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COMPARATIVE PROPERTIES AND EFFICIENCY OF R-421A FOR RETROFIT USE TO REPLACE R-22

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Comparative Properties and Efficiency of R-421A for Retrofit Use to Replace R-22

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SUMMARY

This report addresses the properties and performance of R-421A and other replacement refrigerants for R-22 for aftermarket – not included in original equipment manufacturer (OEM) – use for refrigerant retrofits. R-22 was the most widely used refrigerant in the identified applications from the 1950s through 2009 (and for some products or countries even later). Retrofit use implies consideration of property similarity between the original (design) and replacement refrigerants, often as a drop-in substitute without equipment modification to accommodate the differences. The pressure-temperature (PT) relations of the fluids are a key issue for air-conditioner and heat pump retrofits, as significant deviations alter both general operation and thermostatic expansion valve (or similar device) flow metering. While the expansion device can be modified or replaced during the retrofit, that is not the norm for such equipment due to the costs, selection intricacies, and other considerations. Another key factor is temperature glide and especially so in the evaporator. Increased glide, for systems not explicitly designed for it, may lead to preferential flow of one or more refrigerant blend components and departure from intended operation. Comparative efficiency, expressed as the relative degradation in coefficient of performance (COP), implies the comparative operating cost after retrofit. These data are provided herein along with representative properties for seven retrofit refrigerant options, namely R-407C, R-410A, R-421A, R-422B, R-422D, R-427A, and R-438A along with reference data for R-22.

RETROFIT REFRIGERANT OPTIONS

The refrigerants addressed herein include:

R-22 [chlorodifluoromethane, $CHClF_2$] as the primary reference for comparisons and normalizing data

R-407C [R-32/125/134a (23.0/25.0/52.0)], marketed under various trade names including as DuPont *Suva® AC9000*

R-410A [R-32/125 (50.0/50.0)], marketed under various trade names including as Honeywell *Genetron® AZ-20*

R-421A [R-125/134a (58.0/42.0)], marketed under various trade names including as RMS *Choice R-421A*

R-422B [R-125/134a/600a (55.0/42.0/3.0)], marketed under various trade names including as ICOR *NU-422B*™

R-422D [R-125/134a/600a (65.1/31.5/3.4)], marketed under various trade names including as DuPont *Isceon*® *MO29*™

R-427A [R-32/125/143a/134a (15.0/25.0/10.0/50.0)], marketed under various trade names including as Arkema *Forane*® *FX 100*

R-438A [R-32/125/134a/600/601a (8.5/45.0/44.2/1.7/0.6)], marketed under various trade names including as DuPont *Isceon*® *MO99*™ [*]

The "R-" number designations are standard identifiers as assigned in and according to ASHRAE standard 34.[1] No inference is intended that the seven cited refrigerant blends are the only retrofit options to replace R-22, rather they are the primary competitors in markets in which R-421A is offered.

RMS of Georgia, LLC, markets R-421A as "Choice Refrigerant R-421A," a non-ozone-depleting alternative for R-22 for use in air-conditioning as well as medium- and high-temperature residential, commercial, and industrial refrigeration applications. R-421A is a binary zeotrope formulated as 58.0 ±1.0% R-125 and 42.0 ±1.0% R-134a by mass – R-125/134a (58.0/42.0) (±1.0/±1.0). The blend molar mass is 111.746487 g/mol (0.24635883 lb/mol) and the component mole fractions are 54.001 and 45.999 %, respectively. Both components are hydrofluorocarbons (HFCs). The blend has low acute toxicity and ASHRAE Standard 34-2013 classifies it as an "A1" refrigerant, signifying "lower toxicity" and "no flame propagation" for prescribed safety criteria.[1]

PRESSURE-TEMPERATURE COMPARISONS

Table 1 and Table 2, in metric (SI) and inch-pound (IP) units of measure, respectively, compare the pressure-temperature (PT) relationships for coexisting vapor and liquid of the selected refrigerants. Similar PT relationships indicate a basic level of operational comparability including for thermostatic expansion valve (TXV) sensing bulbs that regulate refrigerant flow. PT similarity also implies that internal (inside the refrigerant circuit) low- and high-side (evaporator and condenser) pressures are similar for the compared refrigerants operating between the same evaporating and condensing temperatures.

[*] Forane; Genetron; MO29, MO99, and Suva; and NU-422B are trademarks or registered trademarks of Arkema, Honeywell, DuPont, and ICOR, respectively.

Table 1: Pressure-Temperature Data for Selected Refrigerants (SI units)

temperature		pressure of vapor coexisting with liquid at the bubble temperature (kPa)							
(°C)	(°F)	R-22	R-407C	R-410A	R-421A	R-422B	R-422D	R-427A	R-438A
-40	-40	105	120	176	105	108	118	116	113
-35	-31	132	151	219	131	135	147	146	142
-30	-22	164	187	270	163	167	182	181	176
-25	-13	201	230	331	201	205	223	222	216
-20	-4	245	280	401	245	250	270	270	263
-15	5	296	338	482	296	301	326	326	318
-10	14	355	405	575	355	360	389	390	380
-5	23	422	481	681	422	428	461	463	452
0	32	498	568	801	499	505	543	546	534
5	41	584	666	936	585	592	636	641	626
10	50	681	776	1088	683	689	740	746	729
15	59	789	900	1258	792	799	856	865	845
20	68	910	1038	1448	914	920	985	997	974
25	77	1044	1190	1657	1049	1056	1128	1143	1117
30	86	1192	1359	1889	1199	1205	1286	1305	1275
35	95	1355	1545	2145	1364	1370	1460	1483	1449
40	104	1534	1749	2426	1545	1550	1651	1678	1640
45	113	1729	1972	2734	1744	1749	1860	1892	1850
50	122	1943	2216	3071	1961	1965	2089	2125	2078
55	131	2175	2481	3439	2198	2201	2338	2379	2326
60	140	2428	2769	3842	2456	2458	2609	2656	2596

Table 2: Pressure-Temperature Data for Selected Refrigerants (IP units)

temperature		pressure of vapor coexisting with liquid at the bubble temperature (psig)							
(°F)	(°C)	R-22	R-407C	R-410A	R-421A	R-422B	R-422D	R-427A	R-438A
-40	-40.0	0.6	2.7	10.8	0.5	0.9	2.4	2.2	1.7
-30	-34.4	4.9	7.7	17.8	4.8	5.4	7.1	7.0	6.4
-20	-28.9	10.2	13.7	26.3	10.1	10.7	12.9	12.8	12.0
-10	-23.3	16.5	20.9	36.5	16.5	17.1	19.8	19.7	18.8
0	-17.8	24.0	29.5	48.4	24.0	24.7	27.9	27.9	26.8
10	-12.2	32.8	39.5	62.4	32.8	33.6	37.5	37.6	36.3
20	-6.7	43.1	51.2	78.7	43.1	43.9	48.5	48.8	47.3
30	-1.1	55.0	64.7	97.4	55.0	55.9	61.3	61.7	59.9
40	4.4	68.6	80.2	118.8	68.7	69.6	75.9	76.6	74.5
50	10.0	84.1	97.9	143.2	84.3	85.3	92.6	93.6	91.1
60	15.6	101.6	117.9	170.7	102.0	103.0	111.4	112.8	109.8
70	21.1	121.4	140.5	201.8	122.0	123.0	132.6	134.4	131.0
80	26.7	143.6	165.8	236.5	144.4	145.4	156.3	158.6	154.7
90	32.2	168.4	194.1	275.4	169.5	170.4	182.8	185.7	181.2
100	37.8	195.9	225.5	318.5	197.4	198.2	212.2	215.8	210.6
110	43.3	226.4	260.3	366.4	228.3	229.0	244.7	249.1	243.1
120	48.9	260.0	298.6	419.4	262.4	263.1	280.7	285.8	279.1
130	54.4	296.9	340.7	477.9	300.1	300.6	320.2	326.2	318.5
140	60.0	337.4	386.9	542.5	341.5	341.8	363.7	370.4	361.9
150	65.6	381.7	437.5	613.9	386.9	387.1	411.4	418.9	409.2

The PT comparisons are summarized in Figure 1.

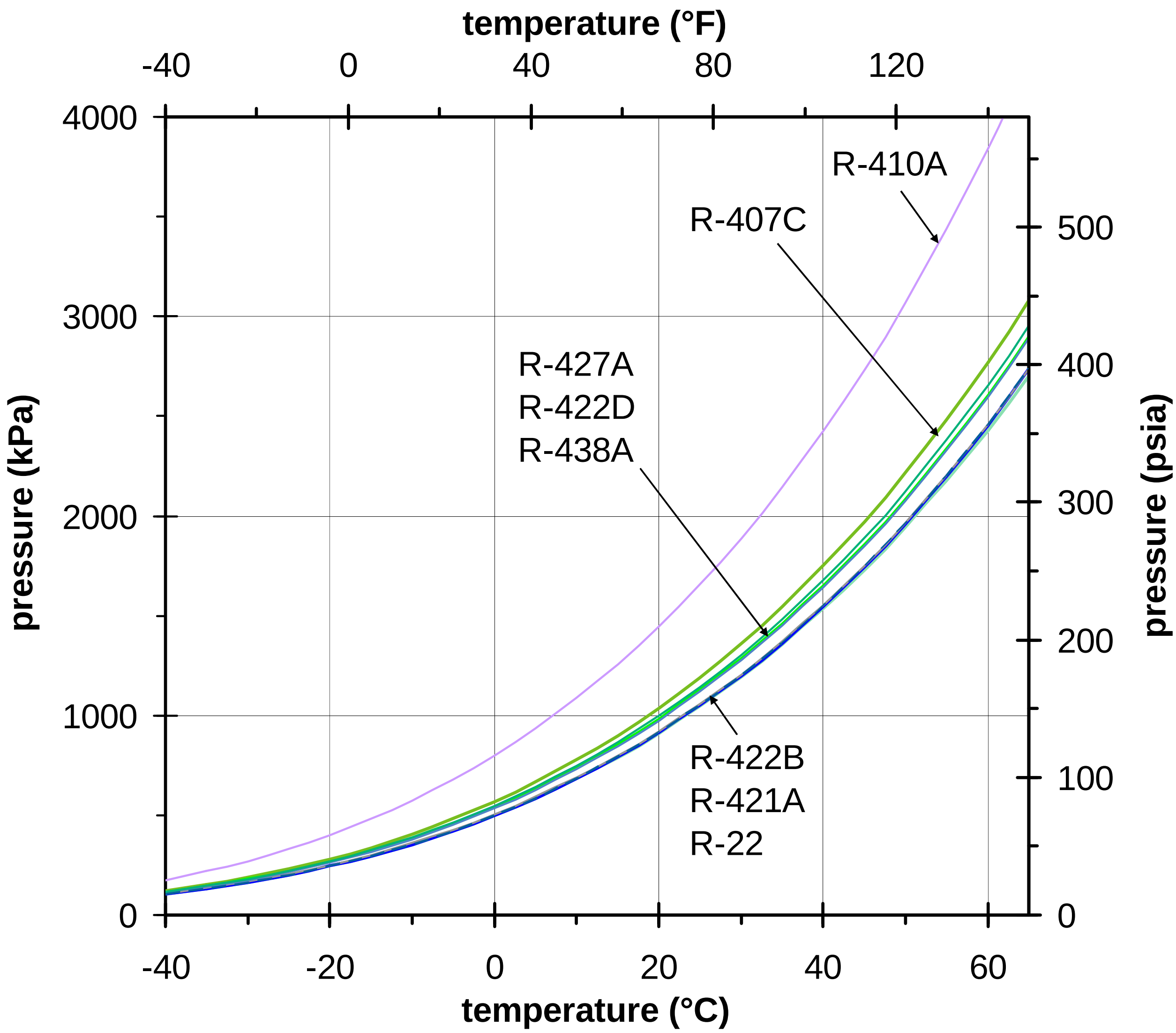

Figure 1: Pressure-Temperature Comparison

Examination of the PT data in the preceding figure and tables show remarkable similarity between R-22 and R-421A, further indicated by the very small pressure differences shown in Table 3 (SI) and Table 4 (IP) below:

Table 3: Pressure-Temperature Similarity for R-22 and R-421A (SI units)

temperature (°C)	pressure (kPa)		difference (%)
	R-22	R-421A	
-40	105	105	-0.60%
-35	132	131	-0.47%
-30	164	163	-0.35%
-25	201	201	-0.25%
-20	245	245	-0.16%
-15	296	296	-0.08%
-10	355	355	0.00%
-5	422	422	0.07%
0	498	499	0.14%
5	584	585	0.21%
10	681	683	0.27%
15	789	792	0.34%
20	910	914	0.41%
25	1044	1049	0.48%
30	1192	1199	0.56%
35	1355	1363	0.64%
40	1534	1545	0.73%
45	1729	1743	0.83%
50	1943	1961	0.93%
55	2175	2198	1.04%
60	2427	2456	1.16%
65	2701	2736	1.29%

Table 4: Pressure-Temperature Similarity for R-22 and R-421A (IP units)

temperature (°F)	pressure (psig)		difference (%)
	R-22	R-421A	
-40	0.6	0.5	-16.08%
-30	4.9	4.8	-1.81%
-20	10.2	10.1	-0.81%
-10	16.5	16.5	-0.42%
0	24.0	24.0	-0.20%
10	32.8	32.8	-0.05%
20	43.1	43.1	0.06%
30	55.0	55.0	0.16%
40	68.6	68.7	0.24%
50	84.1	84.3	0.32%
60	101.6	102.0	0.40%
70	121.4	122.0	0.48%
80	143.6	144.4	0.56%
90	168.4	169.5	0.65%
100	195.9	197.4	0.74%
110	226.4	228.3	0.84%
120	260.0	262.4	0.95%
130	296.9	300.1	1.08%
140	337.4	341.5	1.21%
150	381.7	386.9	1.35%

The reason the difference values appear slightly lower in Table 3 (metric units, SI) than in Table 4 (inch-pound units, IP), for example at 60 °C and 140 °F that are equivalent, is the SI pressures indicated are absolute and the IP are gauge, consistent with common convention for the respective units. When consistently expressed in either absolute or gauge pressures, the difference values are the same.

The important conclusion is that the saturation pressure-temperature dependence for R-421A is nearly identical to R-22 with less than 1% difference for most of the temperature range of interest, as shown in the figure and tables above.

PERFORMANCE COMPARISONS

The following discussion addresses comparative R-421A performance relative to R-22 based on ideal cycle analyses, using the National Institute of Standards and Technology (NIST) Cycle_D program, for conditions consistent with those used and discussed in prior studies by Calm and Domanski.[2,3] Theoretical cycle analyses for ideal conditions indicate the limits or comparative limits to attainable performance for simple cycles without regard to differences in equipment and component deviations from ideal, heat transfer, additional thermophysical properties, and lubricant differences. The resulting coefficients of performance (COPs) indicate thermodynamic limits to what is attainable for different refrigerants in comparably optimized systems, but do not imply either that all systems will achieve such performance or that performance rankings of different refrigerants would not change in order of preference for systems not comparably optimized for the individual refrigerants.[3,4] Although excluded from the analyses herein to focus on refrigerant influences, real-world equipment performance properties will be lower than theoretical limits not only for the reasons mentioned, but also because fan, control, and sometimes pump burdens as well as start-up transients factor into standard equipment ratings.

Table 5 summarizes the cycle conditions used for the analyses addressed herein.

Table 5: Conditions for Performance Comparison

parameter	theoretical cycle limit for air conditioning
average evaporating temperature	
input temperature	10 °C (50 °F)
superheat	0 °C (0 °F) more rigorously expressed as 0 K (0 °F)
average condensing temperature	
input temperature	35-65 °C (95-149 °F)
superheat	0 K, 0 °C (0 °F)
compressor efficiencies	
isentropic	100%
volumetric	100%
motor	100%
piping losses (drop)	
suction line	none: 0 K, 0 °C (0 °F)
discharge line	none: 0 K, 0 °C (0 °F)
suction line / liquid line heat exchanger	none (0%)
fans and control power burdens	
indoor fan / chilled water pump	not included (0 W)
outdoor fan / condensing water pump	not included (0 W)
controls	not included (0 W)

The following figure compares the COPs for cooling (air conditioning) for a range of refrigerant condensing temperatures (necessarily higher than a corresponding range of ambient temperatures for air-cooled equipment). The range shown reaches extreme temperatures, at which the R-125 component of R-421A approaches its critical point temperature and reduces the accuracy of modeling.

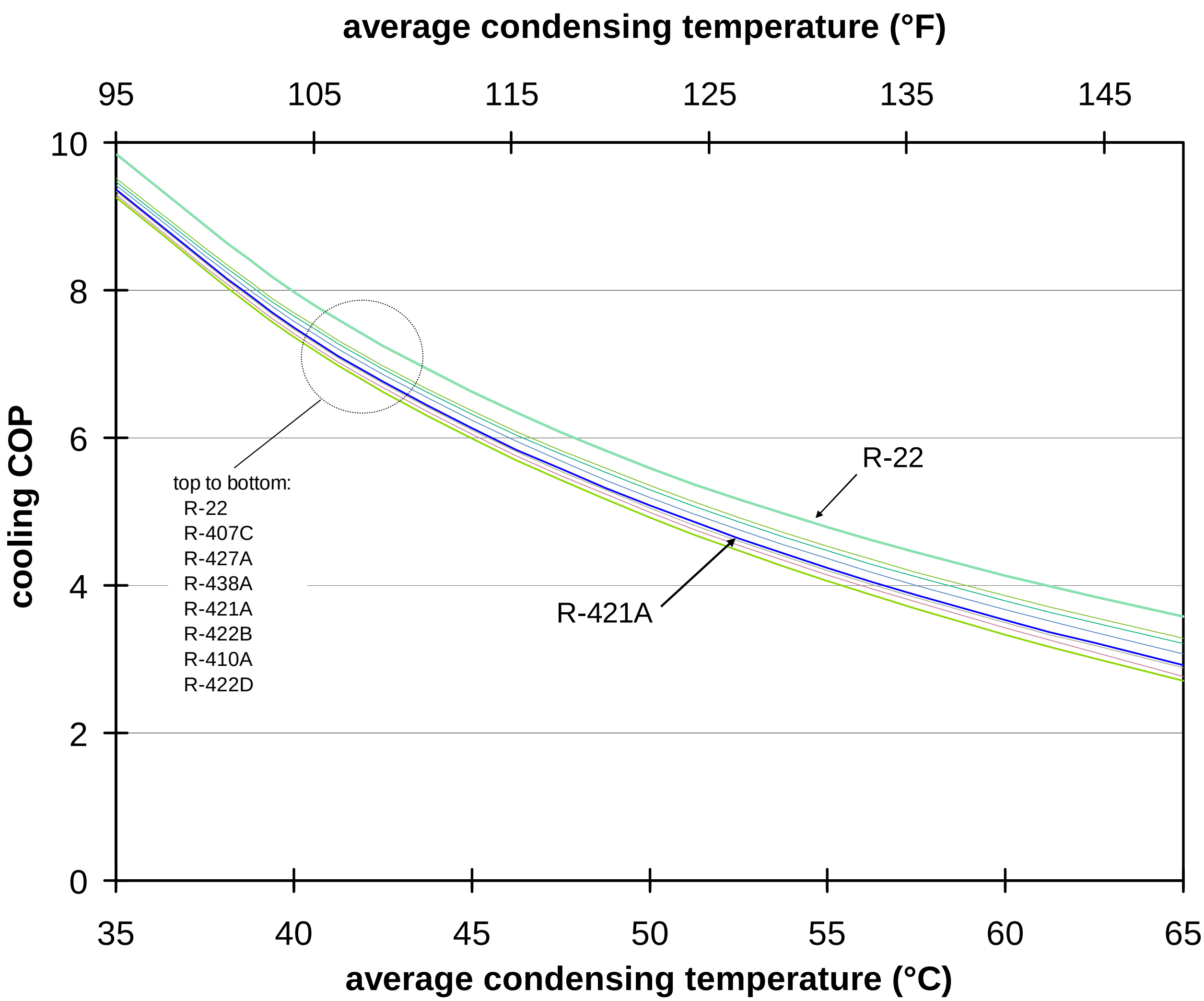

Figure 2: Cooling Coefficient of Performance (COP) Comparison without Adjustment for Pressure-Temperature Differences

As shown, the R-421A efficiency is approximately 4.8% lower at 35 °C (95 °F), the most common comparative rating point for air conditioners. While real equipment (including equipment and deviations from ideal and burdens such as fan power) would not approach the theoretical limits indicated, the limits are a good indicator of relative performance with variations by temperature and for refrigerants with adjusted charge amounts and expansion device flow metering.

Figure 3 depicts the comparative cooling efficiency of R-421A at increasing condensing temperatures relative to that of R-22 for cycles each optimized for equivalent performance at standard rating conditions (35 °C, 95 °F), but again excluding control, fan power, and similar power burdens.[5]

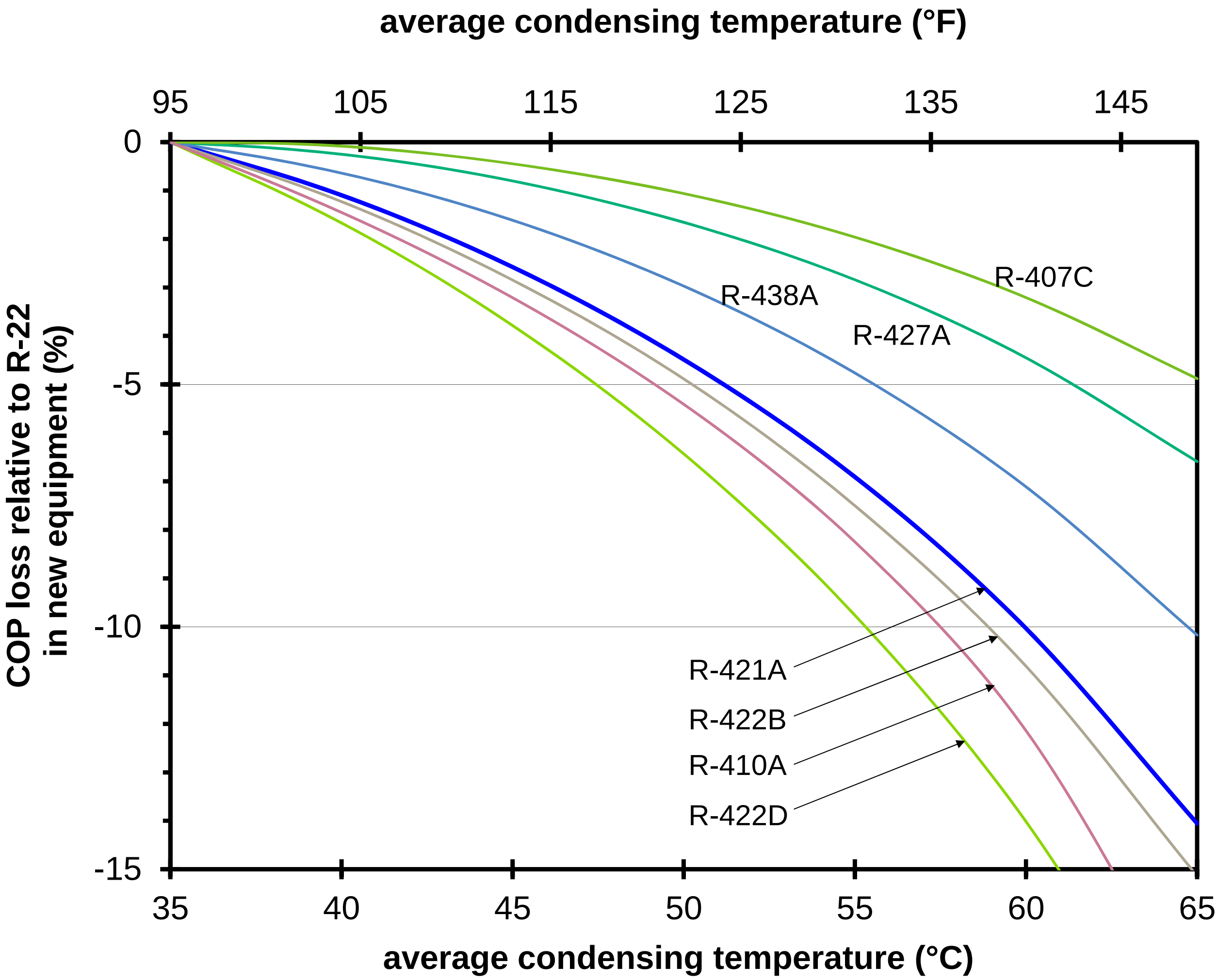

Figure 3: Relative COP Degradation with Increasing Condensing Temperature for Equipment Designed for Equivalent Performance at the Nominal Rating Point (35 °C, 95 °F) without Adjustment for Pressure-Temperature Differences

REPRESENTATIVE PROPERTIES

Without further consideration of temperature glide, R-421A offers neither the highest nor lowest cooling efficiency based on theoretical limits compared to R-22, but affords simpler retrofit based on the PT similarities addressed above. Refrigerant blends with higher temperature glide, such as R-407C that also offers good PT similarity to R-22, are subject to higher blend fractionation in typical evaporators. That effect reduces or eliminates theoretical performance advantages without equipment modification to maintain operating blend composition. Likewise, blends with higher latent heat by mass (or more accurately by volume for positive-displacement compressors, such as rotary, scroll, or reciprocating-piston compressors) require equipment optimization (new designs) to exploit such differences, but with appropriate equipment design offer capacity more similar to or even better than R-22. Reduced capacity below design conditions translates to increased equipment run time and lower cooling output at and above such conditions (particularly at extreme condensing temperatures).

Table 6 compares representative properties of R-22 and R-421A based on data calculations using NIST REFPROP 9.1.[6] As shown, the three refrigerants offering slightly higher theoretical COP all exhibit notably higher glide than R-421A. The table also summarizes key indicators for environmental and safety considerations. As shown, R-438A has a lower Refrigerant Concentration Limit (RCL) – approximately a third that of R-22 – potentially requiring other building or system modifications in refrigerant retrofits.

Table 6: Data for Selected Refrigerants (SI units)

properties	R-22	R-407C	R-410A	R-421A	R-422B	R-422D	R-427A	R-438A
molar mass (g/mol)	86.468000	86.203637	72.585414	111.746487	108.518417	109.935124	90.444001	99.100017
normal boiling point (NBP)								
bubble point for blends (°C)	-40.81	-43.63	-51.44	-40.68	-41.31	-43.20	-42.96	-42.33
blend dew point (°C)	-40.81	-36.63	-51.36	-35.36	-35.89	-38.34	-36.20	-36.14
maximum temperature glide								
at NBP (K)	0.000	6.998	0.079	5.316	5.427	4.860	6.758	6.189
at 20 °C (K)	0.000	5.592	0.116	3.657	3.464	2.985	5.179	4.781
density at NBP								
saturated liquid (kg/m^3)	1409	1381	1350	1461	1398	1402	1369	1391
saturated vapor (kg/m^3)	4.704	4.631	4.174	5.976	5.818	5.956	4.854	5.316
latent heat of vaporization								
at NBP (kJ/kg)	233.8	249.1	273.0	191.8	195.7	190.0	236.5	215.7
at NBP (kJ/m^3) vapor	1100	1153	1139	1146	1139	1132	1148	1147
at 60 °C (kJ/kg)	139.9	130.8	105.1	96.4	97.1	88.2	123.2	109.9
saturated vapor pressure								
at 20 °C (kPa)	910	880	1443	821	832	904	856	847
at 60 °C (kPa)	2427	2529	3834	2333	2346	2512	2447	2411
critical point								
temperature (°C)	96.15	86.03	71.34	82.78	83.21	79.57	85.32	85.27
pressure (kPa)	4990	4629	4901	3919	3958	3905	4392	4304
specific volume (L/kg)	1.909	2.065	2.178	1.818	1.900	1.890	2.041	1.959
ozone depletion potential (ODP) relative to R-11								
scientific	0.040	0	0	0	0	0	0	0
regulatory (MP)	0.055							
global warming potential (GWP) for 100 yr ITH								
scientific relative to CO_2	1790	1700	2100	2600	2500	2700	2100	2200
ASHRAE 34 / ISO 817 safety classification	A1	A1	A1	A1	A1	A1	A1	A1
ASHRAE 34 Refrigerant Concentration Limit (RCL) ($ppm_{v/v}$)	59,000	81,000	140,000	61,000	56,000	58,000	79,000	20,000

Table 7: Data for Selected Refrigerants (IP units)

properties	R-22	R-407C	R-410A	R-421A	R-422B	R-422D	R-427A	R-438A
molar mass (lb/mol)	0.190629	0.190046	0.160023	0.246359	0.239242	0.242365	0.199395	0.218478
normal boiling point (NBP)								
bubble point for blends (°F)	-41.46	-46.53	-60.60	-41.22	-42.36	-45.76	-45.33	-44.19
blend dew point (°F)	-41.46	-33.93	-60.46	-31.65	-32.59	-37.01	-33.16	-33.05
maximum temperature glide								
at NBP (°F)	0.000	12.597	0.142	9.569	9.769	8.747	12.164	11.140
at 68 °F (°F)	0.000	10.065	0.209	6.582	6.234	5.373	9.323	8.605
density at NBP								
saturated liquid (lb/ft^3)	87.97	86.19	84.26	91.19	87.25	87.51	85.46	86.84
saturated vapor (lb/ft^3)	0.2936	0.2891	0.2606	0.3731	0.3632	0.3718	0.3030	0.3319
latent heat of vaporization								
at NBP (Btu/lb)	100.6	107.2	117.4	82.5	84.2	81.8	101.8	92.8
at NBP (Btu/ft^3) vapor	29.53	30.98	30.60	30.78	30.58	30.40	30.83	30.80
at 140 °C (Btu/lb)	60.20	56.29	45.23	41.48	41.78	37.94	53.00	47.28
saturated vapor pressure								
at 68 °F (psia)	132.0	127.7	209.3	119.0	120.7	131.1	124.2	122.8
at 140 °F (psia)	352.1	366.8	556.1	338.3	340.3	364.3	355.0	349.7
critical point								
temperature (°F)	205.1	186.9	160.4	181.0	181.8	175.2	185.6	185.5
pressure (psia)	723.7	671.4	710.9	568.4	574.0	566.3	637.0	624.3
specific volume (ft^3/lb)	0.0306	0.0331	0.0349	0.0291	0.0304	0.0303	0.0327	0.0314
ozone depletion potential (ODP) relative to R-11								
scientific	0.04	0	0	0	0	0	0	0
regulatory (MP)	0.055							
global warming potential (GWP) for 100 yr ITH								
scientific relative to CO_2	1790	1700	2100	2600	2500	2700	2100	2200
ASHRAE 34 / ISO 817 safety classification	A1	A1	A1	A1	A1	A1	A1	A1
ASHRAE 34 Refrigerant Concentration Limit (RCL) (lb/Mcf)	13	18	26	17	16	16	18	4.9

The grey regions of Table 6 and Table 7 indicate inapplicable data, namely the absence of composition-based glide based for the single-compound R-22. They also signify inapplicable data for blends not directly regulated by ozone depletion potential (ODP) in international treaties (notably the Montreal Protocol) and most regulations, though regulatory consequences result indirectly based on mass-weighted formulations of the blends.

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