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Johnson Controls

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Lower GWP Fluids for A/C applications. Comparisons between alternatives.

Outline/Agenda

- Context and objectives of the study.
- Fluids in the study.
- Behavior of blends.
- Formulation of blends.
- Impact on performance.
- Example: 134a and its alternatives.
- Conclusions.

Context and purposes

- Four “benchmark” fluids are currently used in A/C (Chillers and D-X): R-123, R-134a, R-22 and R-410A.
- The phase-out of R-123 and R-22 is completed in “developed countries”, and ongoing in Art-5 countries.
- Lower GWP alternatives to R-134a and R-410A are desired.
- So, alternatives are being investigated for **all** the fluids currently used in A/C.
- One of the proposed alternatives (R-290) is highly flammable; many others alternatives have lower flammability (“2-L” class)
- It is agreed that alternative solutions should not result in lower energy efficiency.
- The quest for alternatives results in a trade-offs between flammability, GWP, energy efficiency and cost.
- **The purpose of this presentation is to shed light of some of these trade-offs.**

Fluids in the study

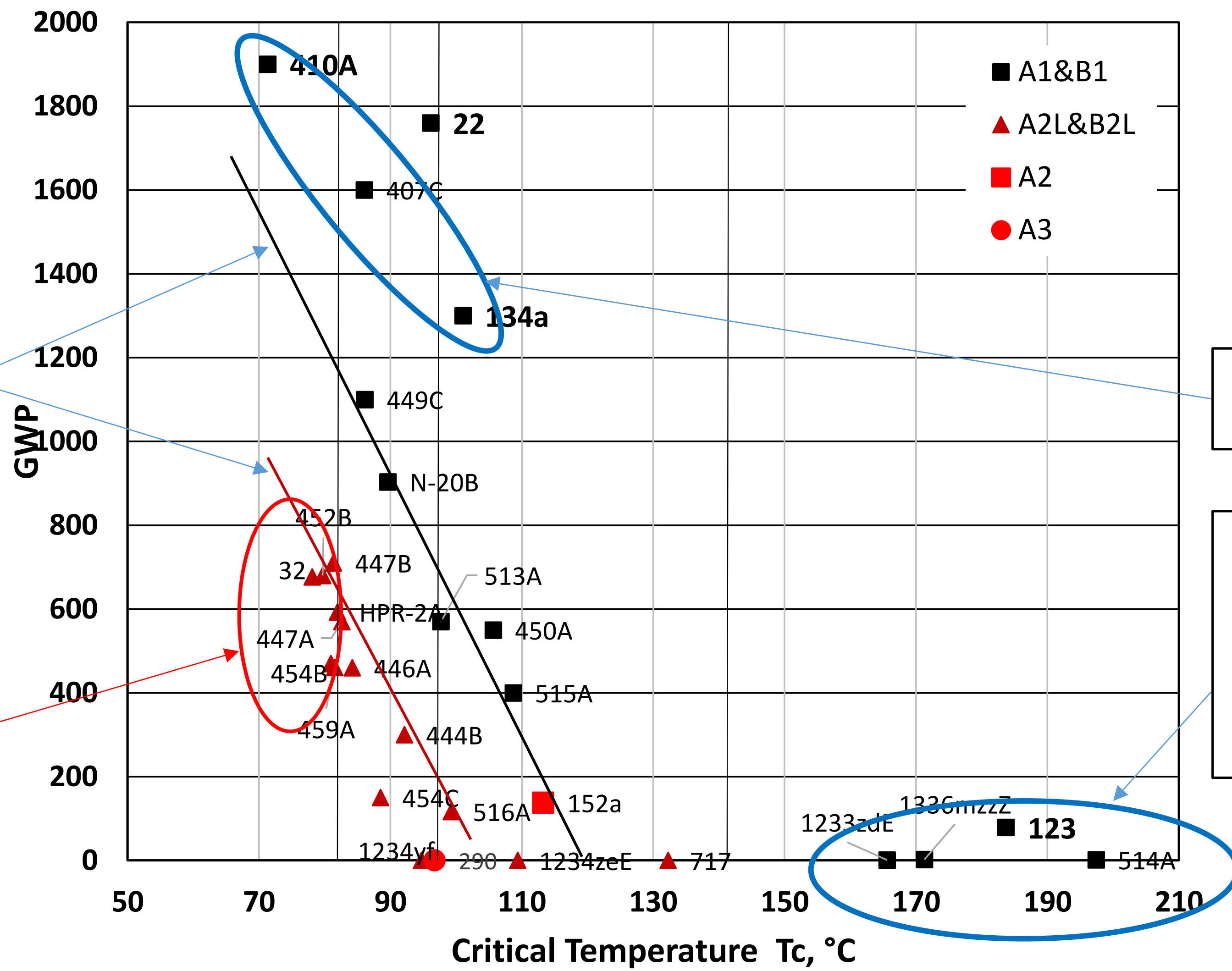
Refrigerant	Alternative to R-N°		Pressure @ 40°C
R-N°	22	410A	Bar-a
410A		O	**24.2**
32		√	24.8
452B		√	22.6
454B		√	22.3
447B		√	21.4
459A		√	21.9
HPR-2A		√	21.7
447A		√	20.8
446A		√	20.7
449C	√		16.3
454C	√		15.6
N-20B	√		14.5
444B	√		15.9
22	O		**15.3**
290	√		13.7

Refrigerant	Alternative to R-N°		Pressure @ 40°C
R-N°	123	134a	Bar-a
1234yf		√	10.2
513A		√	10.7
516A		√	10.5
134a		O	**10.2**
450A		√	8.9
515A		√	7.6
1234zeE		√	7.7
1233zdE	√		2.2
1336mzzZ	√		1.3
123	O		**1.5**
514A	√		1.5

Most of these fluids have been or are being tested under several research programs : AREP, DOE (ORNL), PRAHA, EGIPRA.

An Overview of the Fluids

Alternatives to R-22 or 134a: some are flammable; others are not. At same Tc, the GWP of non-flammable is about 500 higher than flammable.



Higher GWP HFC's.

Alternatives to 410A: all are flammable, with GWP>400.

Alternatives to R-123: all have near-zero GWP. All are non flammable.

More details on the fluids

The alternatives to the base line fluids are ranked by Critical Temperature.

Higher Critical Temperature tends to lower pressure and capacity.

Alternatives blends to 410A have moderate glide (l.3 to 4.2 K)

Alternatives blends to R-22 have higher glide (4.5 to 7.7 K)

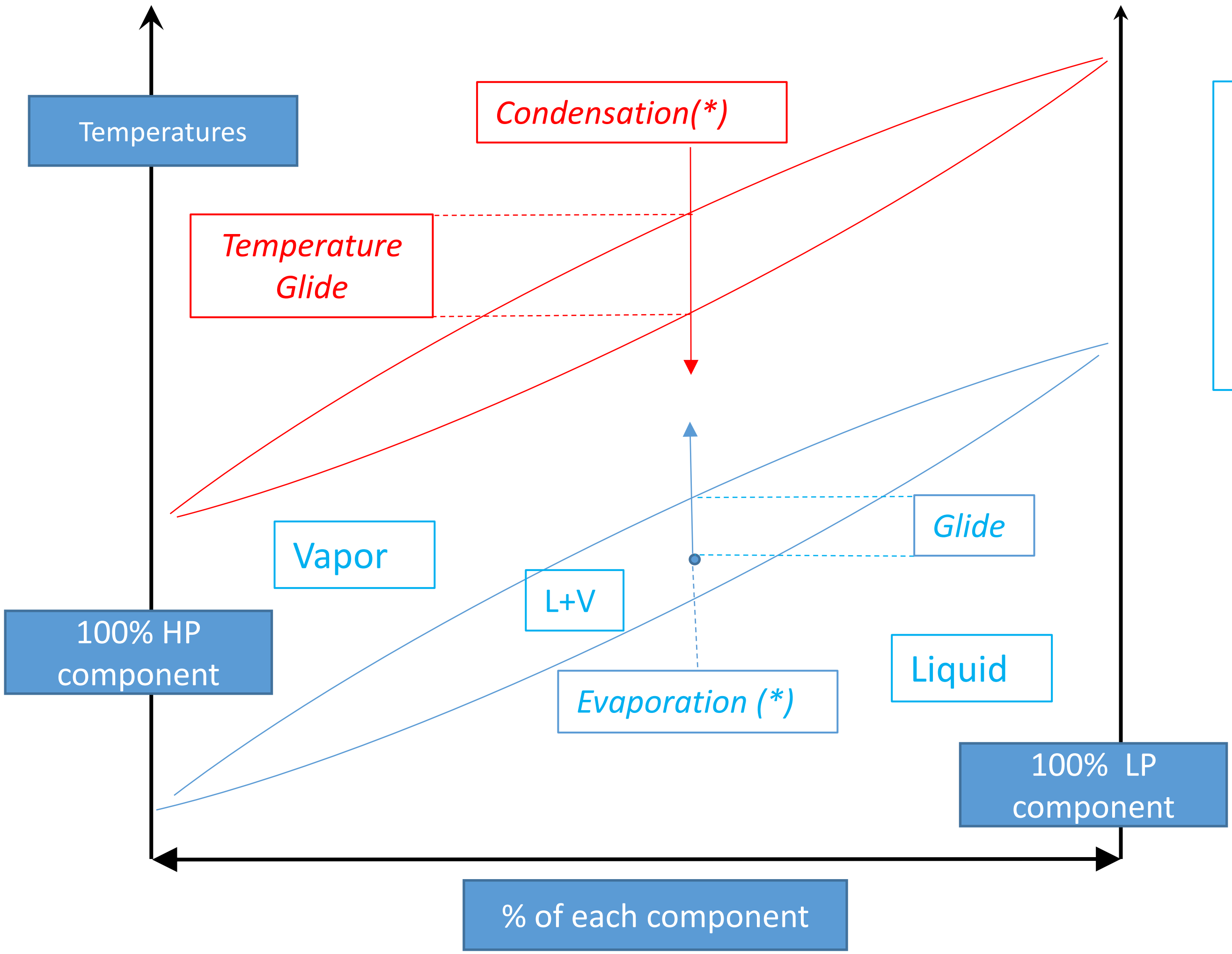
Alternatives to 134a and 123 have little (<0.6 K) or no glide.

Refrigerant	Critical Temperature		Alternative to R-N°:				At 40°C (104°F)		GWP	Safety
							Pressure	Glide	100	class
R-N°	**°C**	**°F**	**123**	**134a**	**22**	**410A**	**Bar-a**	**K**	**(AR5)**	****
125	66.0	151				O	20.1	/	3170	A1
410A	**71.3**	**160**				**O**	**24.2**	**0.1**	**1900**	**A1**
32	78.1	173				√	24.8	/	677	A2L
452B	79.7	175				√	22.6	1.3	680	A2L
454B	80.9	178				√	22.3	1.5	470	A2L
447B	81.3	178				√	21.4	3.9	710	A2L
459A	81.5	179				√	21.9	2.0	*461*	A2L
HPR-2A	81.9	179				√	21.7	3.0	*593*	A2L
447A	82.6	181				√	20.8	3.9	570	A2L
446A	84.2	184				√	20.7	4.2	460	A2L
407C	86.0	187			O		16.4	5.0	1600	A1
449C	86.1	187			√		16.3	4.6	1100	A1
454C	88.5	191			√		15.6	6.3	150	A2L
N-20B	89.6	193			√		14.5	4.5	*904*	A1
444B	92.1	198			√		15.9	7.7	300	A2L
1234yf	94.7	202		√			10.2	/	<1	A2L
22	**96.1**	**205**			**O**		**15.3**	/	**1760**	**A1**
290	96.7	206			√		13.7	/	0	A3
513A	97.7	208		√			10.7	/	570	A1
516A	99.3	211		√			10.5	0.0	131	A2L
134a	**101**	**214**		**O**			**10.2**	**/**	**1300**	**A1**
227ea	102	215		O			7.0	/	3350	A1
450A	106	222		√			8.9	0.6	550	A1
515A	109	228		√			7.6	/	400	A1
1234zeE	109	229		√			7.7	/	<1	A2L
152a	113	236		√			9.1	/	138	A2
717	132	270			√		15.6	/	0	B2L
1233zdE	166	330	√				2.2	/	1	A1
1336mzzZ	171	340	√				1.3	/	2	A1
123	**184**	**363**	**O**				**1.5**	**/**	**79**	**B1**
514A	197	387	√				1.5	/	1.7	B1

Why are blends proposed?

- For each of the base line fluids (R-123, R-134a, R-22, R-410A), the idea is to find alternatives with relatively similar capacity.
- To replace R-22, the only pure compounds with “similar” cooling capacity are Ammonia (R-717) and Propane (R-290).
- Ammonia is toxic, and as of today, it is not suitable for D-X systems (material compatibility and high discharge temperature).
- R-290 is highly flammable.
- No other applicable pure compound has similar cooling capacity.
- Blends to replace R-22 are using a combination of:
  - 2 fluids with higher pressure and capacity:R-125 and R-32.
  - 3 fluids with lower pressure / capacity: R-134a, and the HFO’s R-1234ze and yf.
  - Plus occasionally small amount of other fluids: R-152a and R-227ea (close to 134); R-290.

Non-azeotrip, 2 components blend



Each fuse-shape curve is at constant pressure, but both are at 2 different pressure levels, showing condensation or evaporation pressure

(*) Condensation and Evaporation are represented here at constant composition. This happens in case of in-tube phase change.

Composition of the blends / Flammability

All the alternatives to 410A are flammable.

Some alternatives to R-22 or 134a are flammable. Some others are not.

None of the alternatives to R-123 is flammable.

Ref. fluid	Brand name	ASHRAE R-N°	Compositions by mass						Glide (K) @ 40°C	Safety class	GWP 100 (AR-5)
			R32	R125	134a	1234yf	1234ze	Others			
R-410A		410A	50	50					0.12	A1	1900
	DR-5A	454B	68.9			31.1			1.53	A2L	470
	DR-55	452B	67	7		26			1.34	A2L	680
	L-41-1	446A	68				29	R-290, 3%	4.19	A2L	460
	L-41-2	447A	68	3.5			28.5		3.94	A2L	570
	ARM-71A	459A	68			26	6		2.04	A2L	461
	L41z	447B	68	8			24		3.43	A2L	710
	HPR-2A	/	76		6		18		2.97	A2L	593
R-22	L-20A	444B	41.5				48.5	R-152a, 10%	7.71	A2L	300
	N-20B	/	13	13	31	43			4.54	A1	904
		407C	23	25	52				5.00	A1	1600
	DR-3	454C	21.5			78.5			6.29	A2L	150
	DR-93	449C	20	20	29	31			4.62	A1	1100
R-134a	XP10	513A			44	56			0.00	A1	570
	N-13	450A			42		58		0.63	A1	550
	HDR115	515A					88	R-227ea, 12%	0.00	A1	400
	ARM-42	516A			8.5	77.5		R-152a, 14%	0.01	A2L	131
R-123	DR-10	514A	1336mzz, 74.7% ; R-1130E, 25.3%						0.00	B1	1.7

Flammability color code:	1	2L	2	3

	LP Components		HP components	
	1234yf & ze	R-134a	R-32	R-125
Alternatives to R-22 and 134a Flammability class: 1	Lower	Higher	Lower	Higher
Alternatives to R-22 and 134a Flammability class: 2L	Higher	Lower	Higher	Lower

Higher content of flammable components → higher flammability of the blend.

Composition of the blends / Pressures

Ref. fluid	Brand name	ASHRAE R-N°	Compositions by mass						Glide (K) @ 40°C	Safety class	GWP 100 (AR-5)
			R32	R125	134a	1234yf	1234ze	Others			
R-410A		410A	50	50					0.12	A1	1900
	DR-5A	454B	68.9			31.1			1.53	A2L	470
	DR-55	452B	67	7		26			1.34	A2L	680
	L-41-1	446A	68				29	R-290, 3%	4.19	A2L	460
	L-41-2	447A	68	3.5			28.5		3.94	A2L	570
	ARM-71A	459A	68			26	6		2.04	A2L	461
	L41z	447B	68	8			24		3.43	A2L	710
	HPR-2A	/	76		6		18		2.97	A2L	593
R-22	L-20A	444B	41.5				48.5	R-152a, 10%	7.71	A2L	300
	N-20B	/	13	13	31	43			4.54	A1	904
		407C	23	25	52				5.00	A1	1600
	DR-3	454C	21.5			78.5			6.29	A2L	150
	DR-93	449C	20	20	29	31			4.62	A1	1100
R-134a	XP10	513A			44	56			0.00	A1	570
	N-13	450A			42		58		0.63	A1	550
	HDR115	515A					88	R-227ea, 12%	0.00	A1	400
	ARM-42	516A			8.5	77.5		R-152a, 14%	0.01	A2L	131
R-123	DR-10	514A	1336mzz, 74.7% ; R-1130E, 25.3%						0.00	B1	1.7

Pressure color code:	High	Medium-High	2	3
Alternative to:	R-410A	R-22	R-134a	R-123

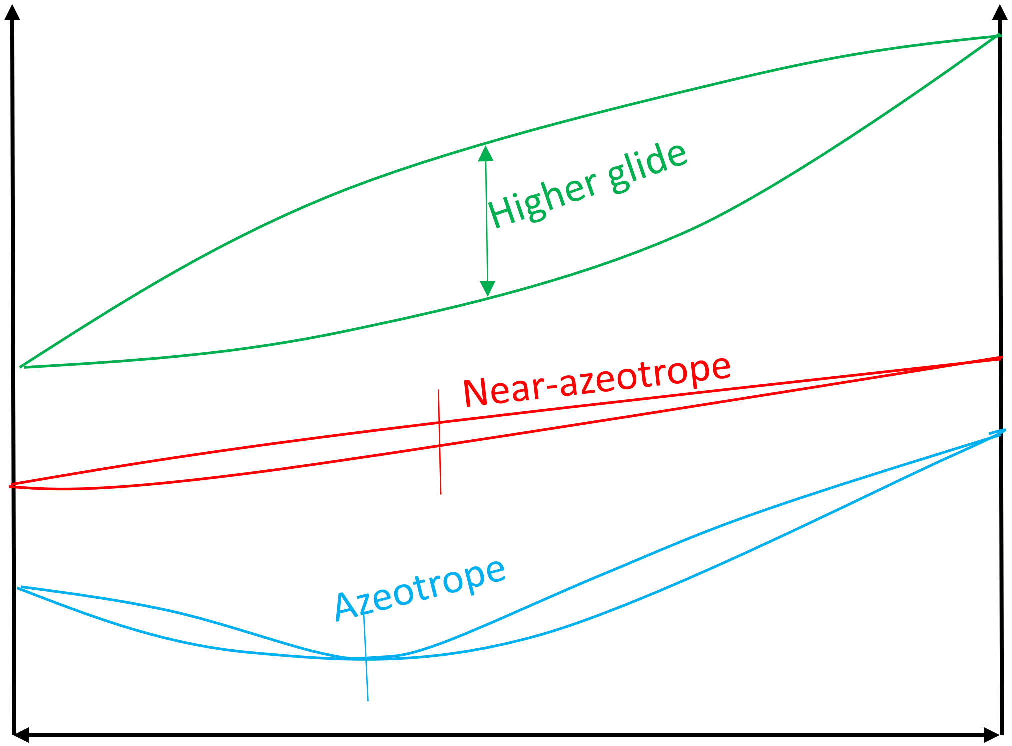
Alternatives to **R-410A and R-22** are blends of **HP and MP** fluids.

Alternatives to **410A** have more HP components and less MP than alternatives to R-22.

Alternatives to **134a** are blends of **only MP** fluids (134a, HFO's 1234yf or ze, 227ea; 152a).

Alternative blend to **R-123** is a blend of LP fluids.

Different blend behaviors



Alternatives to **R-410A and R-22** are blends of **HP and MP** fluids. Large temperature difference between components at equal pressure gives high glide.

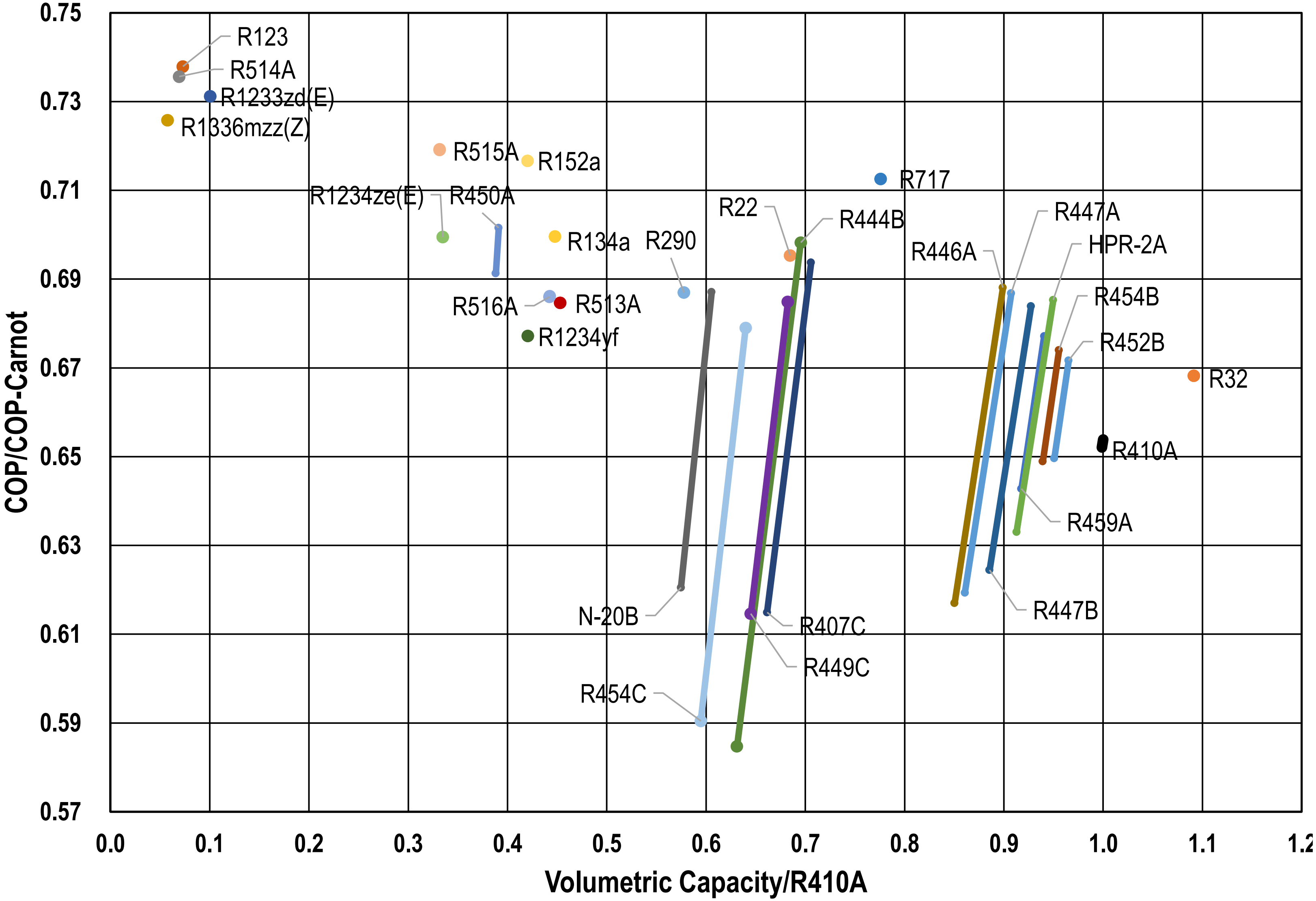
Alternatives to R-134a and R-123 are blends of fluids with relatively similar properties. Such blends have low glide (near azeotropes), or give azeortopes more easily.

Reminder: - A pure fluid or azeotropic blend has no temperature glide.
- A zeotropic (or non-azeotropic) blend has some glide.
- A near-azeotrope (or quasi-azeotrope) has very low glide (e.g. R-410A)

Performance comparisons method

- The various fluids are compared by cycle simulations in the specific case of a « base line » unit: the mini-split 410A unit tested under AREP / ORNL programs, and at AHRI conditions.
- Simulations assume same heat transfer and compressor efficiency for all the fluids (not necessarily true).
- Plots are made giving the volumetric capacity versus COP.
- For blends with glide, the evaporation is not isothermal. Then the performance is very sensitive to the arrangement of the heat exchangers.
- The performance (capacity and COP) is better with Counter-Flow ("Cf") exchangers than with Parallel Flow ("Pf"). A "Constant LMTD" method was developed to analyze this effect.
- On the plots, a pure fluid is represented by a single point. A zeotropic blend is represented by a segment between the best point (Cf on evaporator and condenser) and a worst case (Pf on both exchangers).

Performance comparisons results



Comments on results (@ AHRI-A)

- In general, fluids with lower Tc / higher pressure have higher capacity but lower COP. General trend, with some variations. Trade-off between Capacity and COP.
- In the optimum configuration, blends with glide can have slightly better COP at equivalent capacity. But the performance can also be much lower in the arrangement of heat exchangers is not optimum.
- Zeotropic blends are generally not recommended for heat exchanger with shell and tube exchangers and out-of-tube evaporation or condensation (e.g. flooded evaporators).
- Real designs should be close to optimum, but optimization is not necessarily simple. Example: most current designs of small split A/C units have cross flow evaporator.
- Except R-32, all the alternatives to 410A have lower capacity than 410A. All have a better COP.
- Blend alternatives to R-22 have equivalent or lower capacity than R-22. None of them matches the COP of R-22.

Example: R-134a and alternatives in chillers

Brand name	ASHRAE R-N°	Composition				Glide @ 40°C	Safety class	GWP	Versus 134a	
		134a	1234yf	1234ze	Others				Capacity	COP
	1234yf		100			0.0015	A2L	<1	0.94	0.97
	1234ze			100		0.0015	A2L	>1	0.74	1.00
ARM-42	516A	8.5	77.5		R-152a, 14%	0.01	A2L	131	0.99	0.98
XP10	513A	44	56			0.00	A1	570	1.01	0.98
N-13 (*)	450A (*)	42		58		0.63	A1	550	0.88	1.00
									0.87	0.99
HDR115	515A			88	R-227ea, 12%	0.00	A1	400	0.74	1.03

(*) The performance of N-13 / R-450A is given in 2 configurations: both exchangers Counter flow or Parallel flow

- **All the alternatives have at least 10% lower capacity, except:**
  - 1234yf, but flammable and 3% lower COP.
  - 516A and 513A, with nearly equivalent capacity and COP.
  - Both are near drop-in retrofits to 134a with same capacity, but lower COP (-2%).
  - 516A has lower GWP than 513A (131 versus 570), but it is flammable. 513A is not.
- **Johnson Controls (JCI) policy:**
  - Dual proposal for identical unit with either 134a or 513A.
  - If sold with 134a, guarantee possibility of future retrofit to 513A if mandatory per future regulations.
  - As of today, 134a makes better sense because lower cost and better efficiency; and lower TEWI in most cases.

Conclusions

- Many trade-offs are involved in the choice of fluids, between GWP, safety, cost and energy efficiency.
- It is agreed that alternative solutions must not result in lower efficiency of the systems. It is complex to assess, especially with blends: depends heavily on the system configuration.
- Economics must be taken into account, including initial cost of the system, cost of the fluid, cost of energy, cost of safety measures when needed, resulting in total cost of ownership.
- Much focus is put on the GWP. But if the real purpose is to limit the emissions of green house gasses, then the ultimate criterion should be the best LCCP (Life Cycle Climate Performance) of systems for a given cost of ownership.
- Even the concept of “Low GWP” is practically impossible to define in general: it is closely linked to the application (level of pressure / capacity), and on the acceptability of flammability for the application.

Bibliography

de Larminat, P & Wang, A: “Overview of A2L Fluids for A/C Applications, Chillers and D-X”.

- Part-1: ASHRAE Journal, Feb. 2017
- Part-2: to be published soon

QUESTIONS?

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