



Fundamentals of Refrigeration

Refrigeration Cycles



What you will Learn in this Lesson

- Ideal single stage cycle
- Ideal 2 stage cycle
- Subcooling
- Actual cycle variances

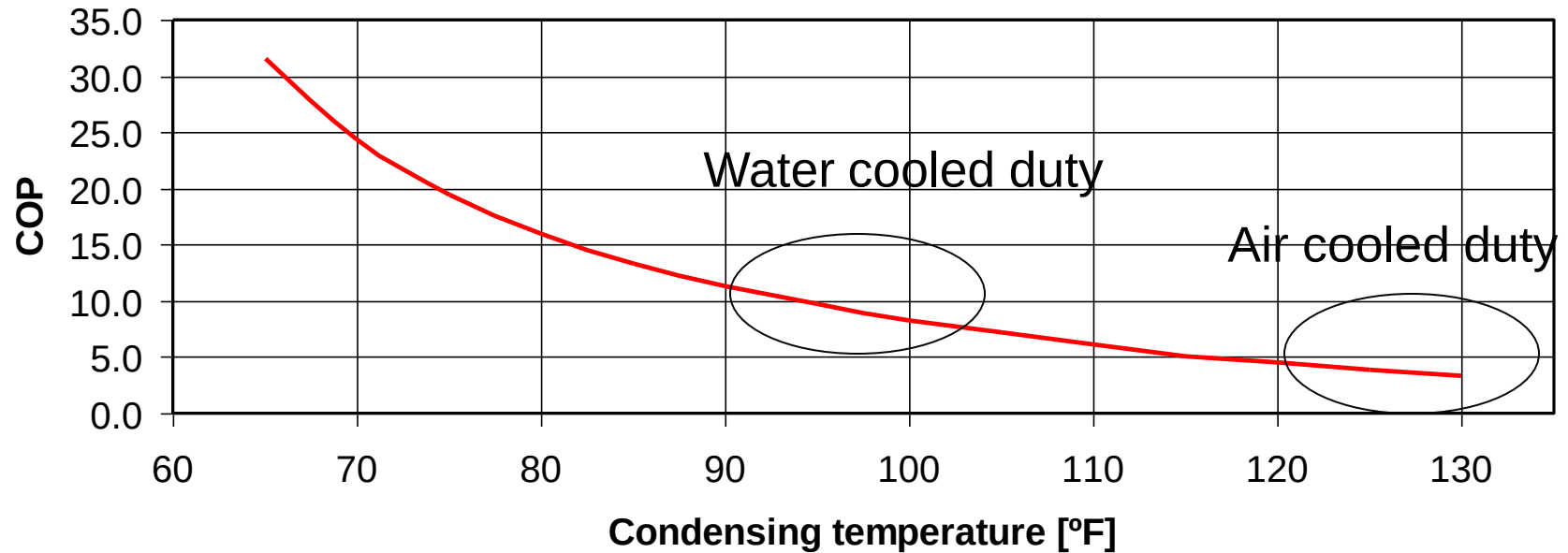
Ideal Cycle - R-410a

- Lets build an ideal, single stage refrigeration circuit assuming;
 - R-410a
 - Condensing pressure = 450 psia
 - Evaporating pressure = 140 psia
 - Capacity = 100 tons

Referring to Refrigerant
Properties tables

Pressure (psia)	140	450
Temperature (F)	43	123
h_l (Btu/lb)	28.66	61.79
h_v (Btu/lb)	120.5	120.1
s_l (Btu/°R·lb)	0.06161	0.1209
s_v (Btu/°R·lb)	0.2443	0.2210

Varying Condenser Conditions



Ideal Cycle R-134a

Single vs. Two Stage Cycle

- Two stage is more efficient at higher lifts
 - The bigger the lift, the bigger the advantage
- However, as lift is reduced, there is little advantage for 2 stage
- Subcooling a single stage system can often match performance
 - It is not (practically) possible to subcool a 2 stage system

2 Stage Ideal Cycle - R-134a

- Consider a single stage system based on;
 - R-134a
 - Condensing temp = 95 °F
 - Evaporating temp = 45 °F
 - Capacity = 100 tons
 - $\text{COP}_{\text{R-134a}} = 8.6$
 - $\text{COP}_{\text{carnot}} = 10.1$
 - $\text{COP}_{\text{R-123}} = 9.1$
- Calculate a 2 stage cycle COP assuming
 - Intermediate temp = 70 °F

You can't do better than this

2 Stage Ideal Cycle - R-134a

Referring to Refrigerant Properties tables

	Point 5	Point 6	Point 7	Point 8	Point 1
Temperature (F)	95	70	70	45	45
Pressure (p) psia	128.6	85.8	85.8	54.75	54.75
Enthalpy (h_L) Btu/lb	43.39	34.8	34.8	26.51	-
Enthalpy (h_v) Btu/lb	-	112.8	112.8	109.5	109.5
Enthalpy (h) Btu/lb	43.39	43.39	34.8	34.8	109.5
Entropy (s) Btu/lb R	-	-	-	-	0.2217

All this data can be found in the Saturated Refrigerant tables

System Performance Parameters

$$\text{Coefficient Of Performance} = \frac{\text{Refrigeration Effect}}{\text{Compressor Power}}$$

- Water cooled chillers in North America
 - $\text{Eff} = \text{kW}_{\text{compressor}}/\text{ton}$
 - E.g. 0.55 kW/ton
- Air Cooled Equipment in North America
 - Energy Efficiency Ratio (EER) = $\frac{\text{Btu/h}_{\text{Cooling}}}{\text{Capacity}/\text{kW}_{\text{input power}}}$
 - E.g. EER = 9.5
- Rest of the world uses COP for everything
- $\text{COP} = \text{XXX}/\text{kW}/\text{ton}$

Part Load Performance Parameters

- Water cooled chillers use IPLV as defined in AHRI Standard 550/590
 - Weighted average of chiller efficiency at 25, 50, 75 and 100% capacity
 - In North America given in kW/ton
 - Rest of the world comes in COP
- Some air cooled equipment (i.e. A/C chillers) has IEER
 - Weighted average of chiller efficiency at 25, 50, 75 and 100% capacity
 - In North America given in IEER
 - Rest of the world comes in COP
- Residential system efficiency given as **Seasonal Energy Efficiency Ratio (SEER)**
 - Weighted average of system performance as defined by the appropriate AHRI standard

Actual System Performance

- Ideal cycles are not actual cycles
- Do not consider
 - Pressure drops
 - Unintentional heat transfer
 - Heat transfer properties of fluids and HX
 - Mach numbers
 - Compressor and motor efficiency

Actual Expansion Device

- Ideal cycle expansion device is adiabatic
 - Enthalpy in = Enthalpy out
- Real cycle heat is lost to surroundings
- Pressure drop through device is irreversible
- Piping from condenser to evaporator has a pressure drop
 - Starting with a saturated refrigerant and then incur a pressure drop, some of the refrigerant will flash
 - Not good for expansion device
- Real systems have subcooling or static head to avoid flashing

Actual Evaporator

- Ideal evaporator boils refrigerant at constant pressure and temperature
- Refrigerant flowing through tubes in evaporator will experience a pressure drop
 - The leaving evaporator pressure is lower than the entering evaporator pressure
 - The expansion device controls the pressure at the entrance
 - Pressure drops are subtracted from this point
 - Evaporator pressure drop lowers the pressure entering the compressor
 - Raises the compression ratio
 - Increase compressor work

Actual Evaporator Cont'd

- Any liquid refrigerant carry over to the compressor is not good
 - To manage, all systems have some amount of superheat to ensure refrigerant is fully boiled
 - Superheat add little cooling effect, raising the temperature, lowers compressor efficiency
- Piping from the evaporator to the compressor adds more pressure drop
 - Lowers compressor inlet pressure
 - Raises compression ratio
 - Increase compressor work

Actual Compressor Performance

- Ideal compressors are isentropic
 - $s_1 = s_2$
- Real compressors have losses
 - Heat, friction, noise etc.
 - $s_1 \neq s_2$
- As compressor process curve shifts to right, more compressor work is required
- If the compression ratio increase, the compressor work increases
- $\eta_{\text{isentropic}} = (h_{3s} - h_2) / (h_3 - h_2)$
- Typical efficiencies are 75 to 80%
- Suction and discharge valves add pressure drops that increase compression ratio
- Any additional heat added to the system by the compressor must be dealt with by the condenser as THR

Actual Condenser

- Ideal condenser desuperheats then condenses refrigerant at constant pressure and temperature
- Refrigerant flowing through tubes in condenser will experience a pressure drop
 - The leaving condenser pressure is lower than the entering condenser pressure
 - Evaporator pressure drop raises the required discharge pressure from the compressor
 - Raises the compression ratio
 - Increase compressor work
- Piping from compressor to the condenser adds a pressure drop
 - Raises the compression ratio
 - Increase compressor work

Impact of Refrigerants

- Real system performance is significantly effected by
 - Prandtl, Nusselt, Reynolds (heat transfer)
 - Mach numbers (compressibility)
 - Azeotropic and zeotropic refrigerants (glide)
 - Critical point (condensation)
- To say nothing of....
 - Toxicity
 - Flammability
 - Materials compatibility
 - Cost
 - Environmental impact

End of Lesson

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