R-22 Alternative Refrigerants in COMMERCIAL-TEMPERATURE REFRIGERATION

Discover compressor function in R-22 commercial-temperature refrigeration and how alternative refrigerants affect its performance.

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As of Jan. 1, 2010, HCFC consumption in the U.S. was reduced to 25% of the Montreal Protocol baseline cap, a figure largely based on 1989 HCFC production and consumption. The EPA defines consumption as the country's production plus imports minus exports.

On that date, R-22 refrigerant, the most widely used HCFC, was banned for use in new equipment in the effort to lower demand. HCFC consumption in the U.S. will be further reduced to 10% of the baseline cap in 2015, and then to 0.5% in 2020. R-22 production and importation in the U.S. will completely stop on Jan. 1, 2020. The use of R-22 after this date will depend on existing and reclaimed supplies of R-22.

In recent months, demand for R-22 has been outstripping supply, causing its price to rise significantly. These rising prices have resulted in increased interest in alternatives to R-22.

ASHRAE No.	Composition (Mass Percentages)	Trade Names	Refrigerant Supplier/ Manufacturer
R-417A	R-125/R-134a/R-600 (46.6/50/3.4)	NU-22 ISCEON MO59	DuPont Fluoro-chemicals, ICOR International
R-422B	R-125/R-134a/R-600a (55/42/3)	NU-22B	ICOR International
R-422D	R-125/R-134a/R-600a (65.1/31.5/3.4)	ISCEON MO29	DuPont Fluorochemicals
R-424A	R-125/R-134a/R-600a/R-600/R-601a (50.5/47/0.9/1/0.6)	RS-44	Refrigerant Services Inc.
R-438A	R-32/R-125/R-134a/R-600/R-601a (8.5/45/44.2/1.7/0.6)	ISCEON MO99	DuPont Fluorochemicals

Figure 1

Note: This table is neither an endorsement nor a complete list of available refrigerants and suppliers/manufacturers

The differences in compressor performance can be estimated theoretically by using well-known fluid-flow equations and the refrigerant's thermodynamic properties.

Alternatives to R-22 have been around for quite some time. Listed in Figure 1 are R-22 service replacement refrigerants, which have the following characteristics:

- All have an A1 ASHRAE 34 Safety Group classification;
- All can be used in a refrigeration system designed for R-22 without the need for significant modification; and
- All contain a small amount of hydrocarbon(s) to promote oil return in systems using mineral or alkylbenzene oil.

In addition, there are R-407-series refrigerants having the same characteristics listed above, except that they require the use of POE oil (see Figure 2).

Say a technician installing and servicing R-22 refrigeration equipment is interested in using one of these R-22 replacement refrigerants. Can that technician expect the same performance?

ASHRAE No.	Composition (Mass Percentages)	Trade Names	Refrigerant Supplier/ Manufacturer
R-407A	R-32/R-125/R134a (20/40/40)	—	Various
R-407C	R-32/R-125/R-134a (23/25/52)	—	Various
R-407F	R-32/R-125/R-134a (30/30/40)	Genetron Performax LT	Honeywell

Figure 2

Using an R-22 to R-407C comparison as an example for a commercial-temperature condensing unit rated for both of these refrigerants, say the unit is operating at a 25°F evaporator, 115°F condensing, 0°F subcooling, and a 40°F return-gas temperature. R-407C compressors have been around for some time since R-407C was an early "heir apparent" to R-22 for air-conditioning and chiller applications. R-407C has since found its way into commercial-temperature refrigeration.

Assume this unit has a Tecumseh R-22/R-407C dual-rated compressor model AWG5520WXT having a 13,000-Btuh R-22 rating at these conditions. The differences in compressor performance can be estimated theoretically by using well-known fluid-flow equations and the refrigerant's thermody-

ASHRAE No.	Net Refrigerating Effect (Btu/lb)	Return-gas Density (lb/ft3)	Flow Rate (lb/h)	Capacity (Btuh)	Capacity Change from R-22	Pressure Ratio
R-22	65.3	1.122	199	13,000	0	4.05
R-407C	63.6	1.116	199	12,640	-2.8%	4.43

Figure 3

namic properties. These estimates are listed in Figure 3.

In this case, a reduction in capacity of about 3% is seen when using R-407C at these operating conditions compared to R-22. This reduction is due to R-407C having a lower return-gas density and net refrigerating effect.

This is, of course, a simplified estimate. The actual R-407C rating for the AWG5520WXT compressor happens to be approximately 10% less than its R-22 rating at these operating conditions. Why this greater loss in capacity? There are numerous factors that affect compressor capacity, which is why compressor manufacturers must measure it using calorimeter tests.

One problem with the initial estimate is the fact it does not take into consideration the differences in suction and discharge pressures between these two refrigerants. The chart in Figure 3 notes the pressure ratio (also known as "compression ratio" in the industry) at the stated operating conditions. This ratio is discharge to suction pressure in absolute units, and the pressure ratio for R-407C is approximately 9% greater than R-22 at these conditions.

As pressure ratio increases, compressor volumetric efficiency decreases. This is particularly true of reciprocating compressors where some re-expansion of the compressed gas occurs in the cylinder due to the "dead space" between the top of the cylinder and the piston. With scroll and rotary compressor designs, however, volumetric efficiency is significantly less affected by pressure ratio. See the volumetric efficiency vs. pressure ratio curve in Figure 4 for Tecumseh's reciprocating-type compressor model AWG5520WXT.

At a pressure ratio of 4.05 and 4.43, volumetric efficiencies of 65.3% and 62.3% are respectively achieved. As a result, reduction in capacity due to loss in volumetric efficiency becomes:

$$1 - 0.623 / 0.653 = 0.046 \text{ or } 4.6\%$$

Adjusting the capacity loss to include volumetric efficiency the following is attained:

$$1 - (1 - 0.028) \times 0.623 / 0.653 = 0.073 \text{ or } 7.3\%$$

The estimate is now roughly in line with the test results. Face it, the time and effort required to qualify a compressor for all the replacement refrigerants available is enormous. It just is not going to happen. But technicians can use estimations such as the above to determine within reasonable accuracy the effect these replacement refrigerants will have on compressor capacity without the need for testing.

Listed in Figure 5 are capacity estimations for the following R-22 replacement refrigerants at the stated operating conditions with the model AWG5520WXT compressor. The "Capacity Change from R-22" column lists the values that consider expected capacity change resulting from fluid densities and thermodynamic properties. The "Capacity Change Vol. Efficiency" column lists the values that account for the capacity change due to the change in volumetric efficiency with the model AWG5520WXT compressor. These values are specific to the compressor being used, and will change with other compressor models. The "Total Estimated Capacity Change" combines both of these capacity changes into a total estimated capacity change.

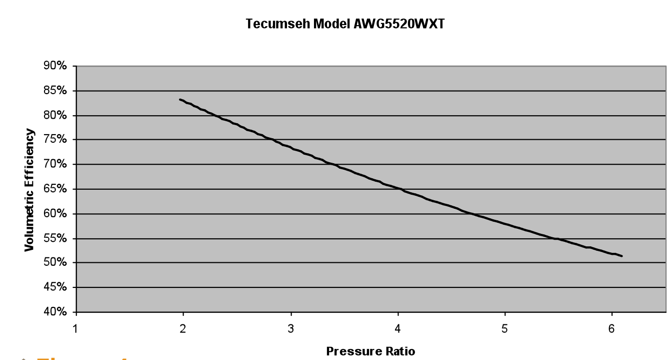

Figure 4

What about low-temperature applications? Due to its high discharge temperatures, R-22 was never ideally suited for low-temperature refrigeration, and this was thus largely the reason R-502 was developed for these applications in 1962.

A similar analysis can be performed for low-temperature applications. For this example, the operating conditions will be changed to a -10°F evaporator, 115°F condensing,

ASHRAE No.	Capacity Change from R-22	Pressure Ratio	Capacity Change Vol. Efficiency	Total Estimated Capacity Change	Capacity (Btuh)
R-22	0	4.05	0	0	13,000
R-407A	-5.7%	4.35	-3.7%	-9.2%	11,800
R-407C	-2.8%	4.43	-4.6%	-7.3%	12,100
R-407F	3.3%	4.32	-3.2%	0%	13,000
R-417A	-24.7%	4.41	-4.4%	-28%	9,400
R-422B	-25.2%	4.34	-3.5%	-27.8%	9,400
R-422D	-26%	4.24	-2.3%	-27.7%	9,400
R-424A	-25.2%	4.41	-4.4%	-28.5%	9,300
R-438A	-16.5%	4.39	-4.1%	-19.9%	10,400

Figure 5

0°F subcooling, and a 20°F return-gas temperature, and a Tecumseh model AEA1415EXA—a low-temperature R-22 1/3-hp reciprocating compressor—will be used to provide volumetric efficiency data (see Figure 6). Note that this compressor is not dual-rated with any of the R-407-series refrigerants, as it is provided only with alkylbenzene oil. In addition,

ASHRAE No.	Capacity Change from R-22	Pressure Ratio	Capacity Change Vol. Efficiency	Total Estimated Capacity Change	Capacity (Btuh)
R-22	0	8.24	0	0	1,500
R-407A	-8.7%	9.21	-7.7%	-15.7%	1,260
R-407C	-6%	9.48	-9.7%	-15.1%	1,270
R-407F	0.9%	9.10	-6.8%	-6%	1,410
R-417A	-28.8%	9.44	-9.3%	-35.4%	970
R-422B	-29.2%	9.22	-7.7%	-34.7%	980
R-422D	-29.7%	8.87	-4.9%	-33.1%	1,000
R-424A	-29.3%	9.45	-9.5%	-36%	960
R-438A	-20.2%	9.37	-8.8%	-27.2%	1,090

Figure 6

this analysis does not consider any capacity gains that may be achieved with these alternative refrigerants by eliminating some or all of the desuperheating when it is required to maintain suitable discharge temperatures with R-22.

Conclusions

First, understand that there is no such thing as a "drop-in" replacement refrigerant, despite what may be claimed in the industry.

Second, recognize that there is a reason why R-22 has been used for as long as it has been. R-22 was a superb refrigerant for air-conditioning, heat-pump and commercial refrigeration applications. It should be used within the law as long as it is economical to do so for these applications. Unfortunately, its time is nearing an end.

Third, expect a measurable loss in condensing-unit capacity for commercial refrigeration applications, particularly if an R-22 replacement refrigerant is used other than R-407-series refrigerants. If the condensing unit is dual-rated for R-22 and R-407C, the technician will best serve the customer by staying with one of the R-407-series refrigerants. If maintaining UL approval for the condensing unit is important, stay with the nameplate refrigerants.

Condensing units using either scroll or rotary compressors will have the benefit of minimizing capacity loss due to volumetric efficiency. All compressor types, however, are subject to capacity loss due to the differences in fluid densities and thermodynamic properties of the replacement refrigerants when compared to R-22.

As an example, a technician interested in changing out a 13,000 Btuh commercial-temperature (1.5-hp) R-22 condensing unit with a new R-22 condensing unit having a reciprocating compressor and using R-422D, since a 27.7% loss in capacity could be expected with a unit having a reciprocating compressor, the technician should consider selecting an R-22 condensing unit with an R-22 rating of approximately

13,000 / (1 - 0.277) = 18,000 Btuh

"Condensing units using either scroll or rotary compressors will have the benefit of minimizing capacity loss due to volumetric efficiency."

The technician can best serve the customer by selecting a replacement unit in the 2-hp range. Upsizing the condensing unit will require the technician to review the supply-wire size and fuse or circuit-breaker ratings.

Note: Thermodynamic properties presented in this article were calculated using NIST REFPROP version 8. For the R-22 alternative refrigerants, the condensing and evaporating temperatures stated in the article are treated as mid-point temperatures as defined by ANSI/AHRI Standard 540-2004 Appendix C, and these points were used for calculating thermodynamic properties. This standard may be downloaded for free at www.ahrinet.org/search+standards.aspx.

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