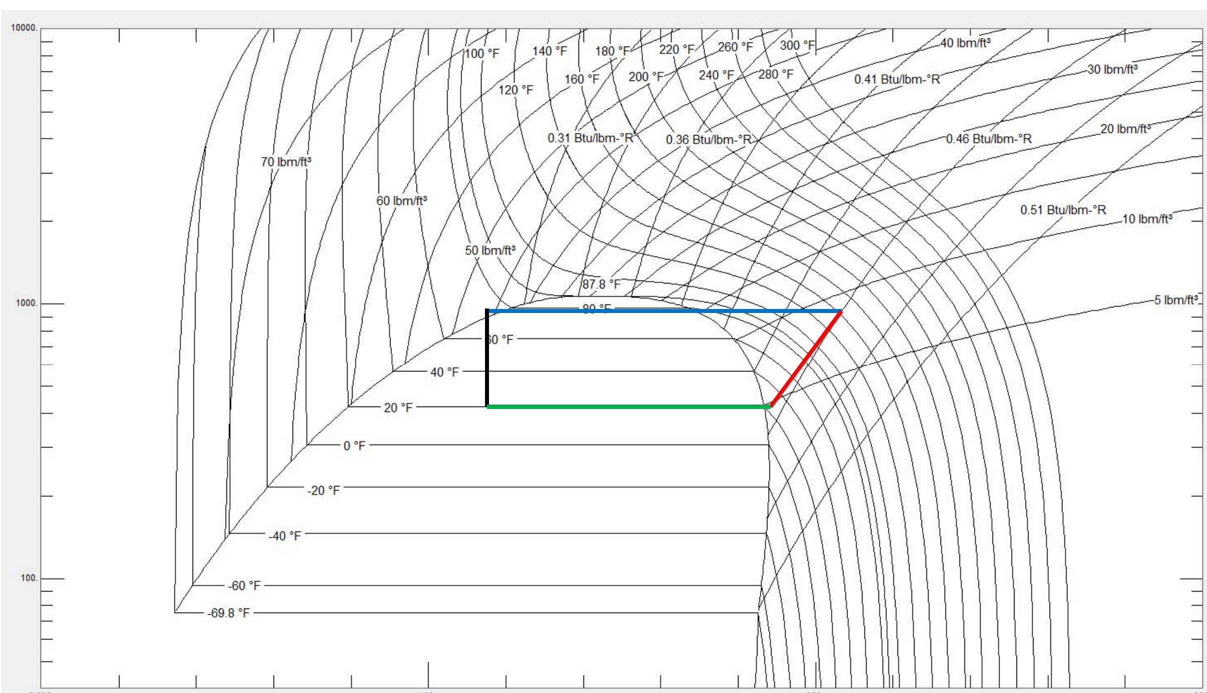
CO_2 System Terminology

Subcritical

- Systems that operate only below the critical point.

Transcritical

- Systems that operate both above and below the critical point. They have both subcritical and supercritical operating modes.



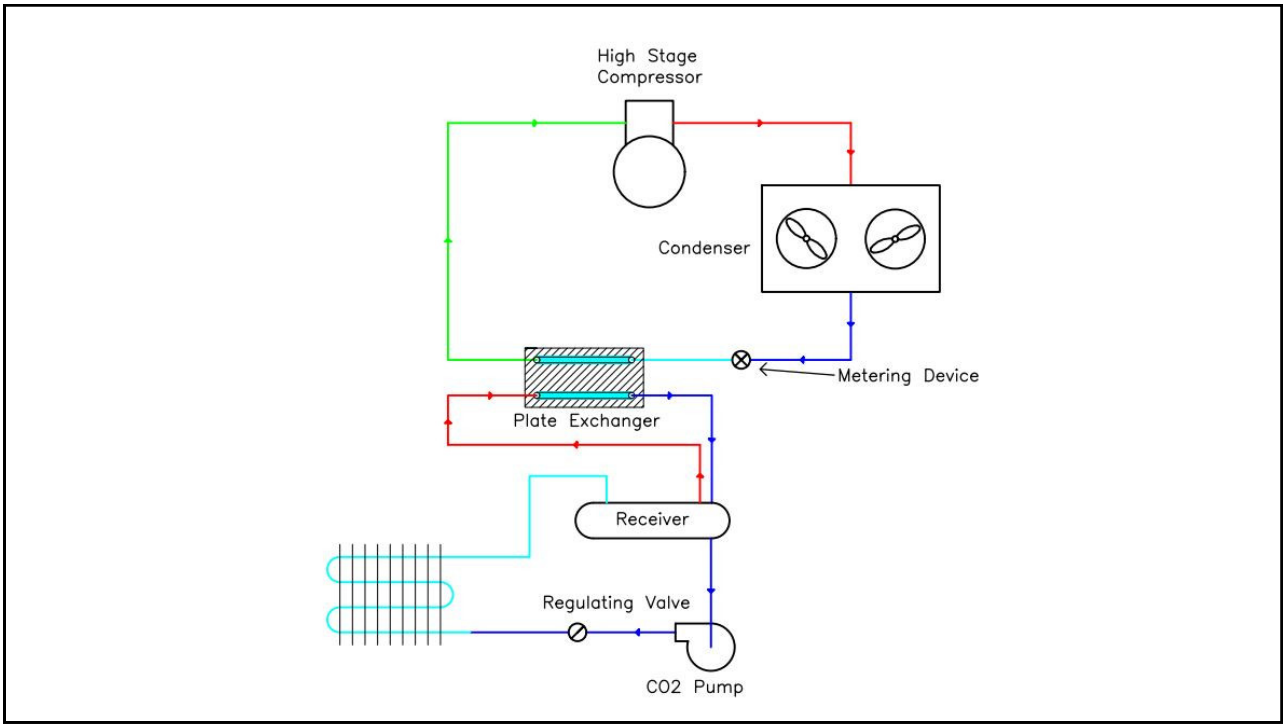
Subcritical CO_2

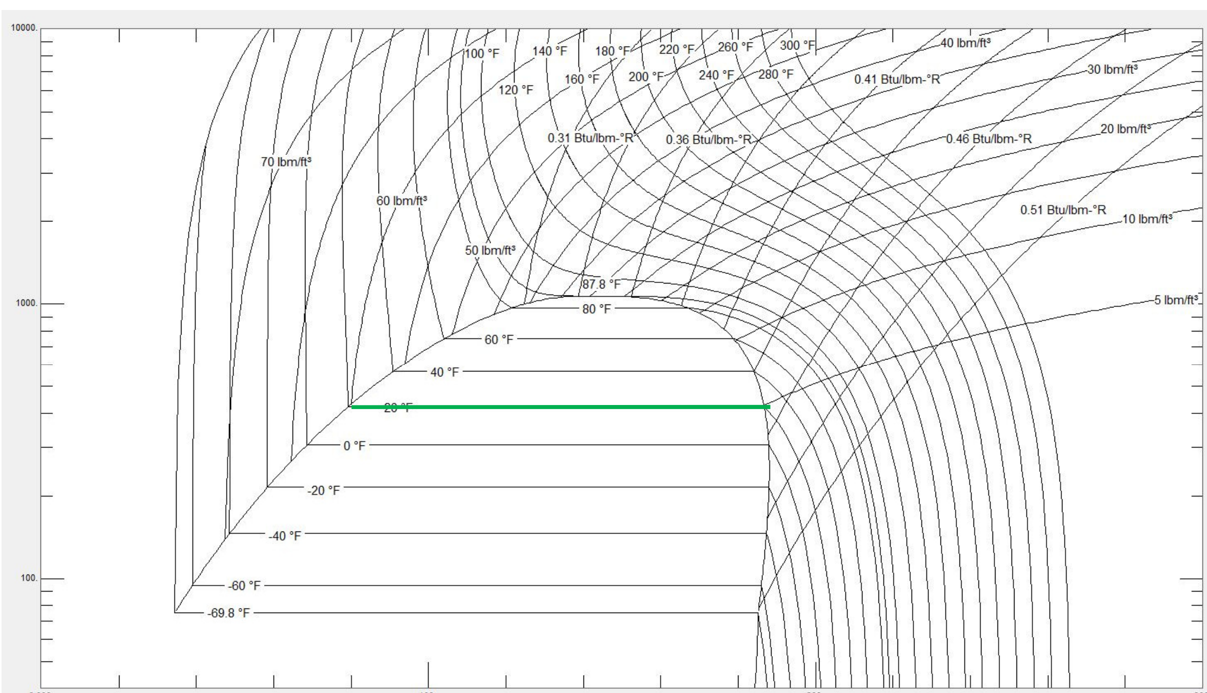
- In order to use on a conventional refrigeration plant we would have to ensure cooling water or ambient conditions 100% of the time.
- Air cooled would be almost impossible except in certain winter only applications.
- Better suited to secondary applications.

Subcritical CO_2 Secondary Applications

Secondary Applications

- Cascade condensing
- Volatile Brine (no compression)


High Stage Compressor
Condenser
Metering Device
Plate Exchanger
Receiver
Regulating Valve
CO2 Pump


10000.
1000.
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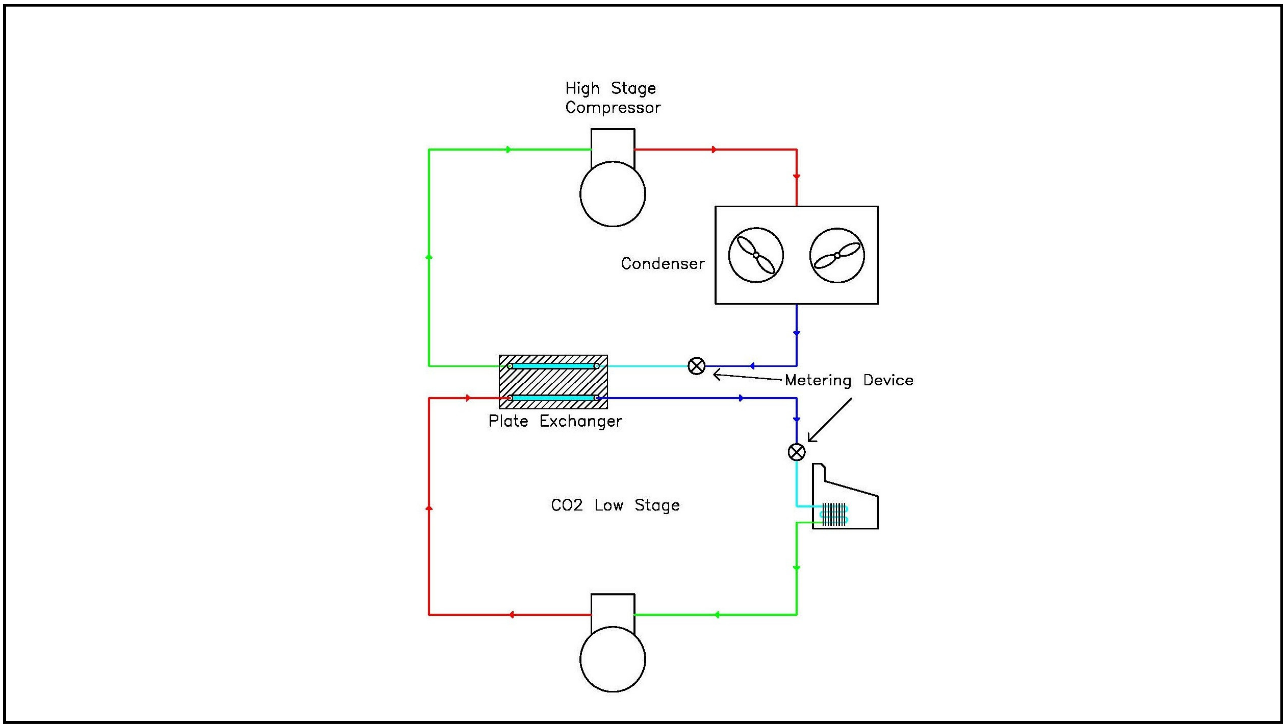
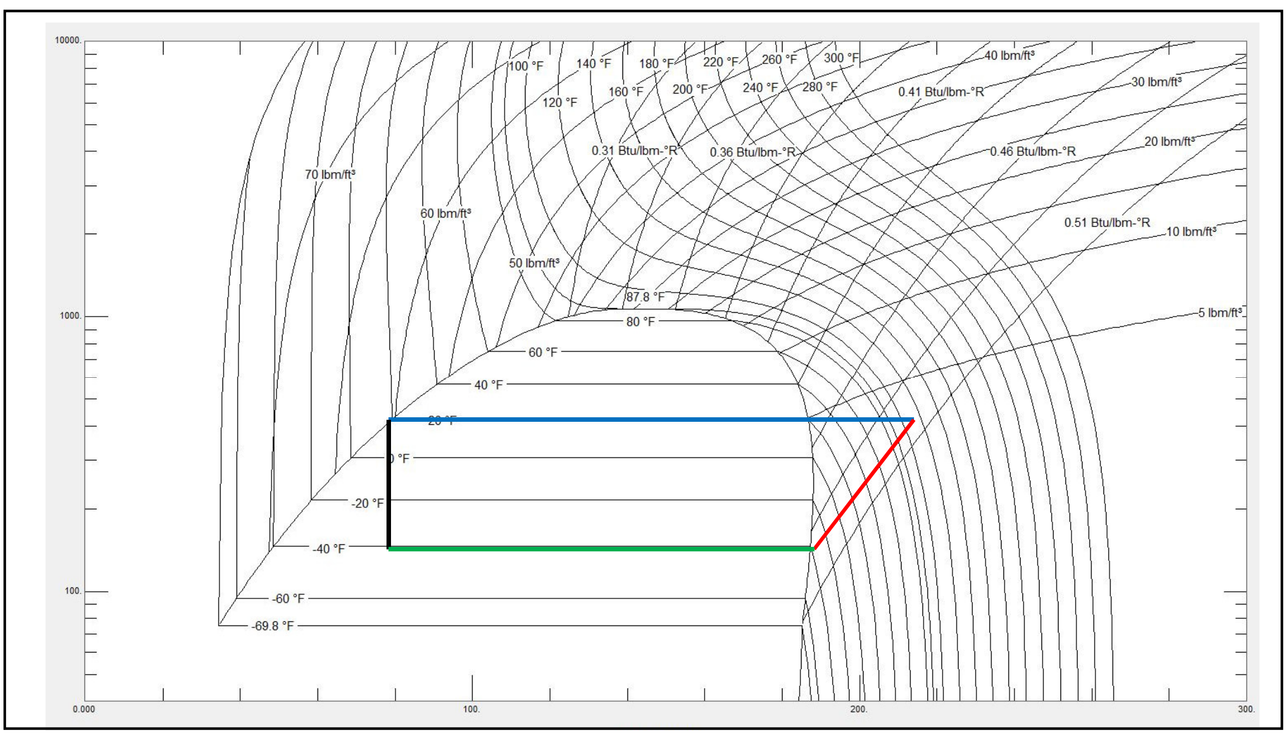
100.
200.
300.
100 °F
120 °F
140 °F
160 °F
180 °F
200 °F
220 °F
240 °F
260 °F
280 °F
300 °F
40 lbm/ft³
30 lbm/ft³
20 lbm/ft³
10 lbm/ft³
5 lbm/ft³
70 lbm/ft³
60 lbm/ft³
50 lbm/ft³
0.31 Btu/lbm-°R
0.36 Btu/lbm-°R
0.41 Btu/lbm-°R
0.46 Btu/lbm-°R
0.51 Btu/lbm-°R
87.8 °F
80 °F
60 °F
40 °F
20 °F
0 °F
-20 °F
-40 °F
-60 °F
-69.8 °F

Why "Volatile Brine"?

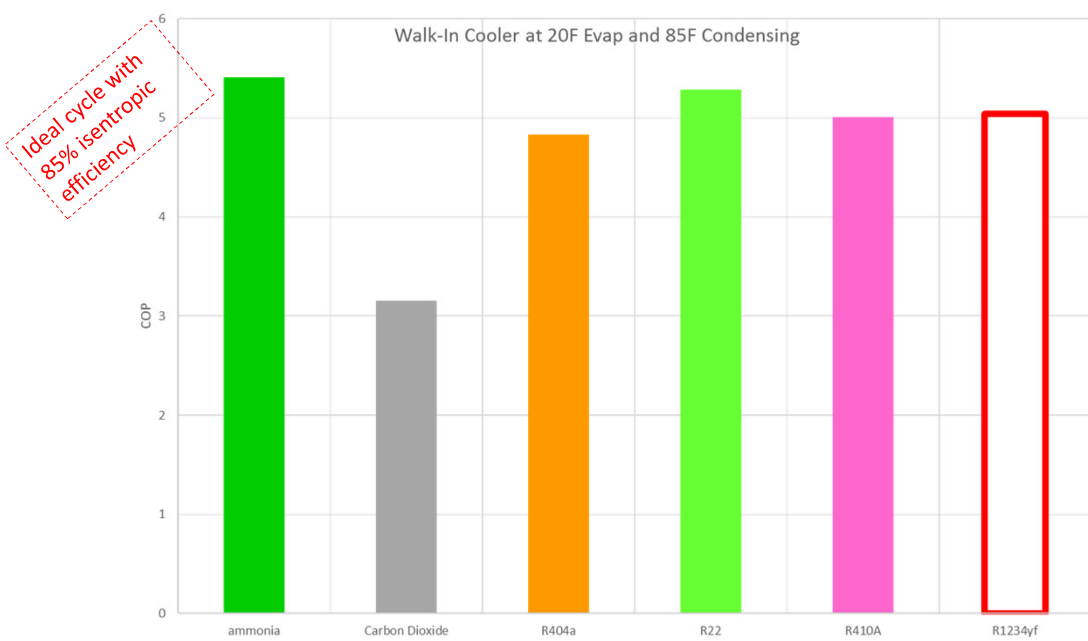
- Safety Considerations - In some facilities volatile brine removes ammonia from occupied space.
- Pumping power – On a per ton basis CO_2 requires only about 11% of the pumping power of glycol.
- No lubricant in the CO_2 compared to cascade compressions.
- Simplicity?
- Cost?



High Stage Compressor
Condenser
Metering Device
Plate Exchanger
CO2 Low Stage



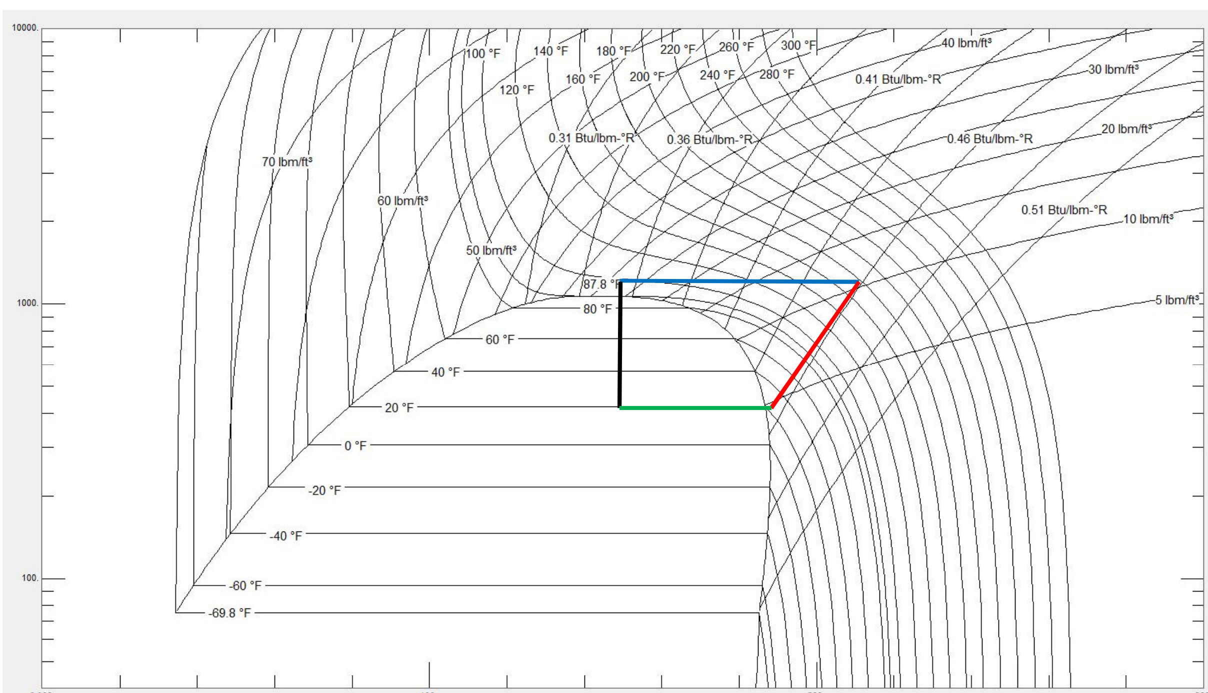
Transcritical CO_2 Applications

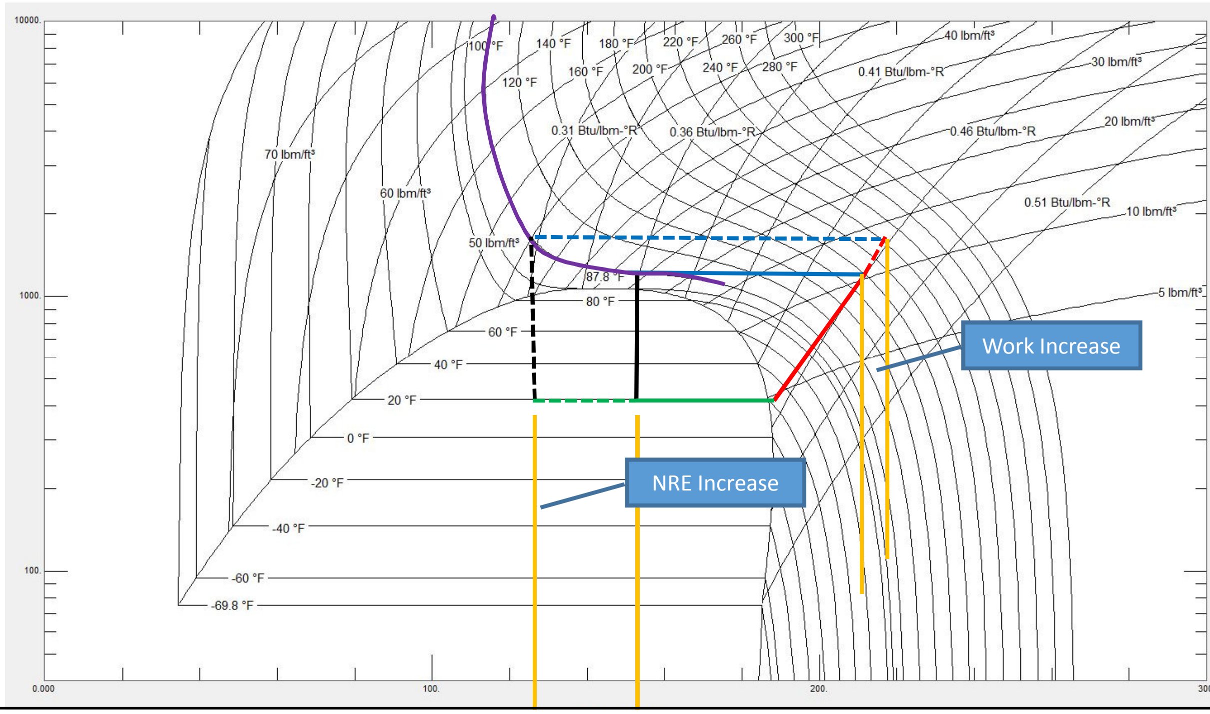
- Acceptable operating efficiency when sub critical.
- Ideal cycle COPs are lower but thermal and physical properties help.
  - Lower viscosity – Low pressure drops
  - High volumetric cooling capacity (approx. 5 times R404a)
  - High heat transfer (high density and pressure)



Transcritical CO_2 Applications

- Efficiency is even lower in supercritical operation.
- The optimal discharge pressure changes based on ambient temperature
- Pressures get pretty high! (1500psi or higher is normal)



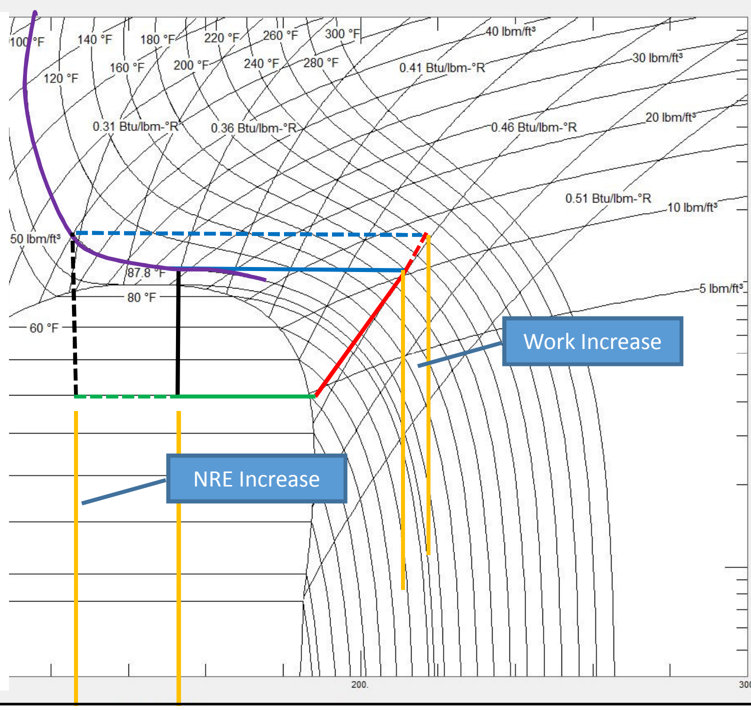


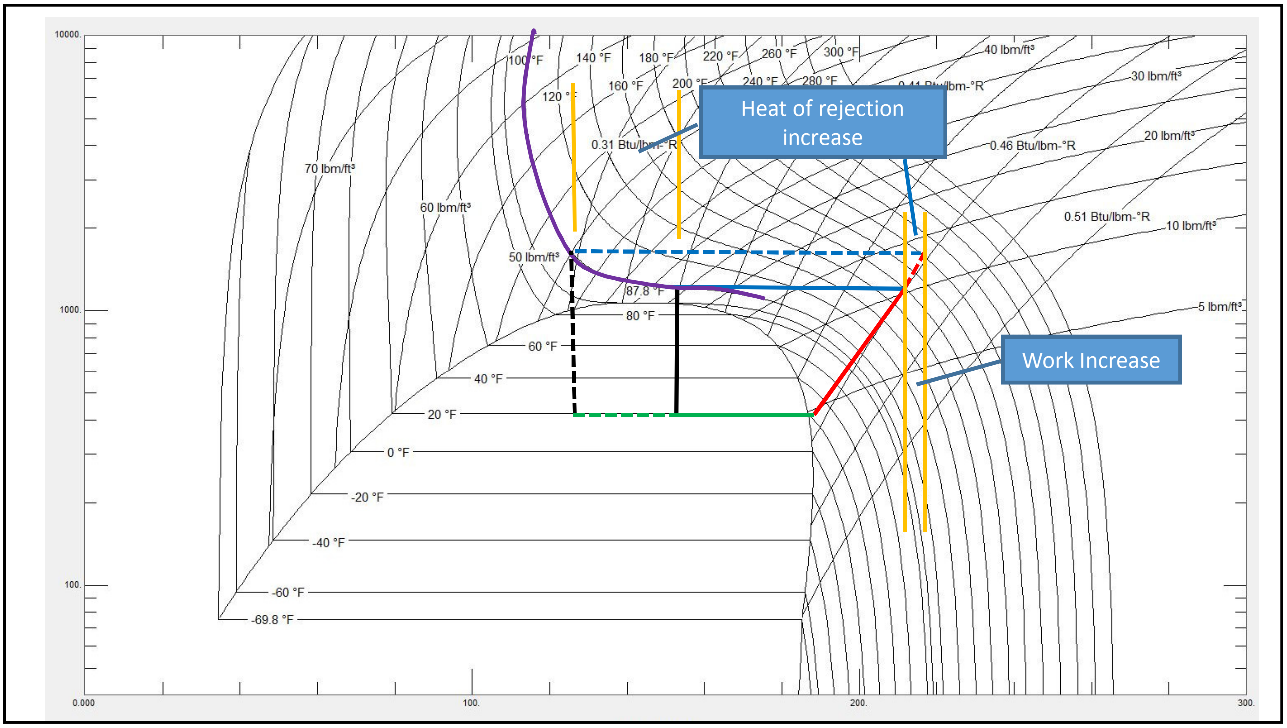
During supercritical operation:

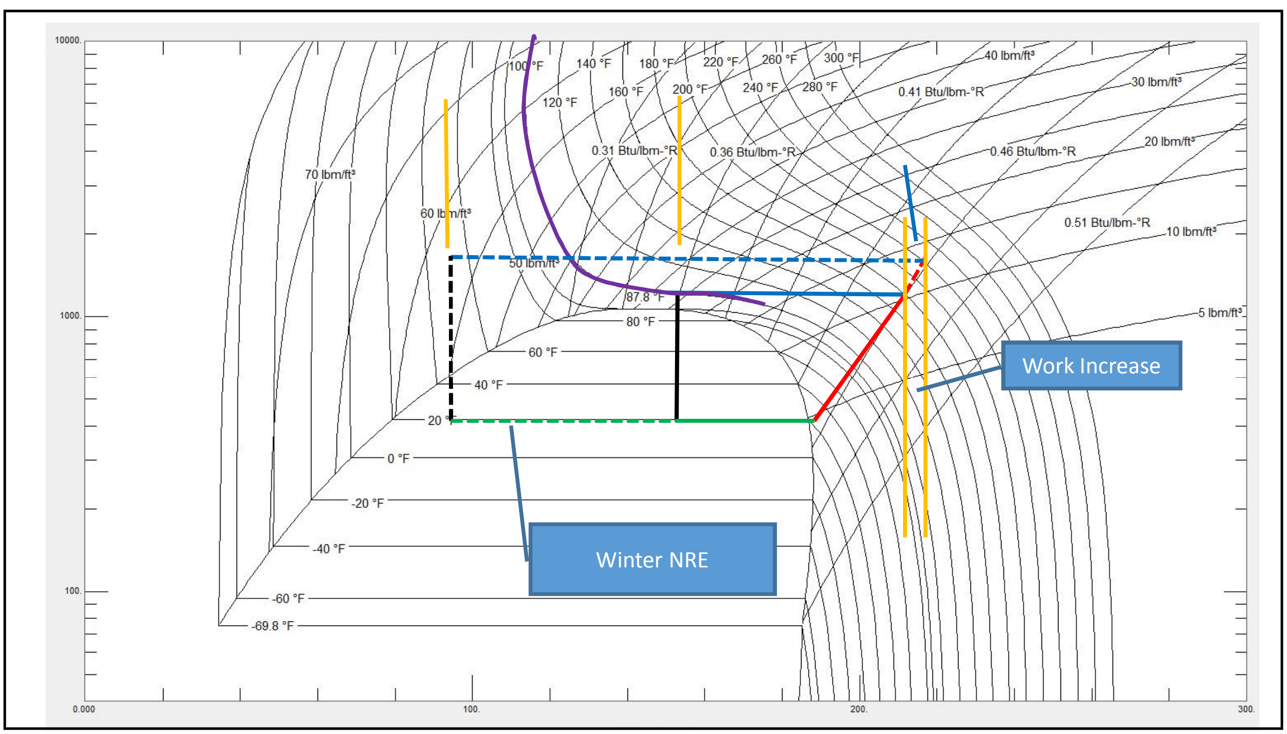
- Increasing the compression ratio increases the capacity.
- There is an optimal discharge pressure (around 1400psi but it varies based on suction pressure and ambient temperature)
- This means that the COP can increase if you increase the discharge pressure!

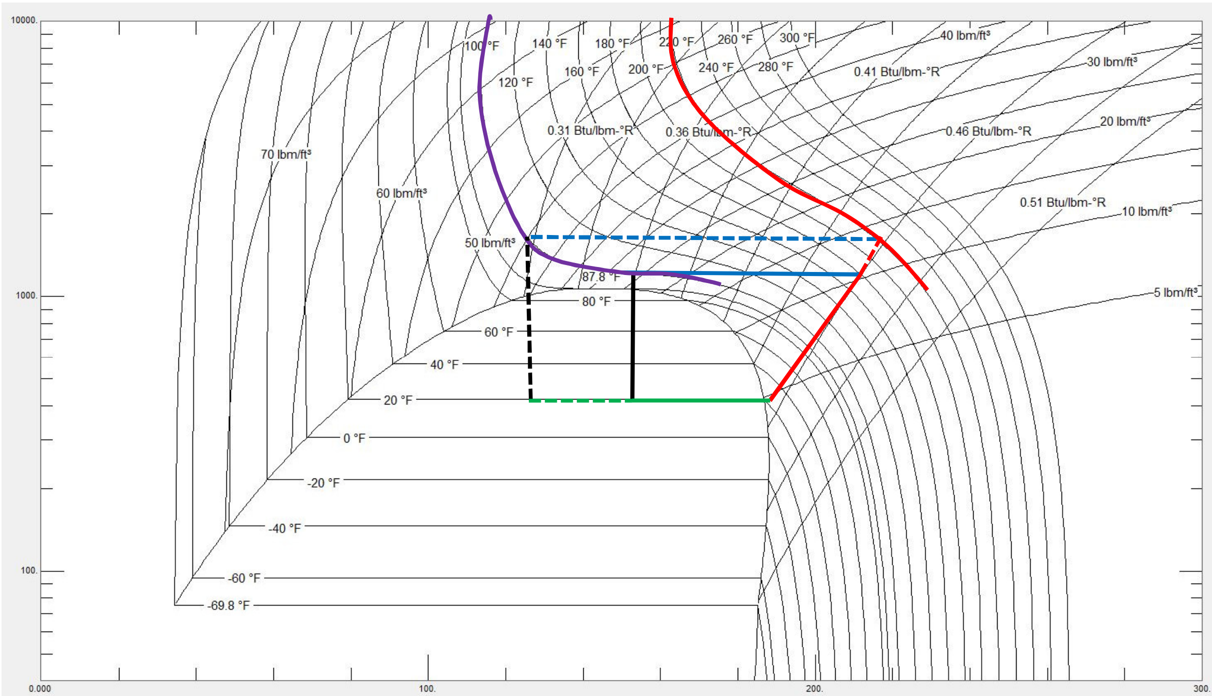
- Good control is critical for 'efficient' operation

- There is one very big advantage in transcritical operation….



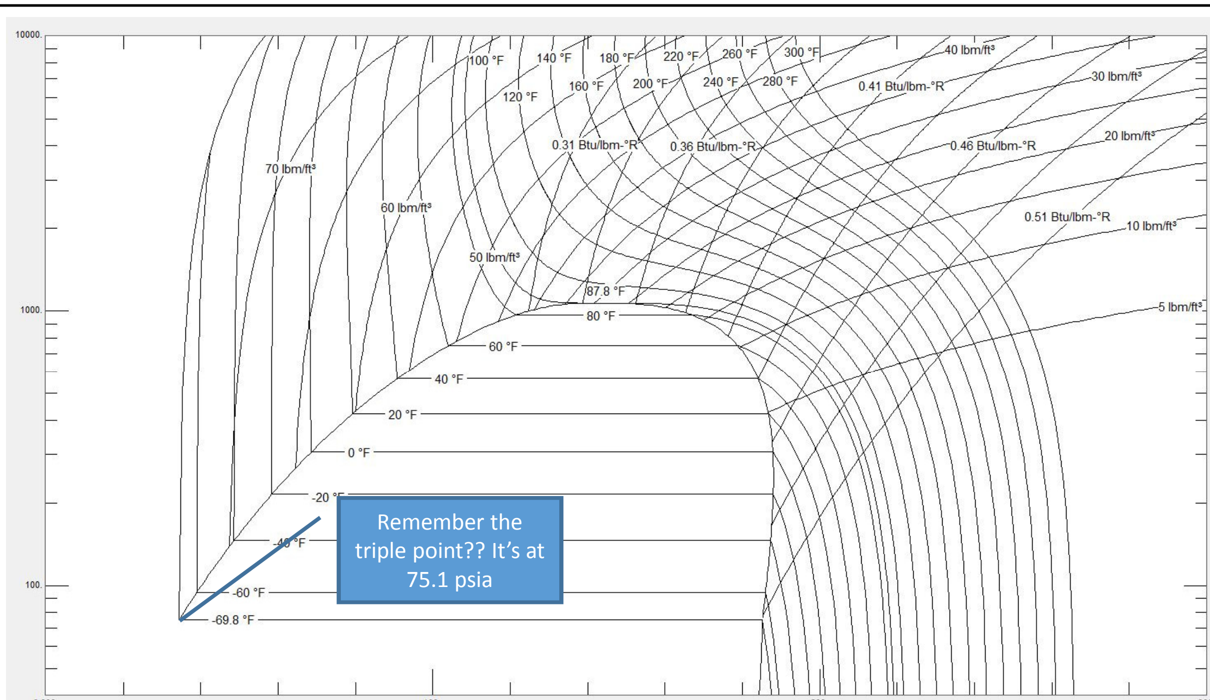

Heat of rejection increase
Work Increase


Work Increase
Winter NRE



Summary of Systems

- CO2 has a lot of very promising applications but it can be challenging to get efficiencies high.
- In jurisdictions or companies that mandate low TEWI CO2 often competes favorably.
- Heat reclaim and or heat pumping specific applications are very promising for CO_2


10000.
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100.
200.
300.
100 °F
140 °F
180 °F
220 °F
260 °F
300 °F
120 °F
160 °F
200 °F
240 °F
280 °F
40 lbm/ft³
30 lbm/ft³
20 lbm/ft³
10 lbm/ft³
5 lbm/ft³
70 lbm/ft³
60 lbm/ft³
50 lbm/ft³
0.31 Btu/lbm-°R
0.36 Btu/lbm-°R
0.41 Btu/lbm-°R
0.46 Btu/lbm-°R
0.51 Btu/lbm-°R
87.8 °F
80 °F
60 °F
40 °F
20 °F
0 °F
-20 °F
-40 °F
-60 °F
-69.8 °F
Remember the triple point?? It's at 75.1 psia

Safety

- There are a lot of safety related issues that differ between CO2 and other refrigerants.

1) It is not “non-toxic”… and actually has relatively small RCL
2) The higher pressures stores a lot of internal energy.
3) Many systems can not handle their “Stand still” pressure and have to have a secondary refrigeration system or lose their charge during a power outage (some have fade away vessels)
4) Design pressure and equipment manufacturing present challenges.
5) Ammonia and CO2 form Ammonium Carbamate
6) Extremely high liquid thermal expansion coefficient
7) We have to worry about trapped vapour because it has a high thermal coefficient of expansion. 55F increase approx. 120 psi increase in pressure.

Final Thoughts & Questions