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Natural Refrigerants in Different Applications

Pega Hrnjak
pega@illinois.edu
Res. Professor, U. of Illinois, Urbana-Champaign
Co-Director ACRC,
President, CTS

A brief reminder

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

Hydrocarbons

- Almost drop-in replacement for R22 (R290)
  - a/c or commercial refrigeration
- Easy replacement for R12 or R134a (R600a)
  - Refrigerators are the most successful application, mostly in Europe
- Flammability mitigated by design and charge
- Charge limits 50g (?) or 150 g (?)
- Lowest charge known: 48g/kW @ 1kW, aircooled

Strong activity to increase use and expand applications

- Ongoing efforts to use R290 as a R22 replacements in a/c (mini splits, …)
- R290 in commercial refrigeration:
  - bottle coolers (Pepsi, …)
  - self contained cabinets (due to low cost and charge)
  - supermarket racks, typically with secondary fluids or in cascade
- Besides Europe push in China, rest of Asia, Latin America, Australia, USA

Carbon dioxide

- Very old refrigerant
- Abandoned because of high pressures and heavy equipment;
- Besides environmental reasons microchannel HXs and better materials reopened the door, especially for MAC applications
- Wrongly assumed to be low efficient refrigerant – will come back to that point briefly

CO_2 is still the most active area

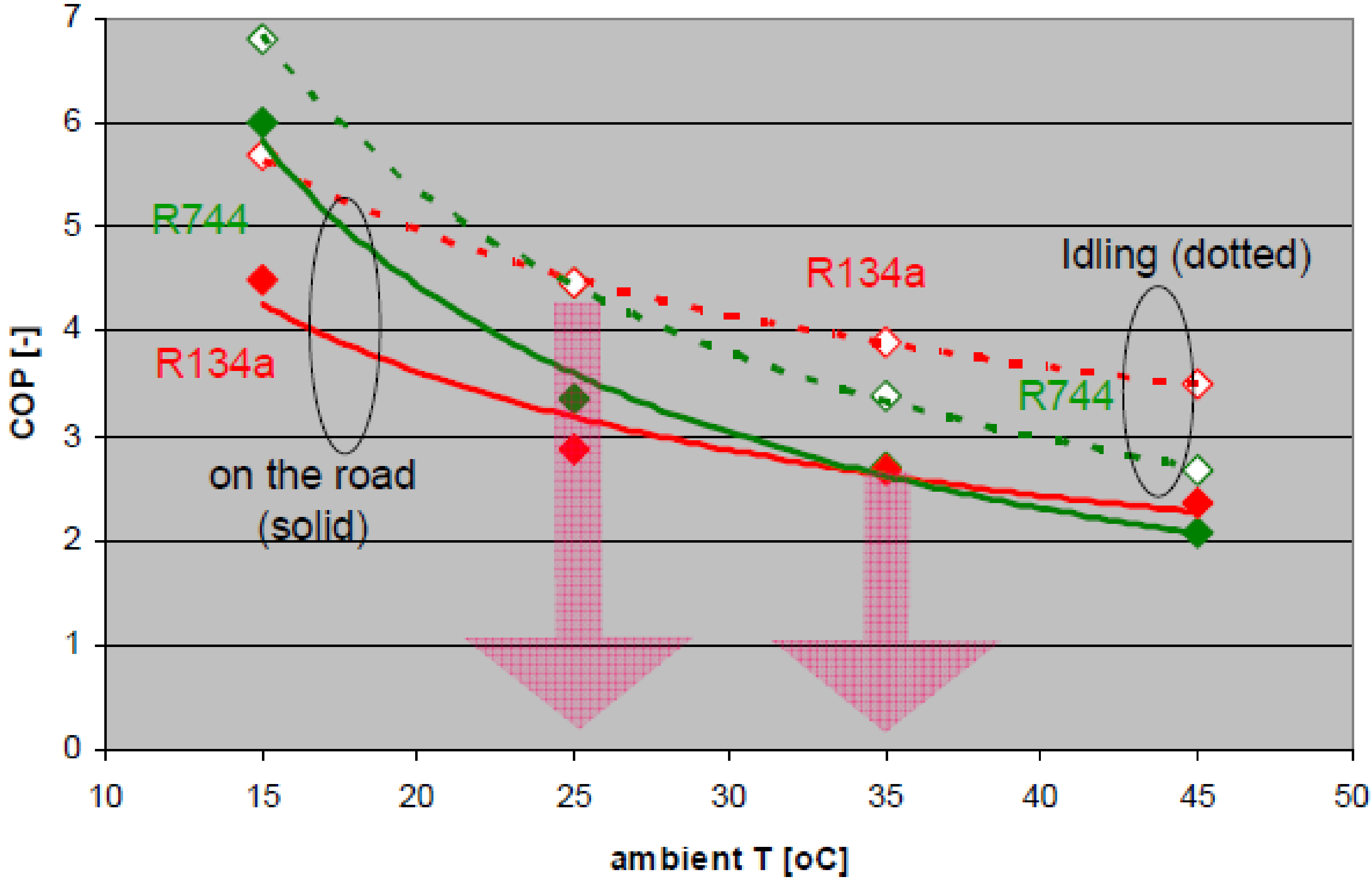
- HPWH – the first successful commercial application of transcritial systems:
  - Besides success in residential sector (reached stabile 0.5e6 p/a) rapidly expanding in commercial and industrial sizes
- Currently supermarkets are expanding application utilizing CO2 in low temp side (cascade, secondary) but more as transcritical:
  - strongest in Europe but elsewhere (Canada, Japan, USA, …)
  - larger stores, with booster systems, heat reclaim etc….
- Convenience stores:
  - Mostly in Japan, but elsewhere too
- Bottle coolers – tens thousands p/a
  - strong push by The Coca Cola (in four year cycles)

In MAC applications

- From extremely strong beginning prospects seemed to be closed when industry selected R1234yf as a replacement for R134a
- Situation changed when Daimler published flammability results in Oct. 2012
- Application: highest risk/highest potential
- Outcome unknown
- One element is certain:

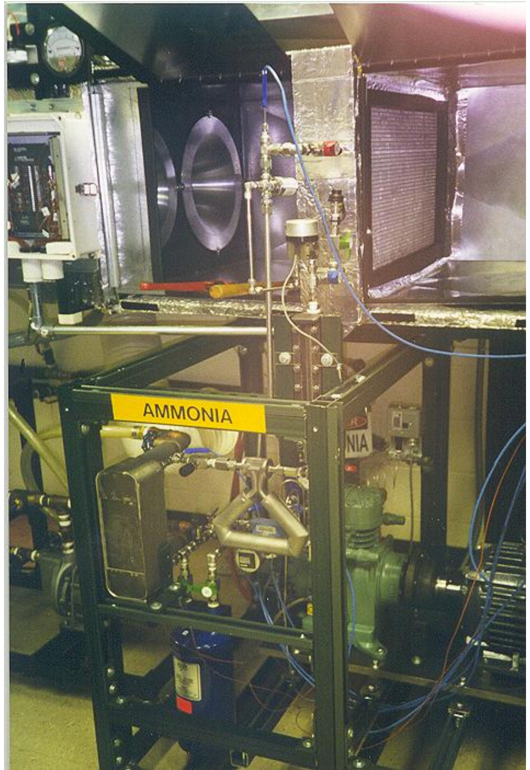
CO_2 was not selected for MAC because low efficiency (COP)

Summary of R134a vs. R744 in SAE MAC program Identical capacity, same size HXs



Ammonia – R717

- The only natural refrigerant that was continuously in use (in industrial refrigeration)
- Not appropriate for populated areas when charge is significant
- US EPA does not require reporting a leak <100 lb (50kg)
- Low charge systems or chillers for a/c or refrigeration with secondary coolant or cascade
- Lowest published charge 18 g/kW@15kW, - aircooled

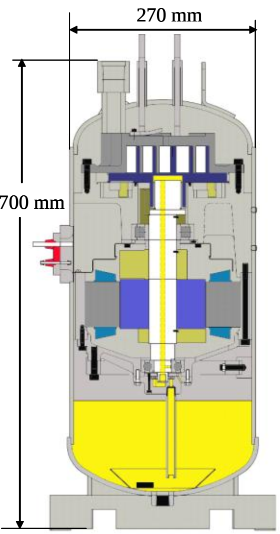


Significant changes in approach to ammonia applications

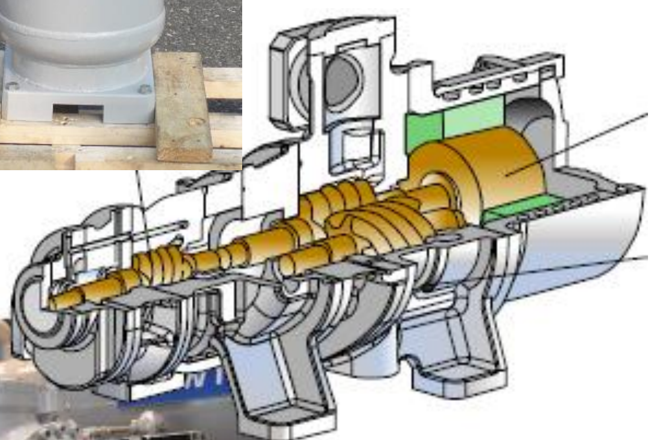
- Increasing number of cascades (R717/R744) for commercial and industrial systems
- Strong push towards low charged, self contained units (we will hear more today – Mayekawa NewTon)

- Push towards chillers (excellent for applications that may otherwise have NH_3 in direct contact with air)

Current advances



- Hermetic or semihermetic compressors
- Microchannel condensers

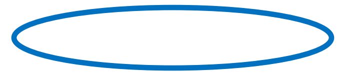
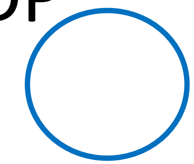


- Ni brazed plate evaporator

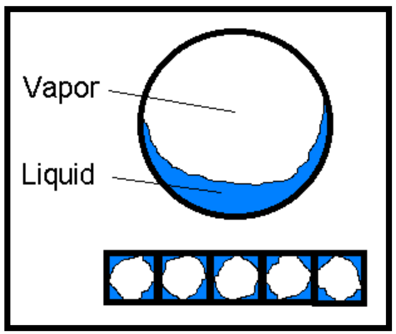
- **Ultra low charged systems – main trend**

we will touch that topic:

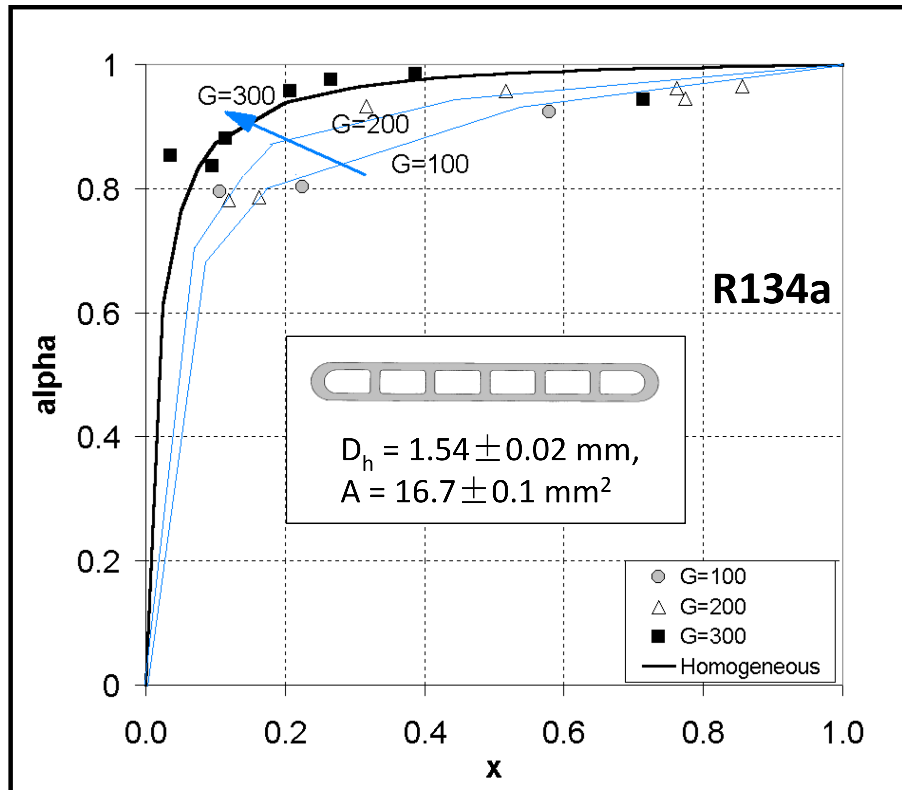
How to reduce charge

- Reduce internal volume, but do not increase DP
- Also shape helps  is better than 
- Increase vapor volume fraction α (void fraction) by changing flow regimes

$$\alpha = \frac{1}{1+\left(\frac{1-x}{x}\right)\frac{\rho_v}{\rho_l}}$$



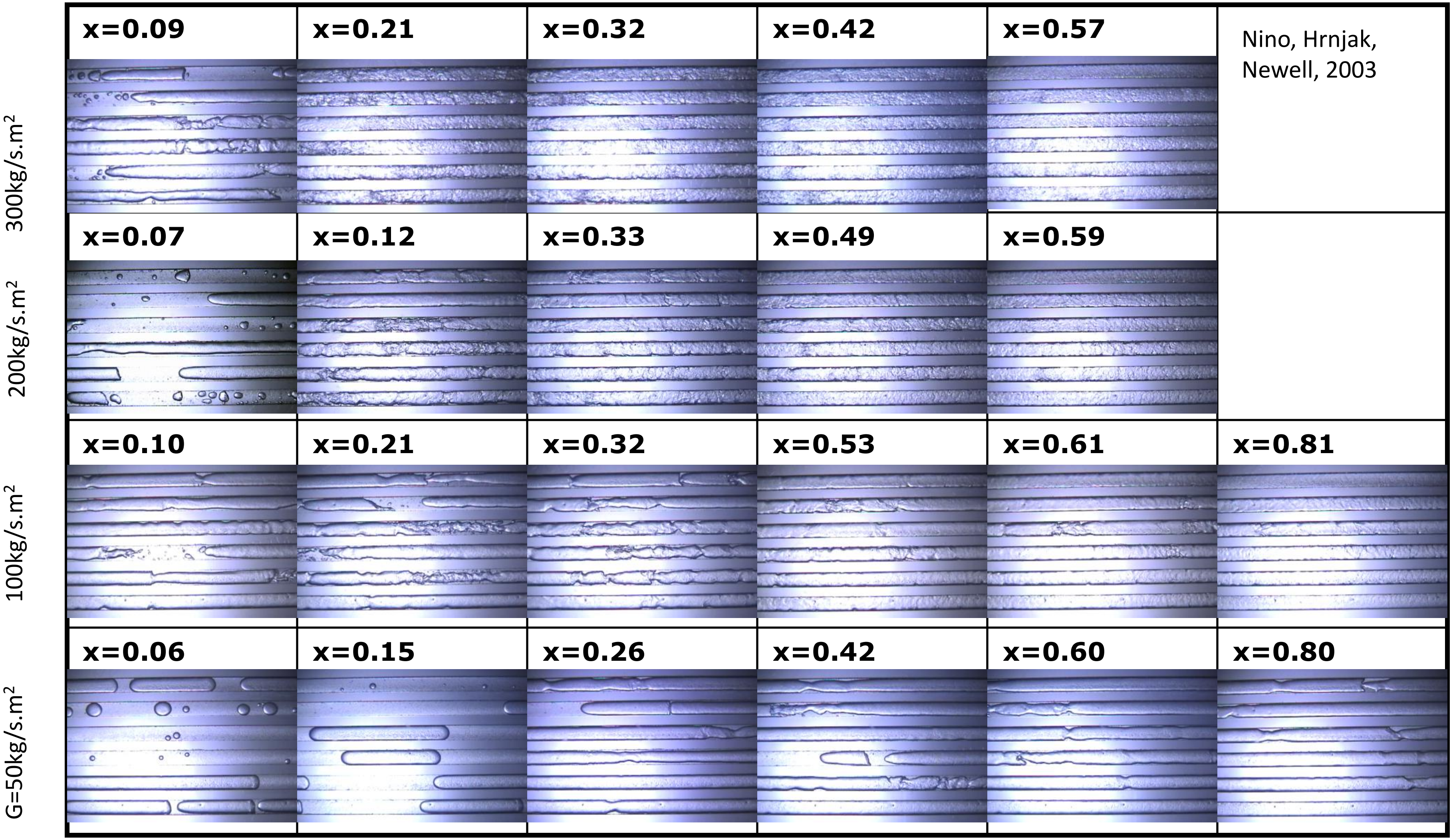
$$\alpha = \frac{Area_{vapor}}{Area_{total}}$$



- Increase heat transfer: that reduces surface!

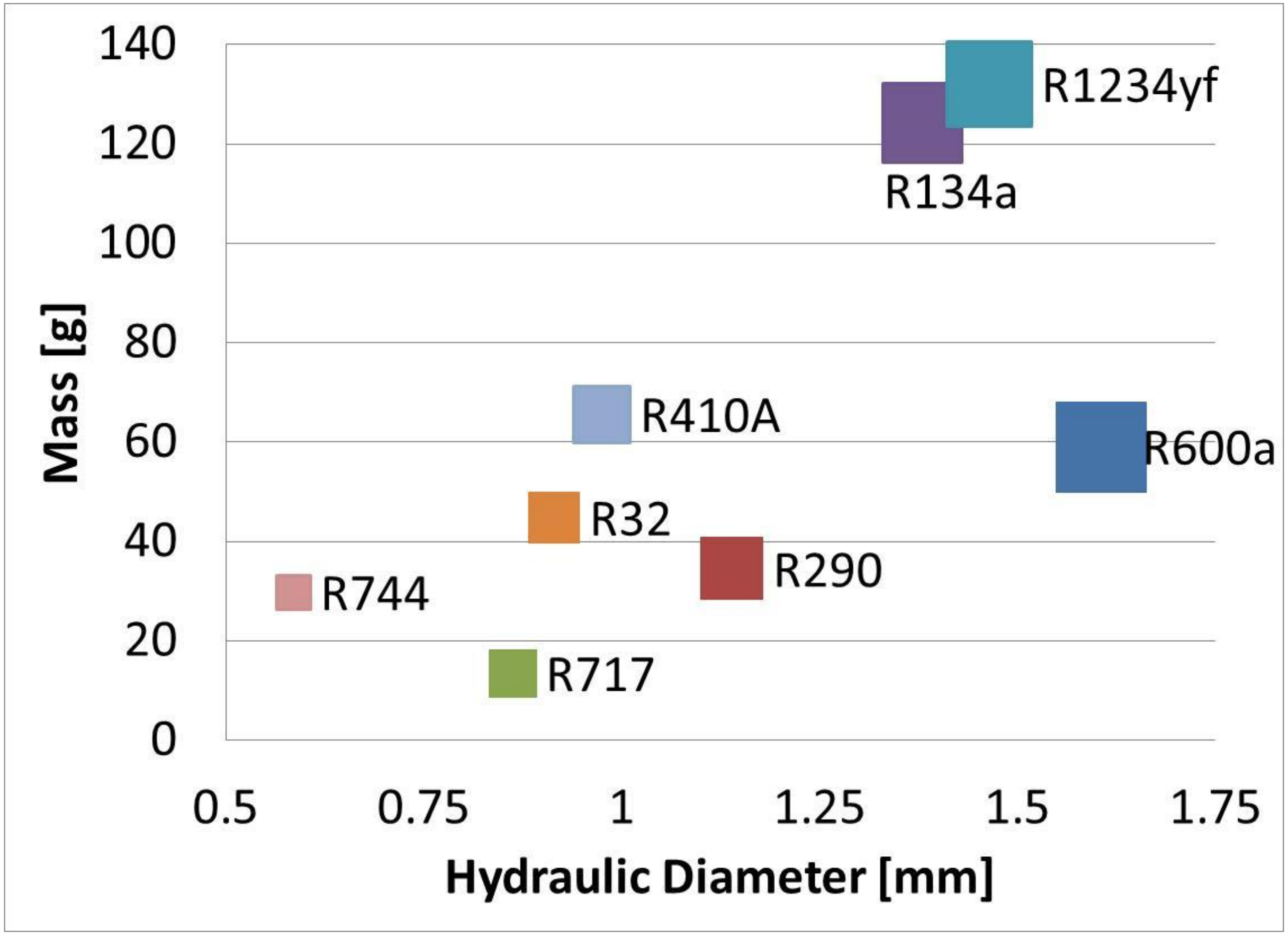
Higher α at higher mass flux

(1mm, 9-port, R134a)



NH_3, CO_2, even R290: excellent charge reduction potential

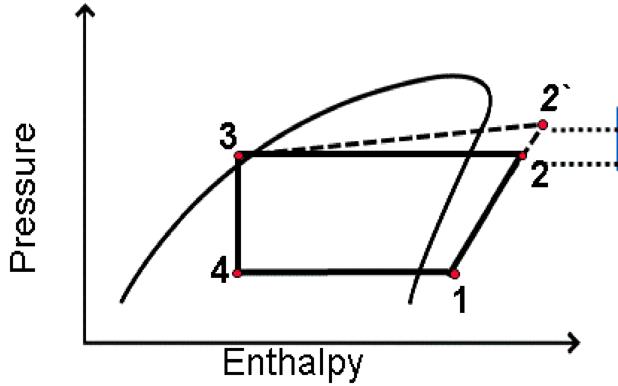
- Example: charge in a MC condenser for different refrigerants



More in IIR **GL Delft -251: Padilla & Hrnjak, 2012**

How to compare refrigerants based on charge reduction potential

- **Objective to minimize:**
  - internal volume and
  - void fraction but
  - charge is also function of density
- **To be fair:**
  - Maintain the same DP effect on COP : DP=f(velocity, L)



$\Delta p \quad 1\% \, \Delta \, COP$

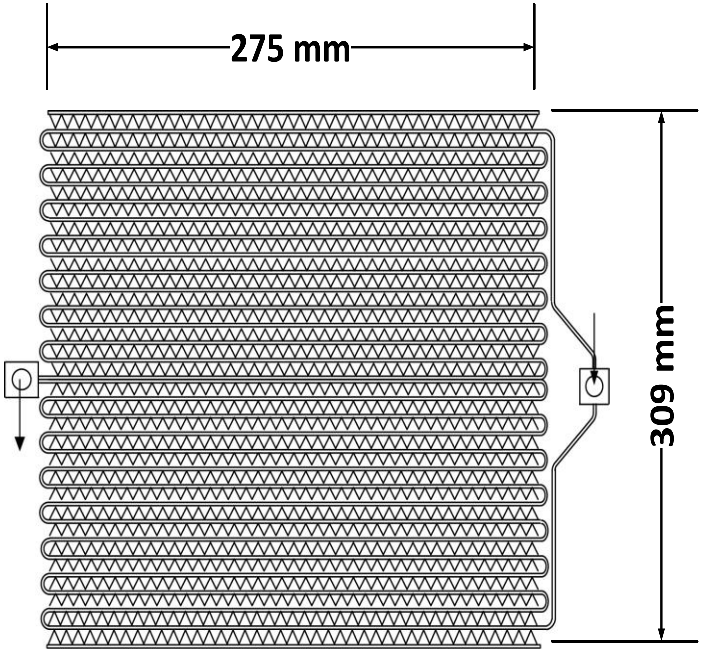
$$COP_{ideal} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{non\_ideal} = 0.99 * COP_{ideal}$$

- **Result**: refrigerant mass and channel size

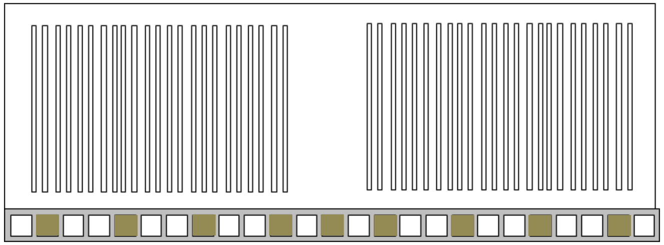
We kept the same

air side (fins, tubes), cooling capacity → m_{ref}

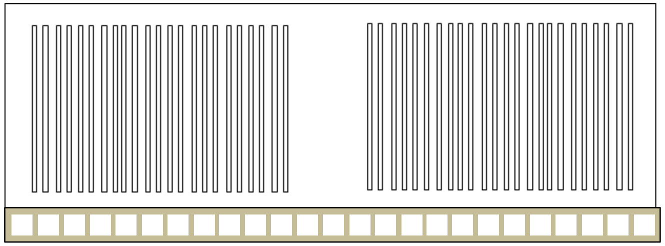


So we varied:

Channel number



Channel size (diameter)



Reasons

Fluid	Ref. Mass	Hydrau. Diam.	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	0.863	0.862	7.45	10.0	24.6	1.043	604	7.72	1169.0
R744	29.8	0.586	5.943	35.79	7.0	24.3	1.103	725	234.70	125.9
R290	34.4	1.140	3.150	6.58	9.6	25.2	1.048	492	20.72	335.7
R32	44.9	0.915	3.636	11.46	9.4	24.8	1.054	963	47.12	271.7
R600a	59.1	1.606	3.310	3.17	9.8	25.5	1.067	550	9.285	329.4
R410A	65.6	0.975	5.320	11.65	9.4	25.1	1.067	1063	66.15	187.8
R134a	124	1.380	5.962	5.52	9.5	25.6	1.094	1206	32.88	177.7
R1234yf	132	1.464	7.520	5.41	9.3	25.6	1.077	1091	38.42	145.6

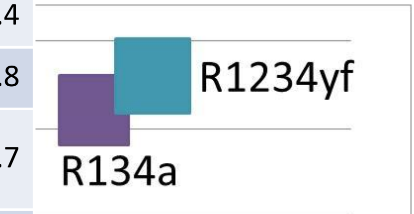
High h_{fg} = Low M_r

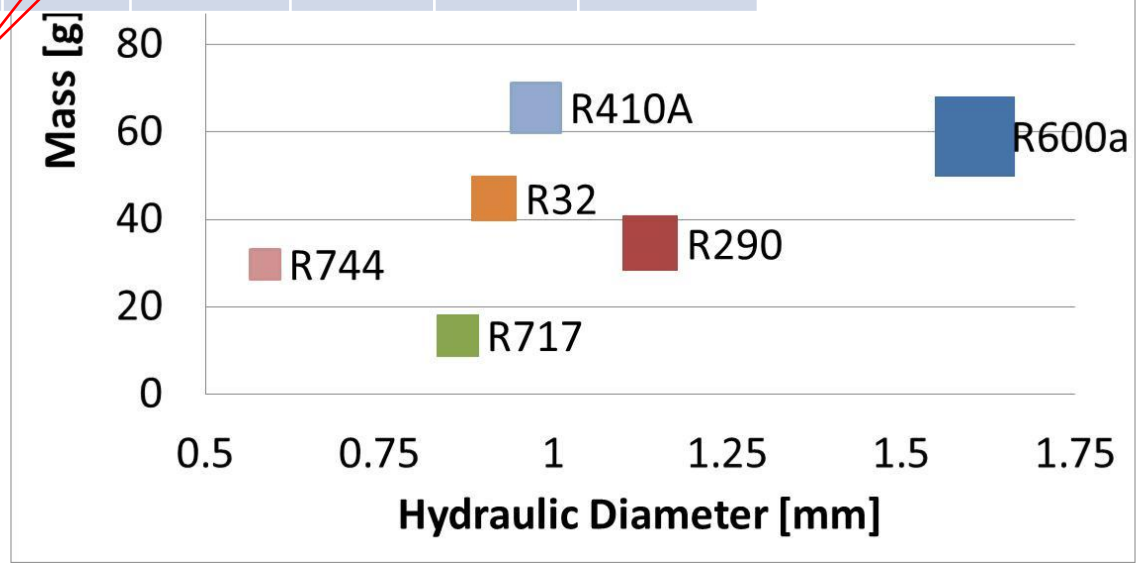
Light vapor and liquid = low mass per volume

Well balanced fluids

Low DP sensitivity = Small channel

Dense fluid = more of it





? - why COP?

- why not CO_2 emission?

- why not cost?

Conclusion as an introduction

- Applications for natural refrigerants are expanding
- Three dominant in respective fields: CO_2 HPWH in Japan, R600a refrigerators in Europe and NH_3 in industrial refrigeration
- Supermarkets, small commercial units, … on a good trajectory
- MAC is back to the proving arena
- When treated with understanding each of the main alternatives is excellent and competitive.
- Major remaining tasks to be completed:
  - Ammonia: application of charge reduction opportunities
  - HCs: extremely low charge
  - CO_2: Reduce expansion losses, improve HXs, prove reliability at MAC
- Still to work on overcoming initial higher cost when advantages of natural refrigerants are clear and desirable