Many Options for Natural Refrigerants

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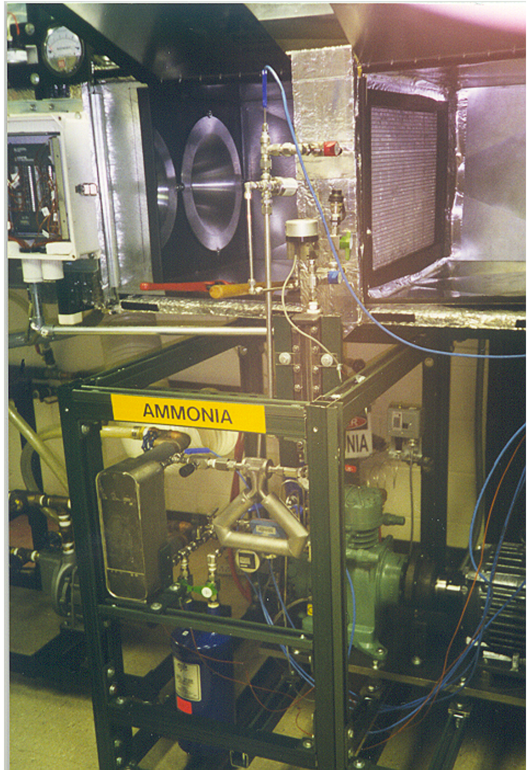
Natural refrigerants

- In **vapor compression** systems:
  - Ammonia: R717
  - Hydrocarbons: R600a, R290, ….
  - Carbon Dioxide: R744
  - Air: R729 (aircrafts, low temperatures,..)
  - Water: R718 – low pressures and large equipment per capacity
  - Helium (Stirling) – cooling issues, niche applications
- In **absorption** systems: (niche applications, inexpensive heat)
  - Ammonia – water
- In **ejector** systems: (when steam is almost free)
  - Steam
- Other **niche refrigeration options**:
  - Magnetic, acoustic, electrochemical, …

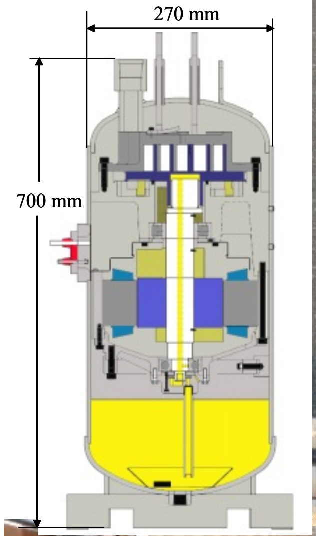
Serious potential to become mainstream option

Ammonia

- The only natural refrigerant that was continuously in use (in industrial refrigeration)
- Not appropriate for populated areas when charge is significant
- Low charge chillers for a/c or refrigeration with secondary coolant or cascade
- Lowest published charge 18 g/kW@15kW, - aircooled



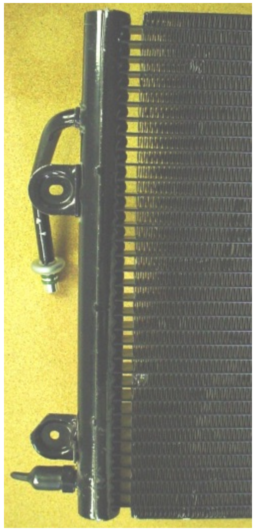
Current advances



- Hermetic compressor
- Microchannel condenser
- Ni brazed plate evaporator

Needed: Cost reduction

- Different materials: aluminum as an option



Hydrocarbons

- The lowest cost alternative
- Almost drop-in replacement for R22 (R290)
  - a/c or commercial refrigeration
- Easy replacement for R12 or R134a (R600a)
  - refrigerators
- Flammable
- Charge limits 50g (?) or 150 g (?)
- Lowest charge known: 48g/kW @ 1kW, aircooled

Carbon Dioxide

- Very old refrigerant
- Abandoned because of high pressures and bulkiness of components
- Microchannel HXs and better materials reopen the door
- Winning applications: HPWH, bottle coolers, commercial refrigeration (supermarkets)
- Automotive applications reconsidered
- Assumed to be low efficient refrigerant – new systems high efficiency

Just a few words about

Efficiency (COP)

because many think that CO_2 is not efficient

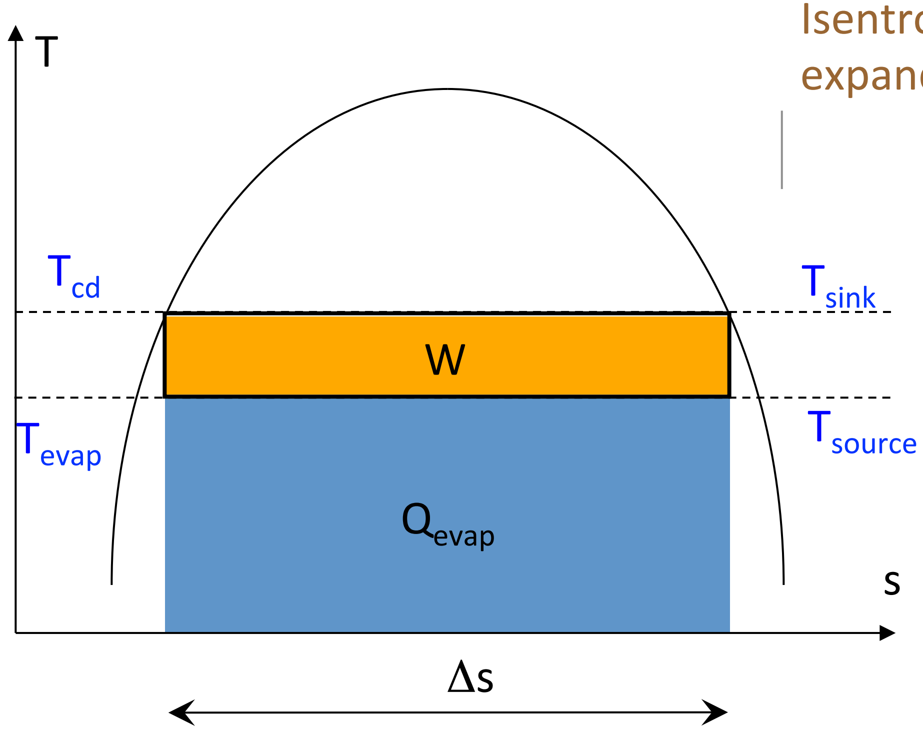
Very often same word is used for different efficiencies:

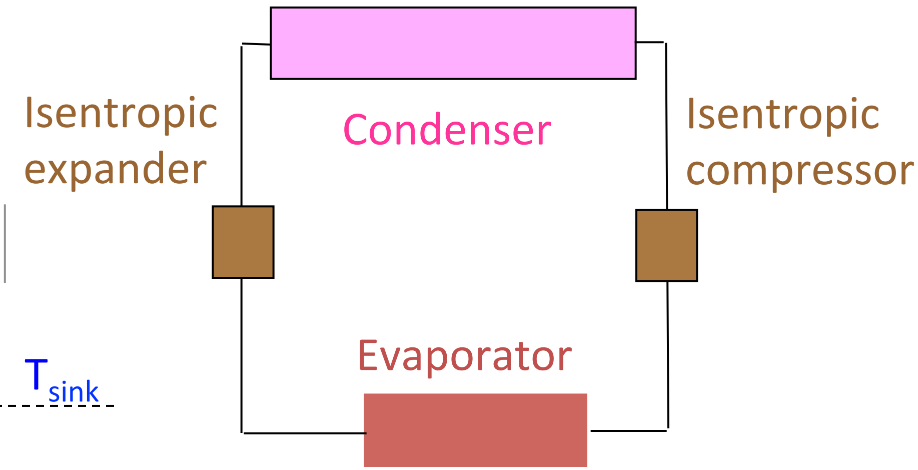
1. Cycles (**refrigerants**)
2. Systems (add effects of **components**)
3. In application (add effects of **operation**)

Cycle analysis

- Use tools of Thermodynamics:
  - Cycle analysis – determines efficiency
  - Thermodynamic properties of the fluid
  - Second law (entropy generation)
- Ignores realities of HX and Cp design: heat transfer, pressure drop, local sink and source change in temperature, fluid interactions, controls, …
- Attractive because it is "clean"
- Just appears to be unbiased if pretends to give the complete answer
- Excellent to evaluate options, as the first of the steps

Carnot cycle





$Q_{cd}=T_{cd}*\Delta s$

$Q_{evap}=T_{evap}*\Delta s$

$W= Q_{cd}-Q_{evap}=(T_{cd}-T_{evap})*\Delta s$

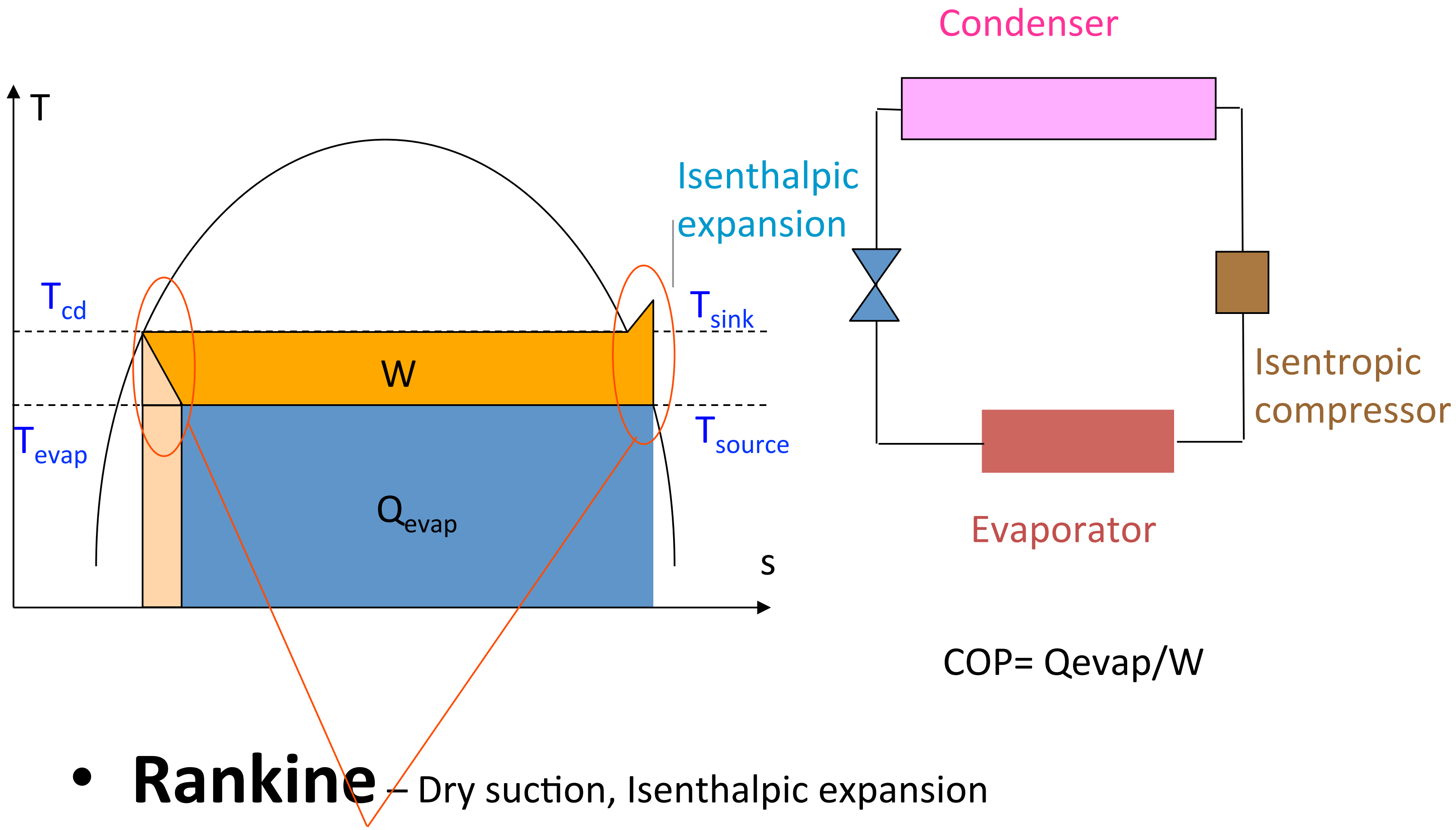
$COP= Q_{evap}/W$

- **Carnot cycle** – ideal
  - Reversible (DT=0, friction=0, slow,…)
- **All fluids are equal!**

So,

- **ALL REFRIGERANTS ARE EQUALLY EFFICIENT IN CARNOT CYCLE**
- They start to differ when designers move a bit away from Carnot for technical reasons
- Let's have a quick reminder:

Rankine (Evans-Perkins) cycle



COP= Qevap/W

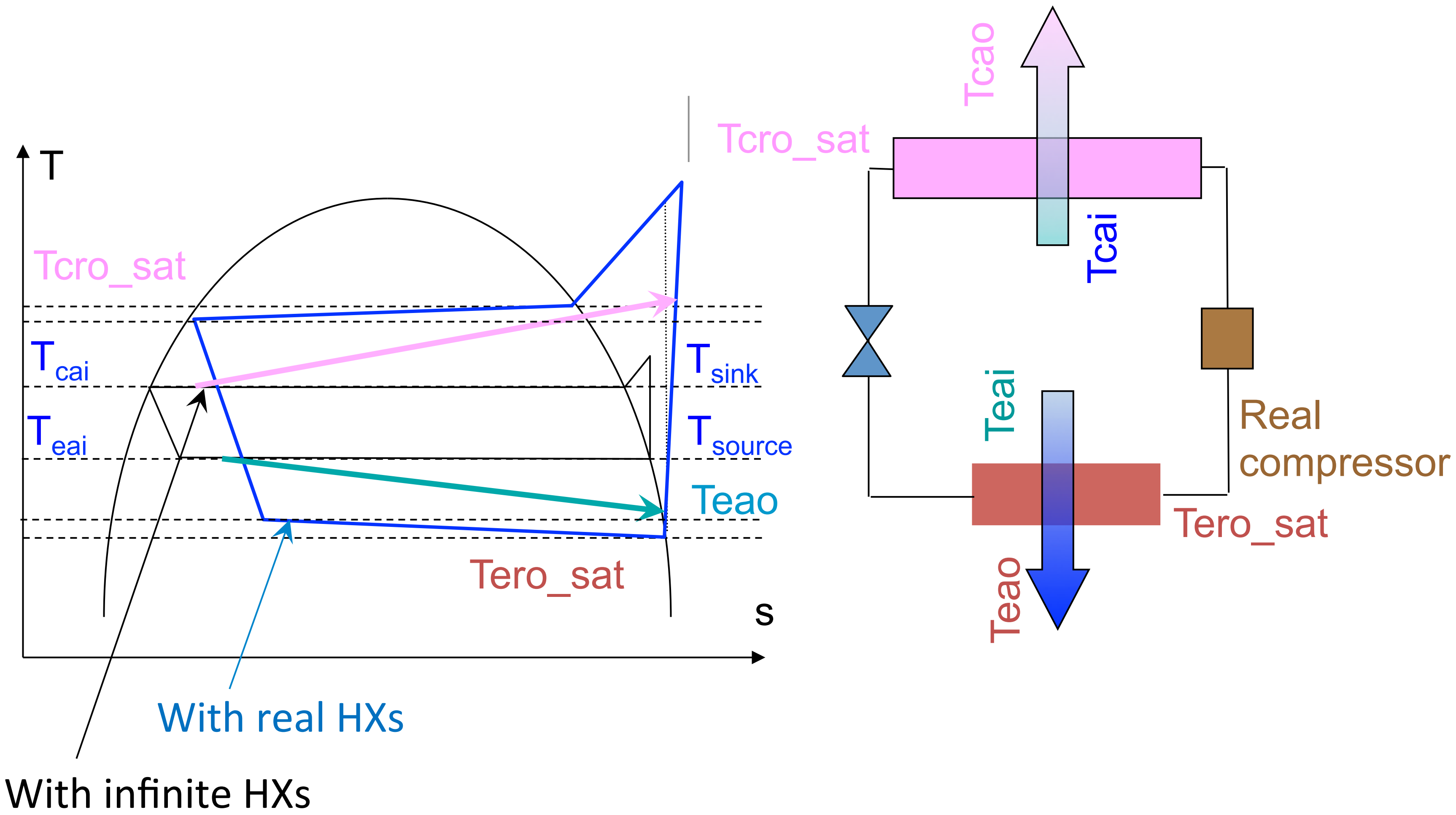
- **Rankine** – Dry suction, Isenthalpic expansion
- Fluids are **NOT** equal – begin to differentiate

When reality of HXs, compressor, expansion devices come into a play

- This is when THERMOPHYSICAL properties become way more important that THERMODYNAMIC properties
- That is where CO_2 and typically all natural refrigerants are good

System,
based on Rankine cycle

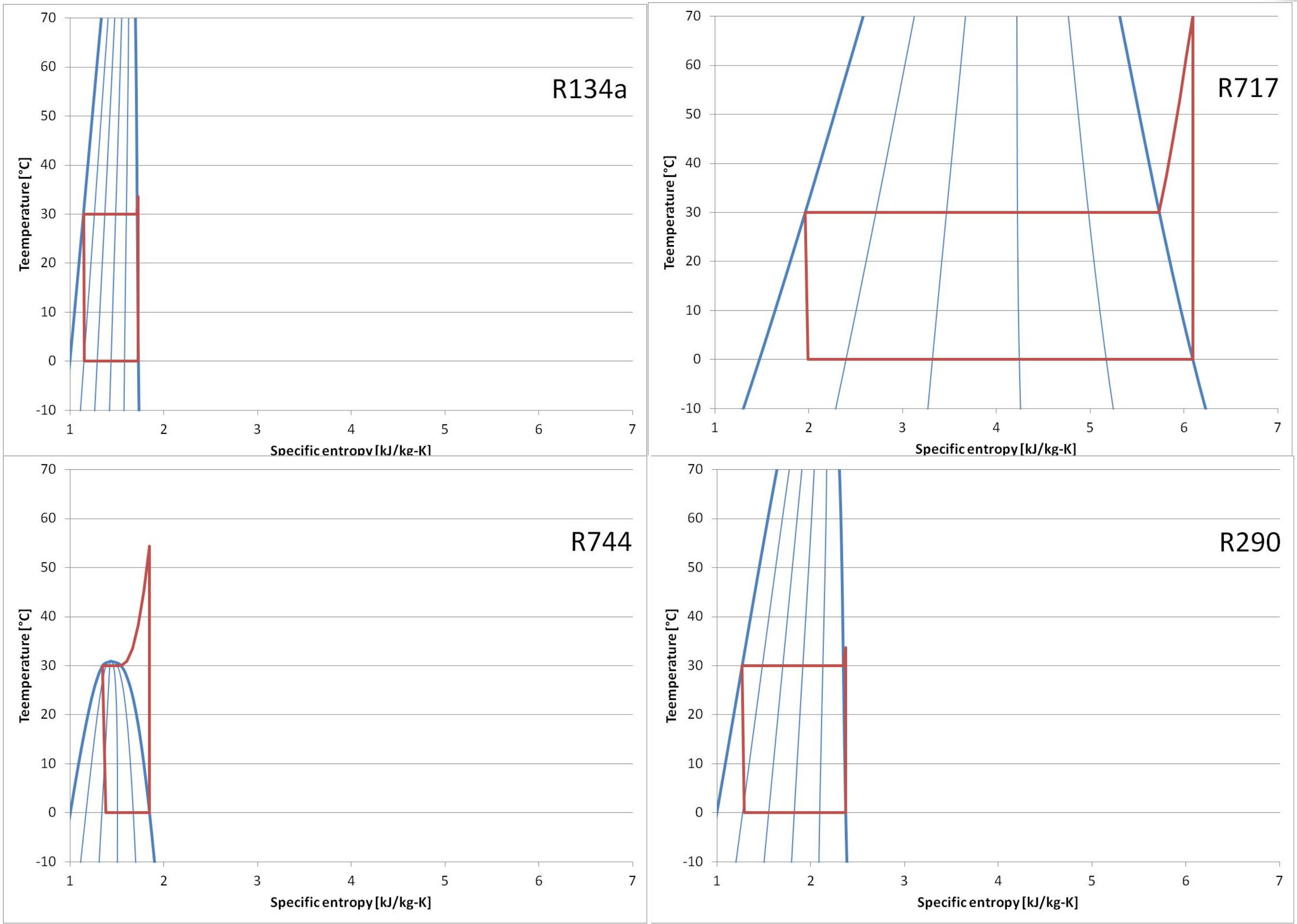
Takes in account realities of: heat exchangers, compressors, expansion devices



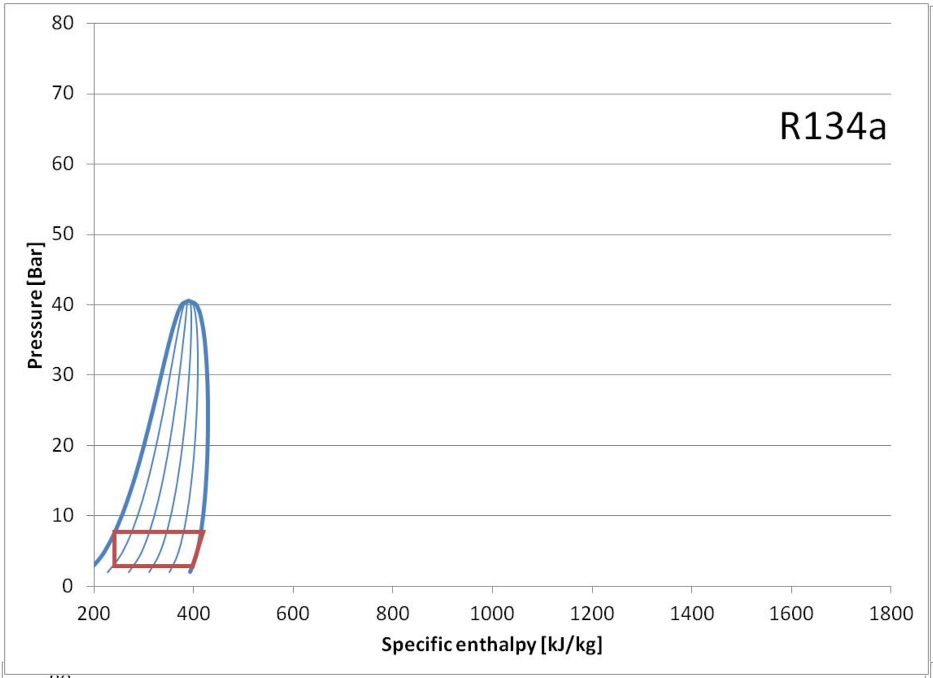
Why is this important?

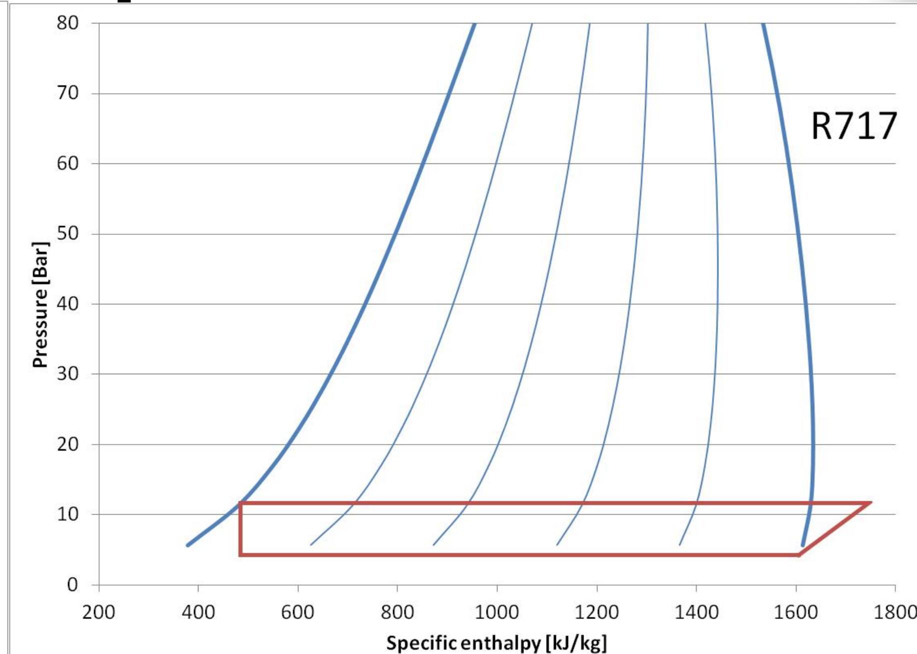
- COPs of the CYCLE is dramatically reduced in the SYSTEM due to:
  - Heat transfer (thermophysical properties of the fluid)
  - Heat exchanger design
  - Compressor design and manufacturing
  - Expansion device (work recovery)
  - System architecture (two stage compression, IHX, subcooling, ….)
- **Good selection can totally change initial expectations because fluids are different:**

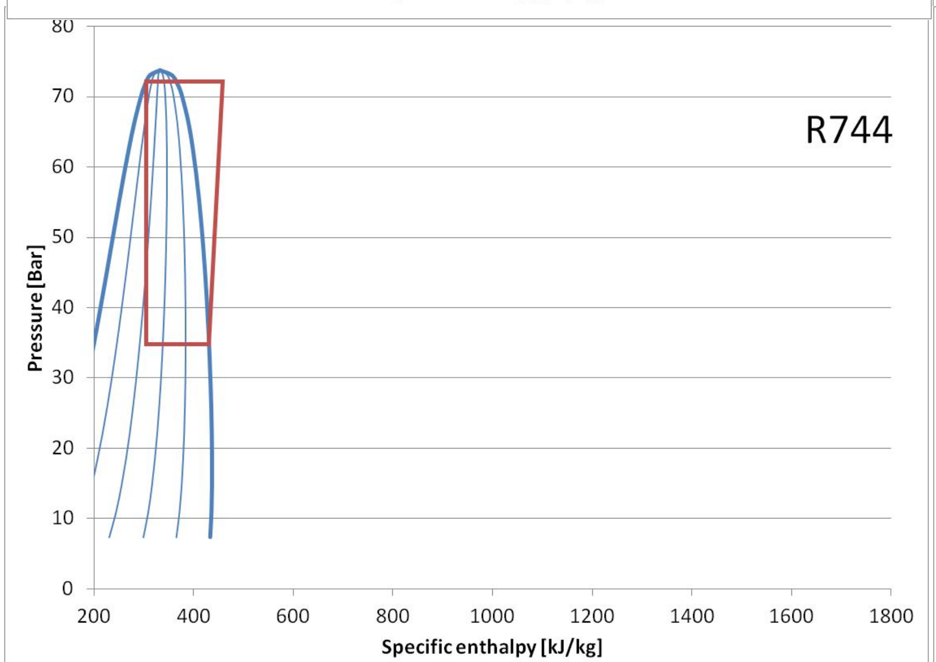
In scale: T-s

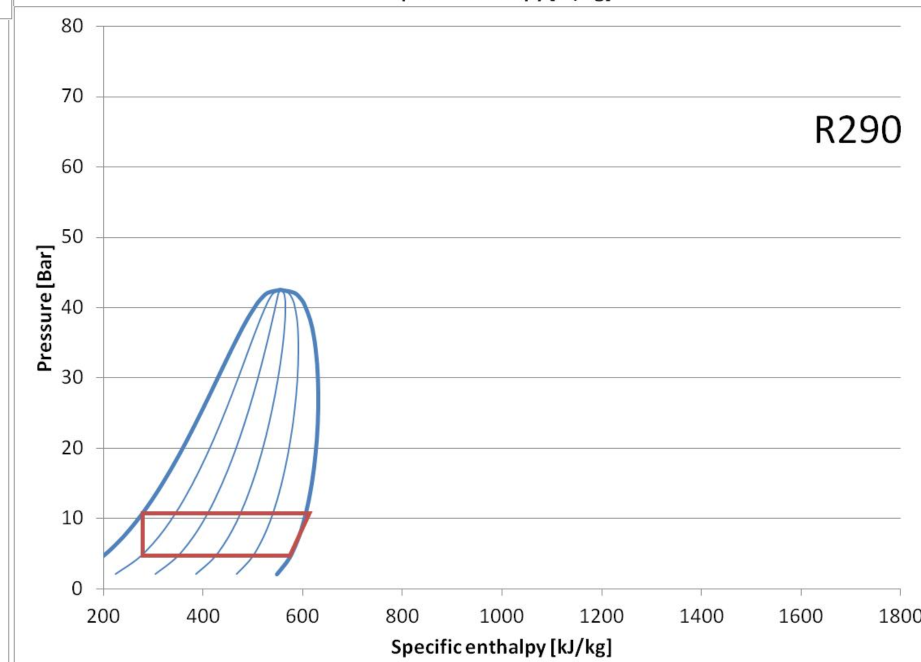

R134a
R717
R744
R290
Teemperature [°C]
70
60
50
40
30
20
10
0
-10
1
2
3
4
5
6
7
Specific entropy [kJ/kg-K]

In scale: p-h


R134a
Pressure [Bar]
0
10
20
30
40
50
60
70
80
200
400
600
800
1000
1200
1400
1600
1800
Specific enthalpy [kJ/kg]


R717
Pressure [Bar]
0
10
20
30
40
50
60
70
80
200
400
600
800
1000
1200
1400
1600
1800
Specific enthalpy [kJ/kg]


R744
Pressure [Bar]
0
10
20
30
40
50
60
70
80
200
400
600
800
1000
1200
1400
1600
1800
Specific enthalpy [kJ/kg]


R290
Pressure [Bar]
0
10
20
30
40
50
60
70
80
200
400
600
800
1000
1200
1400
1600
1800
Specific enthalpy [kJ/kg]

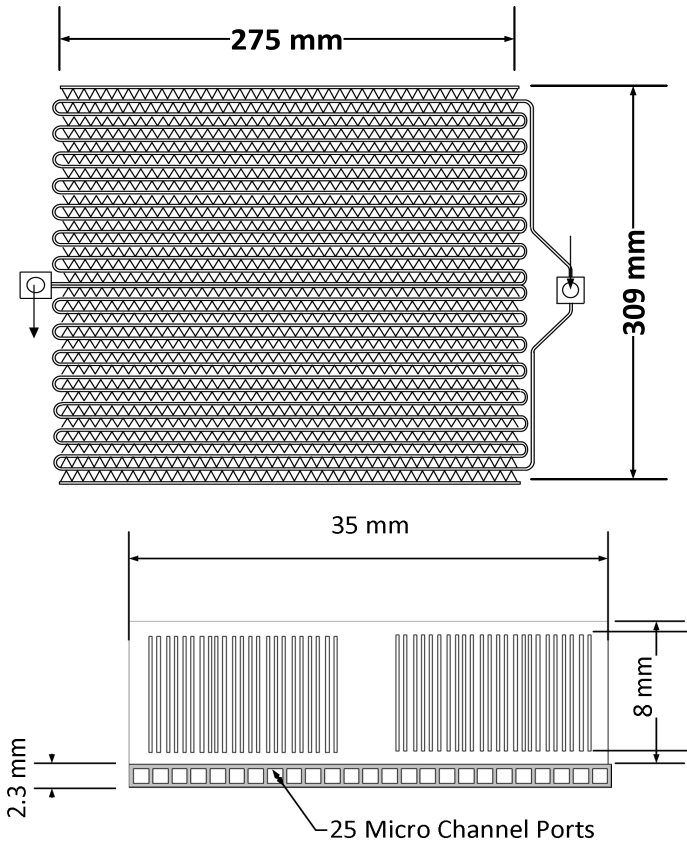
So,

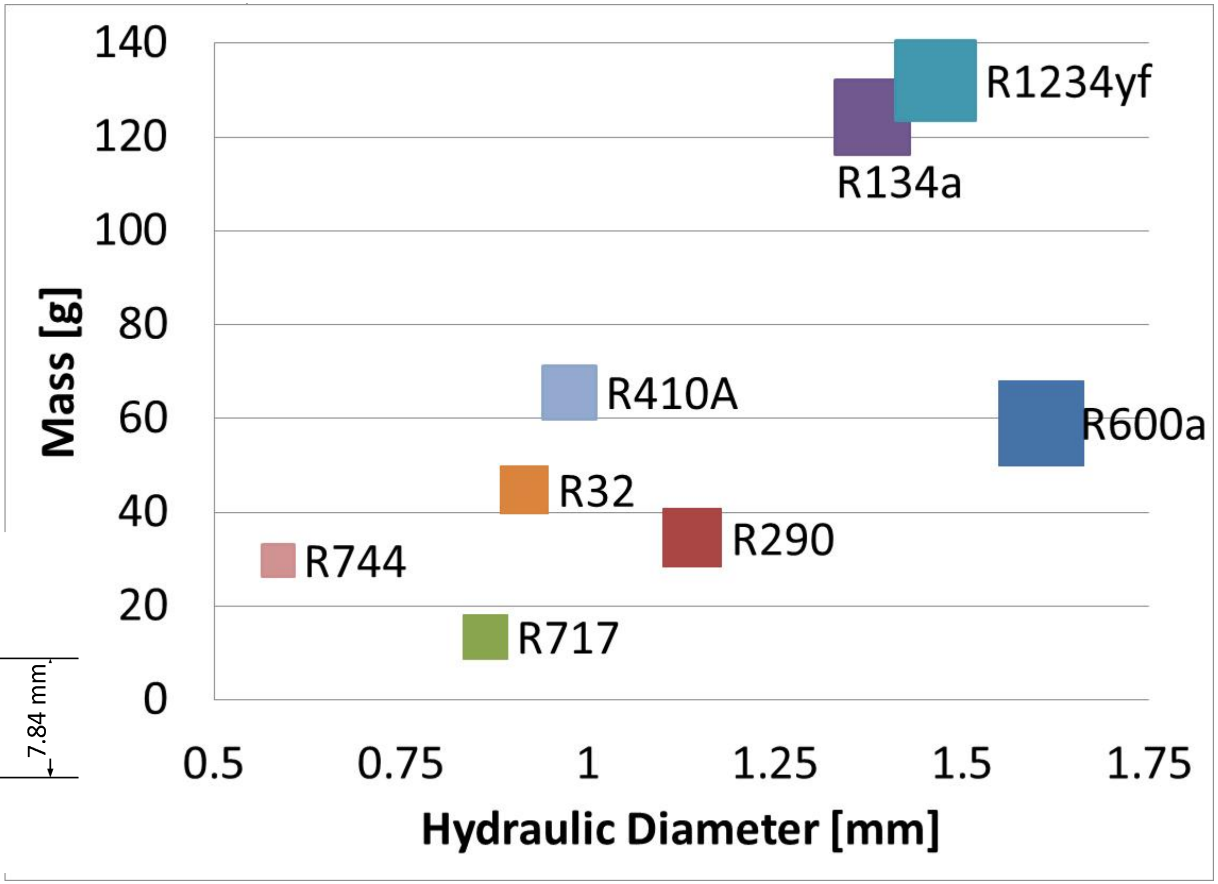
- R744 is very different than R134a, R717, or R290
- Has to be treated as such
- Possible but different way to achieve higher COPs
- Better thermophysical properties – heat transfer advantages have to be utilized
- Lesser sensitivity to pressure drop – easier to make HXs

Excellent potential for charge reduction

Example: equal Q =1kW

DP causes 1% COP reduction





Conclusion

- Each of the main alternatives are excellent and competitive.
- Need to be treated with understanding to maximize opportunities.

- Main issue: how to overcome initial higher cost

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Thank you very much for your attention