# Many Options for Natural Refrigerants

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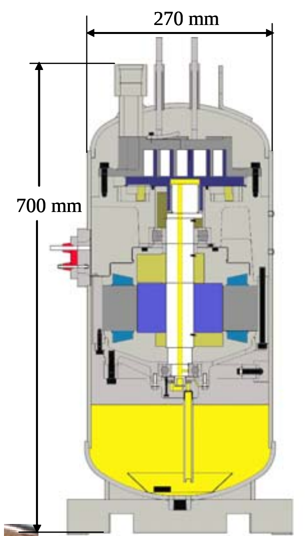
# Natural refrigerants

- In **vapor compression** systems:
  - Ammonia: R717
  - Hydrocarbons: R600a, R290, ….
  - Carbon Dioxide: R744

  **Serious potential to become mainstream option**

  - 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, …

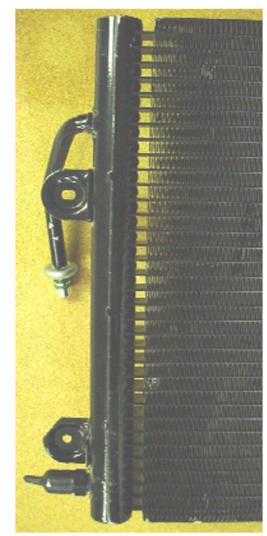
# Current advances




- Hermetic compressor
- Microchannel condenser
- Ni brazed plate evaporator

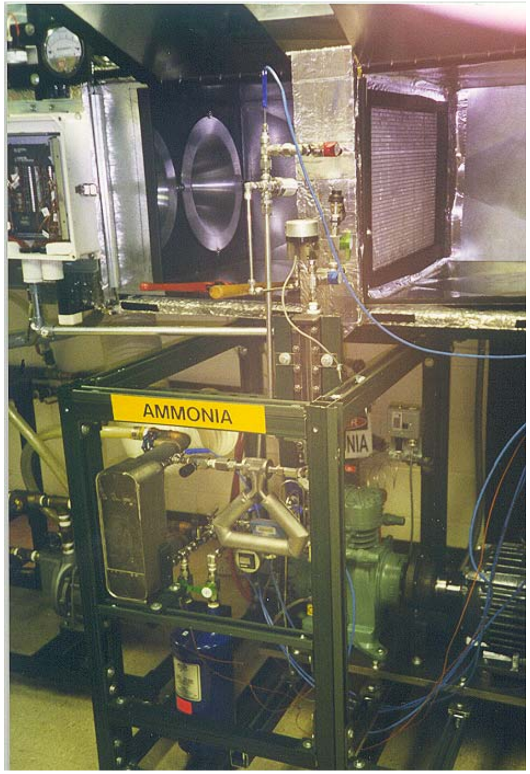
**Needed:** Cost reduction

- Different materials: aluminum as an 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



# 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**

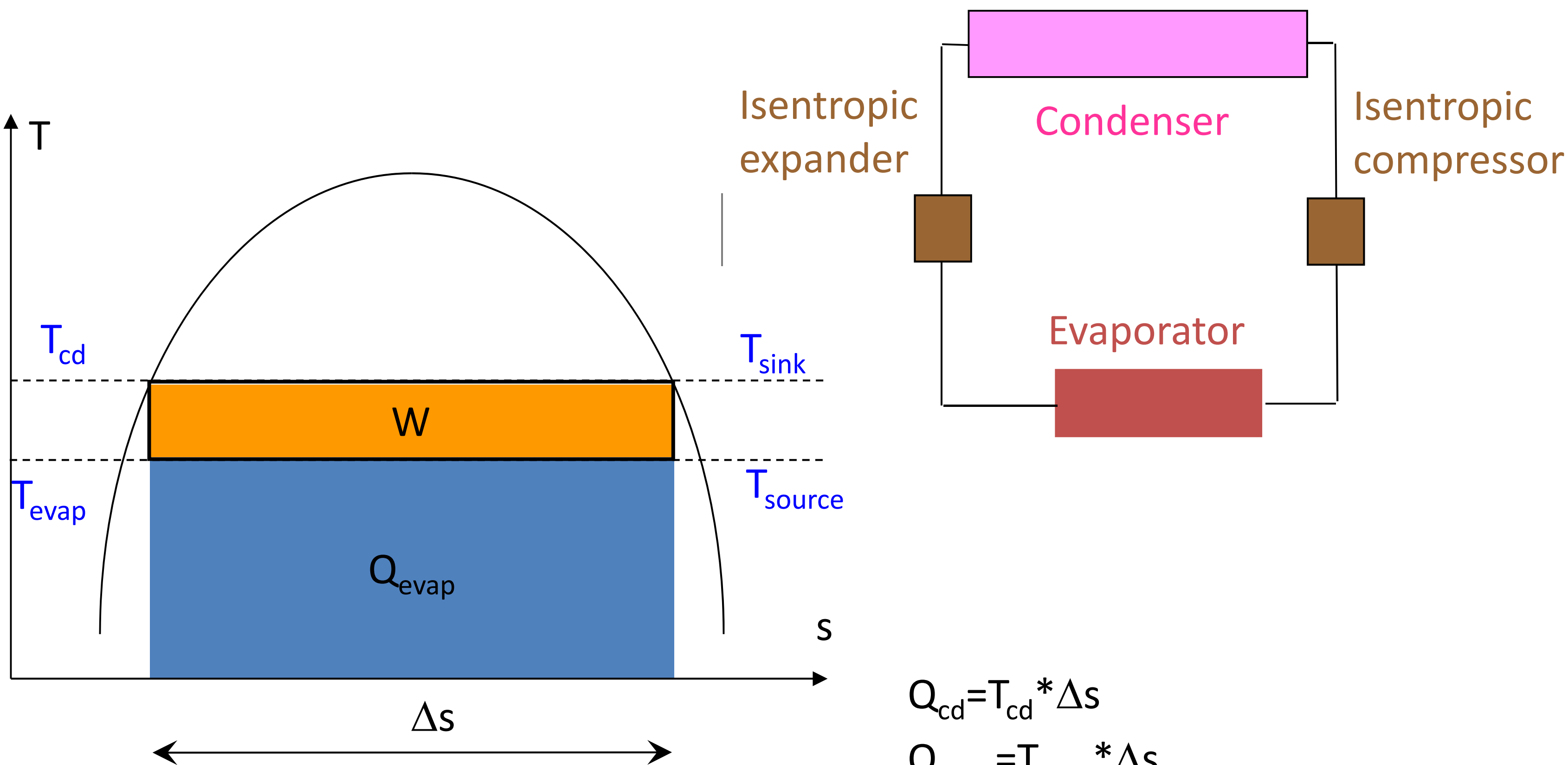
Very often same word is used for different efficiencies:

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




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

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

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

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

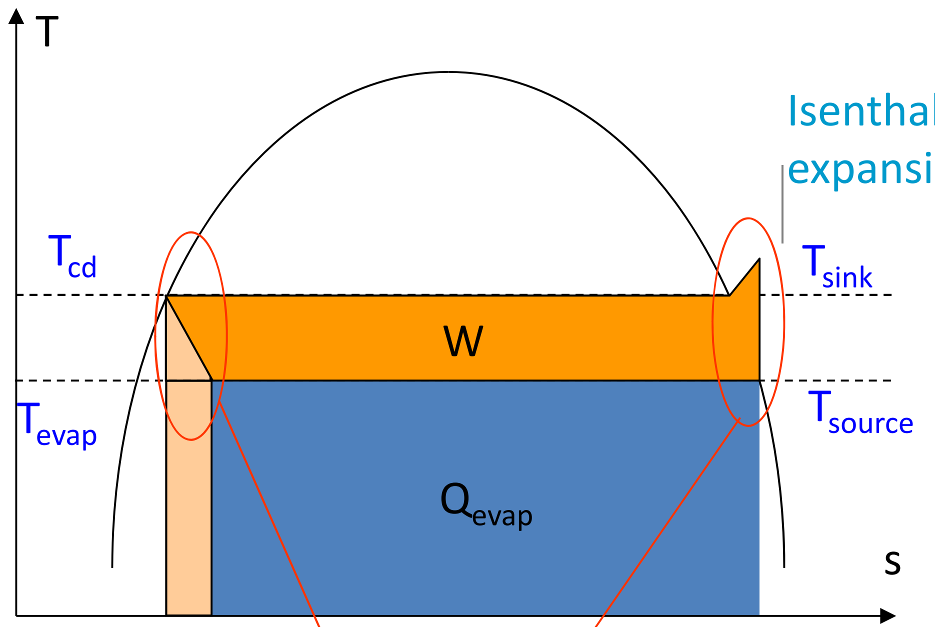
$COP= Q_{evap}/W$

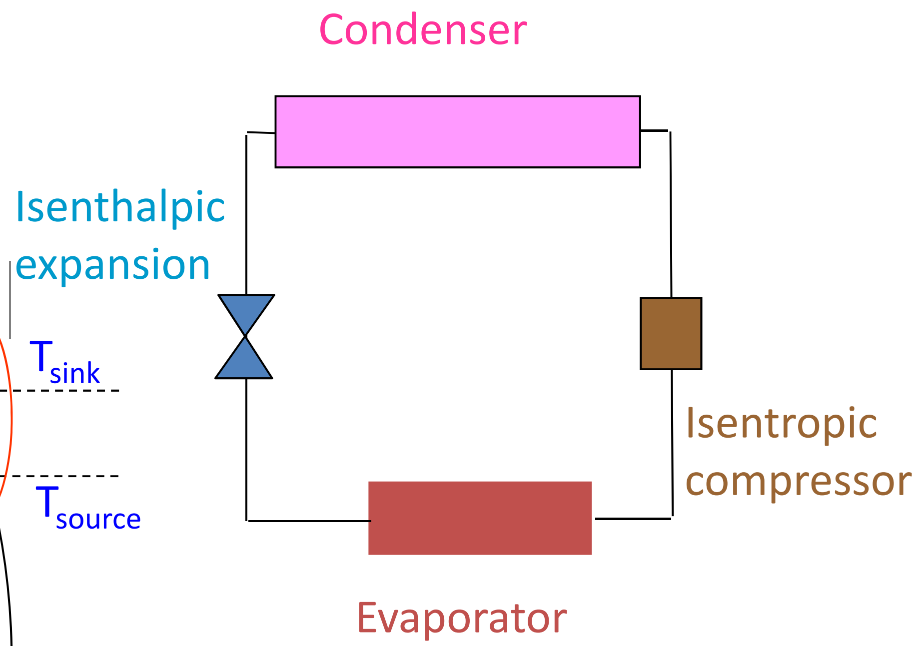
# So,

- **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

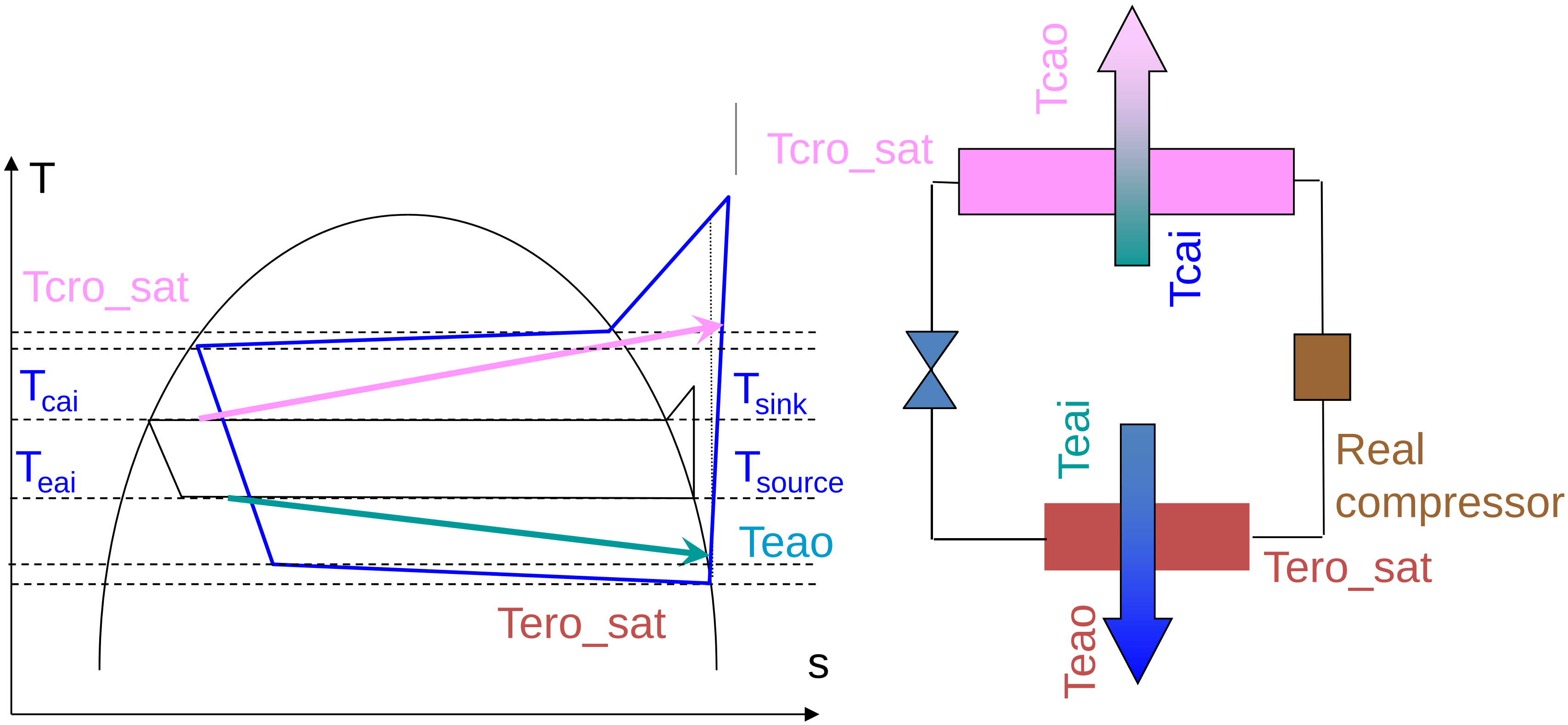
- **Rankine** – Dry suction, Isenthalpic expansion
- Fluids are **NOT** equal – begin to differentiate

# 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

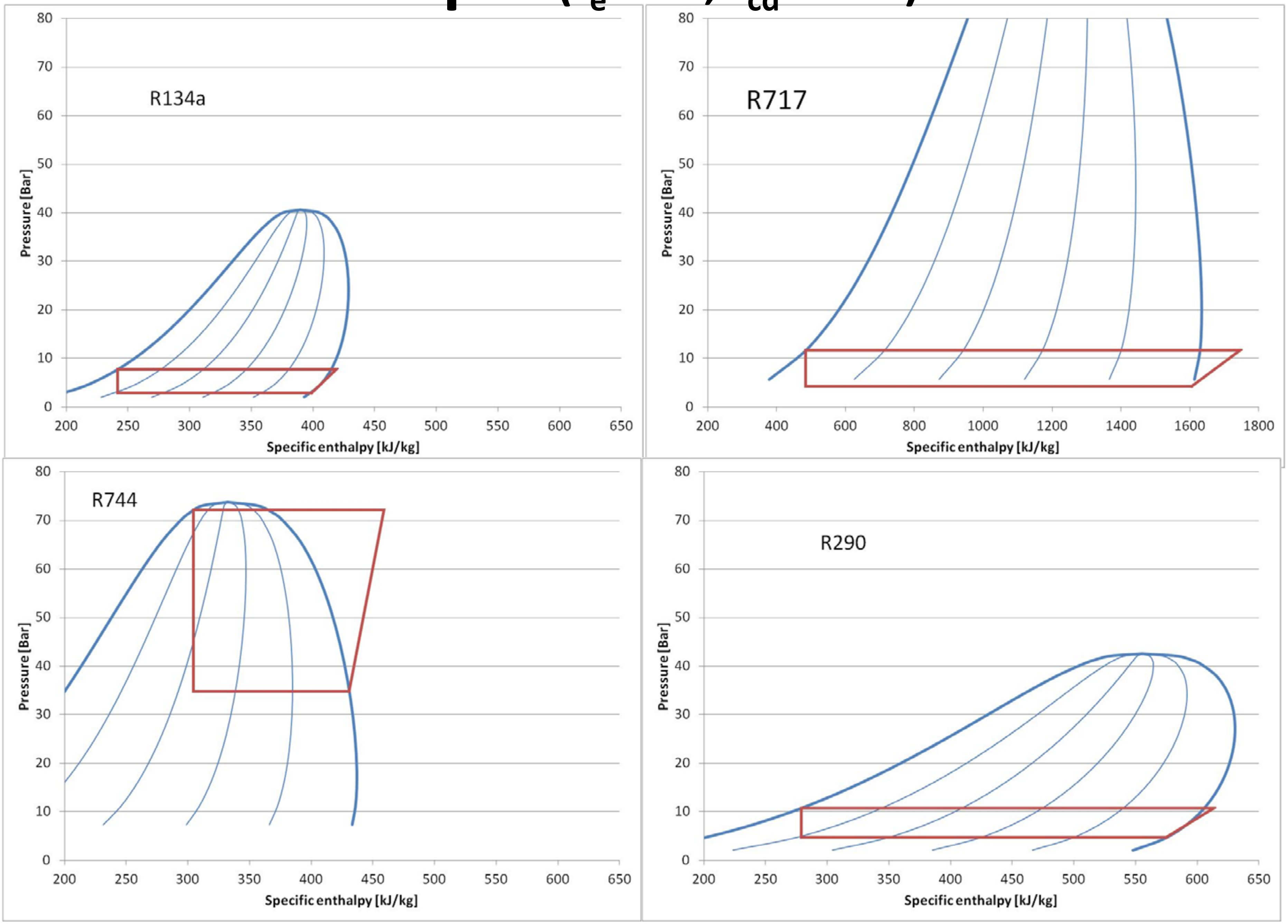
# System,
# based on Rankine cycle

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

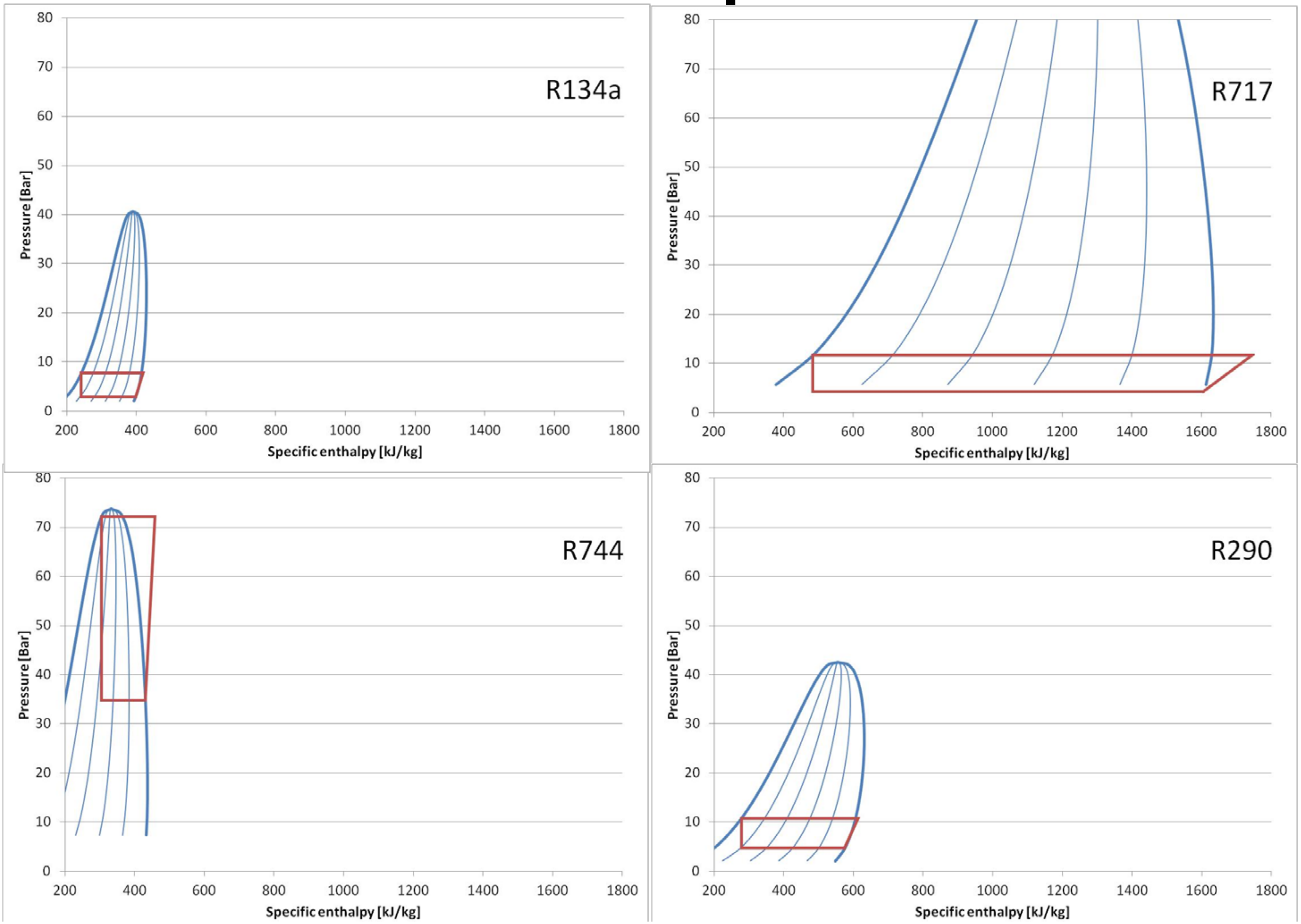



**Rankine system** – measured on the test bench

# ln p-h ($t_e$=0°C, $t_{cd}$=30°C)



# In scale: p-h


R134a
R717
R744
R290
Pressure [Bar]
Specific enthalpy [kJ/kg]
0
10
20
30
40
50
60
70
80
200
400
600
800
1000
1200
1400
1600
1800

# Why is this important?

- COPs of the CYCLE is dramatically reduced in the SYSTEM by effect of:
  - 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**

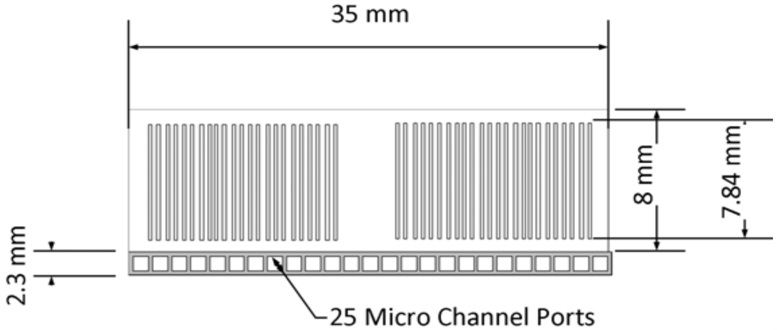
# Situation

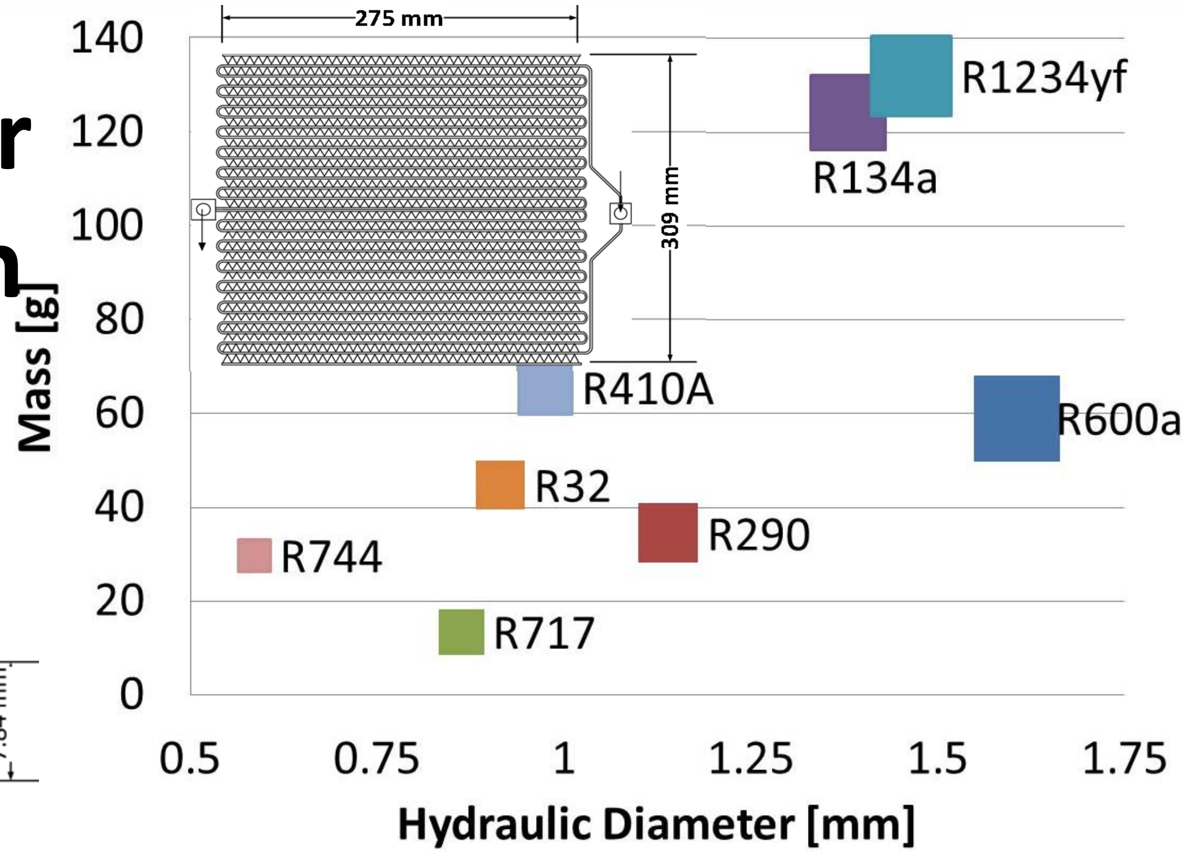
- R744 is very different than R134a, R717, or R290
- Has to be treated as such
- Possible but more difficult to achieve higher COPs
- Better thermophysical properties – heat transfer advantages have to be utilized
- Lesser sensitivity to pressure drop – easier to make HXs

# Also excellent for charge reduction

Example: equal Q =1kW

**DP causes 1% COP reduction**




| Fluid | Ref. Mass | Hydraulic Diameter | Mass Flow Rate | ΔP [1 % COP reduction] | COP Ideal | Cond. Temp. | Rejected Heat | Sat. Liquid Density | Sat. Vapor Density | Latent Heat |
|---|---|---|---|---|---|---|---|---|---|---|
| | [g] | [mm] | [g/s] | [kPa] | [-] | [C] | [kW] | [kg/m³] | [kg/m³] | [kJ/kg] |
| R717 | 13.4 | 0.8625 | 0.862 | 7.45 | 10.04 | 24.6 | 1.043 | 603.9 | 7.72 | 1169 |
| R744 | 29.8 | 0.586 | 5.943 | 35.79 | 7.01 | 24.3 | 1.103 | 724.8 | 234.7 | 125.9 |
| R290 | 34.4 | 1.14 | 3.150 | 6.58 | 9.57 | 25.2 | 1.048 | 492.2 | 20.72 | 335.7 |
| R32 | 44.9 | 0.915 | 3.636 | 11.46 | 9.41 | 24.8 | 1.054 | 962.8 | 47.12 | 271.7 |
| R600a | 59.1 | 1.606 | 3.310 | 3.17 | 9.76 | 25.5 | 1.067 | 550.2 | 9.285 | 329.4 |
| R410A | 65.6 | 0.975 | 5.320 | 11.65 | 9.37 | 25.1 | 1.067 | 1063 | 66.15 | 187.8 |
| R134a | 124.2 | 1.38 | 5.962 | 5.52 | 9.54 | 25.6 | 1.094 | 1206 | 32.88 | 177.7 |
| R1234yf | 132 | 1.464 | 7.520 | 5.41 | 9.31 | 25.6 | 1.077 | 1091 | 38.42 | 145.6 |

# 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