Climate change: melting glaciers, diminishing water resources, trapped sunrays increase global warming

LOWER GWP FLUIDS FOR AIR CONDITIONING

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LOWER GWP FLUIDS FOR A/C APPLICATIONS:
COMPARISONS BETWEEN ALTERNATIVES

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Abstract

The landscape of fluids used in refrigeration and air conditioning is changing rapidly. Fluids that have some potential to deplete the ozone layer are being phased out. But concerns are raised about some of their possible alternatives because of their high GWP. When seeking simultaneously no ODS and low GWP, remaining options are often flammable (like hydrocarbons) or mildly flammable like the new generation of HFOs R-1234ze and yf, formerly existing HFCs like R-32, or blends thereof.

In A/C applications, there are four leading fluids: R-123, R-134a, R-22 and R-410A, in order of increasing pressures. A number of alternatives, including blends, are being proposed. The alternatives most commonly quoted are presented, especially those that have been tested under the "AREP" program. They are ranked by their critical temperature, as this gives a relevant order of magnitude of other key parameters of practical importance like the operating pressures, cycle efficiency and volumetric capacity.

For the blends, some key aspects of the rationale behind their formulation are presented. The purpose is to provide some understanding of how the formulation choices are influencing the properties of the blends, regarding their volumetric capacity, theoretical efficiency, GWP, flammability, and temperature glide. Special emphasis is placed on the relationship between the GWP and flammability, at otherwise similar propoerties. Insight is also provided about how the use of blends can affect the performance of systems, and about some trade-offs between the various parameters.

Introduction

In A/C applications (Chillers and D-X), four "benchmark" fluids are dominantly being used: R123, R134a, R22, and R410A. The phase-out of the HCFC's R123 and R22 is completed in "developed countries", and ongoing in Art-5 countries. But lower GWP alternatives to the HFC's R134a and R410A are also desired. A phase down of HFC's is ongoing in Europe per the F-Gas regulation, and planned globally per the Kigali amendment to the Montreal Protocol. So, alternatives are being investigated for all the fluids currently used in A/C. Among the most frequently considered alternatives, one (R-290) is highly flammable; some others have lower flammability ("2-L" class). It is also agreed that alternative solutions should not result in lower energy efficiency. So, the quest for alternatives results in a trade-off between flammability, GWP, energy efficiency, and also cost. The purpose of this paper is to shed light of some of the issues related to these trade-offs. To do this, some of the most prominent alternatives are presented. As some of them are blends, underlying concepts behind their formulations are introduced. Cycle comparisons between the fluids are presented, emphasizing the interaction between the behavior of blends and the systems they are used in, with potential impact on the performance of these systems. An illustration of trade-offs is given in the specific case of possible replacements of R134a in chillers.

Fluids in the study

Table 1: Fluids in the study

Refrigerant	Critical Temperature		Alternative to R-N°:				At 40°C (104°F)		GWP 100	Safety class
							Pressure	Glide		
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

The list of fluids in the study is given in table 1, showing which one of the four “benchmark” fluids each alternative is intended to replace. The fluids are ranked by their critical temperature.

Some other key properties are also given: GWP, flammability class, pressure and glide at 40°C. This list cannot be exhaustive, but it is a wide sample of some of the most frequently quoted alternatives.

Figure 1 shows the GWP of all these fluids versus their critical temperature, because the critical temperature is strongly correlated to important engineering parameters like the operating pressures (as seen from table 1), but also the volumetric capacity and cycle efficiency of the fluids.

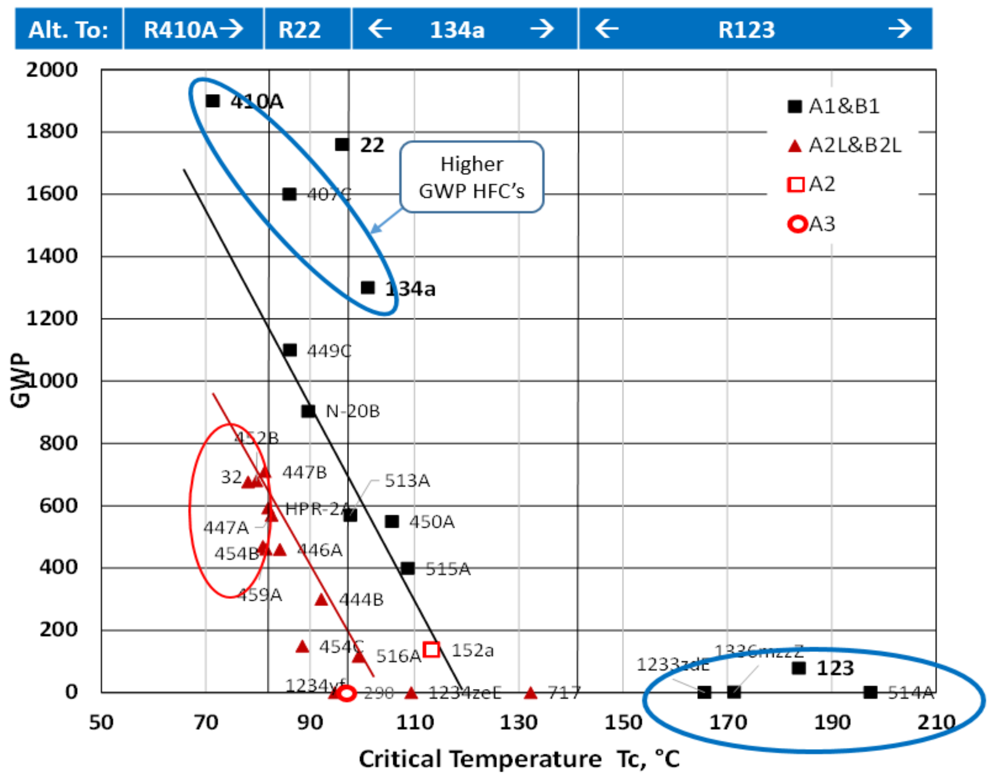

Figure 1: GWP of fluids versus their critical temperature

On Figure 1, it is seen that:

- On the right side of the graph, all the alternatives to R123 have near-zero GWP, and are non- flammable. As seen from table 1, they also have very low or no glide.
- On the left side, all the alternatives to 410A are flammable, with GWP>400. The GWP increases as the critical temperature decreases, meaning also higher pressure and volumetric capacity.
- In between are the alternatives to R22 and 134a. Some are flammable; others are not. Among these, at same Tc, the GWP of the non-flammable fluids is in average about 500 higher than the flammable ones.
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Why must blends be proposed?

After these initial observations, one might wonder why blends are needed. The basic idea is that for each of the base line fluids (R123, R134a, R22, R410A), alternatives with relatively "similar" capacity (typically about +/- 15% compared to the base line). In the case of R22 for instance, the only pure compounds with "similar" cooling capacity are Ammonia (R717) and Propane (R290). But Ammonia is toxic, and as of today, it is not suitable for D-X systems, because of materials compatibility and high discharge temperature. Another possibility is propane (R290) but its use is restricted by its high flammability. Otherwise, no other applicable pure compound has a cooling capacity similar to R22. For this reason, alternatives to R22 must be blends of several components, combining:

- Some “HP” fluids with higher pressure and capacity than R22. In the blends proposed, two “HP” fluids (R-125 and R-32) are used.
- Some medium pressure (“MP”) fluids with lower pressure and capacity than R22. They are selected from the HFC R134a, and the HFO’s R1234ze and yf.
- Small amounts of other fluids are also used occasionally, like R152a and R290 for the alternatives to R22.

The glide is a consequence of the difference in properties between the high and medium pressure components of the blend.

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

Table 2: Composition of the blends

Table 2 gives the composition of the blends proposed. It is seen that the trade-off between GWP and flammability is very logically derived from the composition. For the high pressure components R32 and R125, R32 has lower GWP but it is flammable while R125 is not. Likewise for the medium pressure components, R134a has higher GWP but is not flammable, while it is the opposite for the HFO’s R1234ze and yf. Therefore, a higher content of R32 (as HP component) and HFO’s (for MP) reduces the GWP but increases the flammability. Conversely, adding more R134 and R125 reduces the flammability but increases the GWP.

Performance comparisons

All the various fluids in the study were compared by cycle simulations in the specific case of a « base line » unit: the mini-split 410A unit tested under AREP / ORNL programs, at AHRI conditions. Calculations assume same heat transfer and compressor efficiency for all the fluids. This assumption is not necessarily accurate, but the purpose is to allow performance comparisons at similar cycle conditions. Results shown on Figure 2 give the volumetric capacity of the fluids versus their COP.

As many of the fluids are blends with glide, the in-tube evaporation and condensation are is not isothermal. Then the performance is highly 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 dedicated "Constant LMTD" method was developed to analyze this effect (Ref.1). On the plots, a pure fluid is represented by a single point. A blend with glide is represented by a segment between the best point ("Cf" on evaporator and condenser) and worst case ("Pf" on both exchangers).

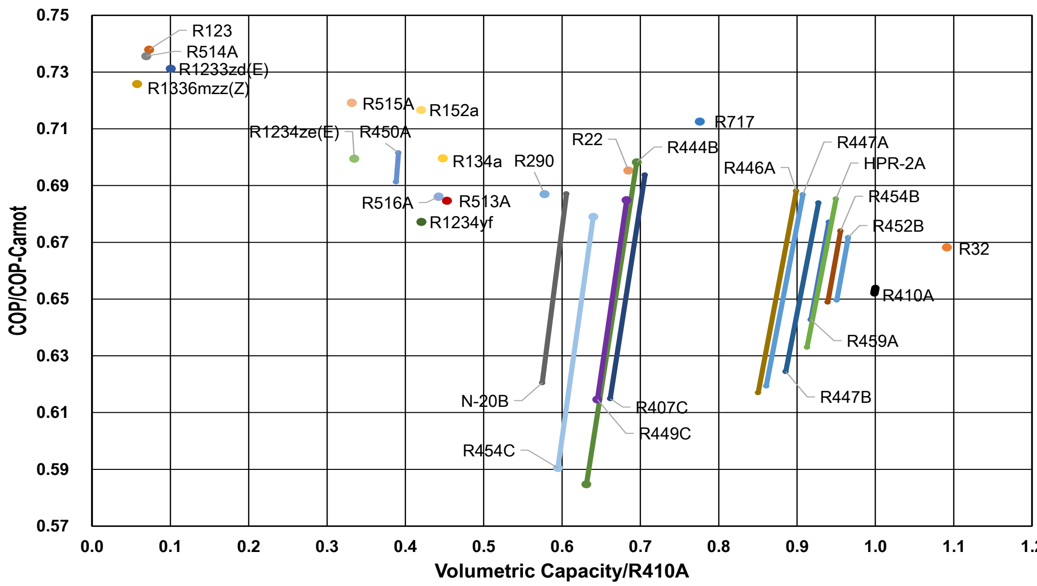

Figure 2: Performance comparisons

Comments on the results

Figure 2 confirms the well-known general trend that fluids with lower Tc (and higher pressure) tend to have higher capacity but lower COP. This illustrates the general trade-off between Capacity and COP.

In the optimum configuration (counter-flow heat exchangers), blends with glide can have slightly better COP than the general trend for pure fluids at equivalent capacity. But the performance can also be much lower if the arrangement of heat exchangers is not optimum. Real designs should be close to optimum, but optimization is not necessarily simple. For example, most current designs of small split A/C units have cross flow evaporator; or reversible systems (alternatively used as coolers or heat pumps) cannot be easily arranged to be optimized in both configurations. It should also be reminded that zeotropic blends are generally not recommended in shell and tube heat exchangers with out-of-tube evaporation or condensation (e.g. flooded evaporators).

All the alternatives to 410A have lower capacity a better COP than R410A. All also have a lower volumetric capacity, except R-32.

Blend alternatives to R-22 have equivalent or lower capacity than R-22. None of them matches the COP of R-22.

An example of trade-off: 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

Table 3: Alternatives to R-134a and performance comparison

Table 3 shows the main possible alternatives to R134a, with results of cycle comparisons for capacity and COP. Regarding the capacity, it is seen that some of the alternatives result in a substantial loss in capacity (>10%). Those that keep nearly the same capacity are:

- R1234yf, but it is flammable and has 3% lower COP than R134a.
- Both R516A and R513A that are near drop-in retrofits to 134a, with almost the same capacity and slightly lower COP (-2%). 516A has lower GWP than 513A (131 versus 570), but it is flammable, while 513A is not.

Based on this, a possible option is to propose units that can operate either with R134a or 513A with exactly the same unit. Even if initially sold with 134a, such a unit can be guaranteed for the possibility of a future retrofit to the non-flammable and lower GWP 513A if mandatory per future regulations.

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. But performance comparisons are complex, especially with blends, as they depends heavily on the system configuration.

There is a general tendency to focus heavily focus is put on the GWP of the fluids. But 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. Economics must be taken into account in a life cycle approach, 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. In the perspective of limiting the emissions of Green House gasses, then the ultimate criterion should be the best LCCP (Life Cycle Climate Performance) of a system for a given cost of ownership.

Reference

Paul de Larminat & Anthony Wang: *"Performance Analysis of Blends for A/C Applications"* - Part 2 (ASHRAE Journal, June 2017).