HVAC&R ENGINEERING
update

# The Impact of the HCFC-22 Phaseout on Direct-Expansion Chillers

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## Overview

HCFC-22 is the world's most widely used refrigerant. It serves in both residential and commercial applications, from small window units to large water chillers, and everything in between. Its particular combination of efficiency, capacity and pressure has made it a popular choice for equipment designers.

Recently, extensive use of HCFC-22 has made it possible to reduce the use of CFC refrigerants, because its Ozone Depletion Potential (ODP) is as much as 95% lower than CFCs. Nevertheless, it does have some ODP, so international law set forth in the Montreal Protocol and its Copenhagen and Vienna amendments have put HCFC-22 on a phase-out schedule. In developed countries, production of HCFC-22 will end no later than the year 2030. In intervening years, production is reduced in a series of specified steps.

Detailed phaseout schedules vary from country to country. In the U.S., HCFC-22 production will be frozen at baseline levels on January 1, 2010, and the production of virgin refrigerant will be banned unless it is used as a feedstock for other refrigerants, or in equipment manufactured prior to January 1, 2010. The countries of the European Community have adopted even stricter measures.

After the phaseout dates, supplies of HCFC-22 should still be plentiful thanks to conservation and recycling techniques developed for CFCs. For instance, CFC-11 hasn't been produced since January 1996, but because of recycling, it is still widely available. Recycled HCFC-22 should be even more plentiful, because it is more widely used than CFC-11. It is important to remember that the phase-out affects only production, not use.

Direct-expansion (DX) chillers are among the many products that have traditionally utilized HCFC-22. Therefore, owners and specifiers of DX chillers have an obvious interest as to how the phaseout will impact such chillers. After all, chillers purchased today will have a service-life well into the 21st century, when the phaseout will have begun to take effect.

The impact will vary from country to country. In countries with a late phaseout date, DX chillers will be sold with HCFC-22 for some time to come. In countries with an early phase-out date, existing DX chillers may never have to switch refrigerants because of the plentiful supply of recycled HCFC-22. However, for new DX chillers to be sold in countries with an early phaseout date, chiller manufacturers are developing units which utilize refrigerants other than HCFC-22.

## HCFC-22 Substitutes for DX Chillers

Obviously, new substitutes should possess what HCFC-22 lacks from an environmental standpoint, while retaining its good thermodynamic characteristics. Environmentally, the ideal candidate must have an ODP of zero and a low Global Warming Potential (GWP).

Thermodynamic similarity is important when retrofitting existing chillers; otherwise, capacity and efficiency may be lost. In new chiller designs, thermodynamic similarity is less of an issue because the equipment can be specifically designed for the replacement refrigerant's particular characteristics.

Several HCFC-22 substitutes have been identified by the Alternative Refrigerant Evaluation Program (AREP). This international, industry-backed program was developed by major refrigerant suppliers and HVAC manufacturers to ensure a broad-based assessment of HCFC-22 alternatives. Refrigerant data was shared among the participants to speed testing and replacement recommendations.

Currently, there are four leading replacement candidates: HFC-407C, HFC-404A, HFC-134a, and HFC-410A.

As an AREP participant, YORK believes all four HCFC-22 alternatives have merits. It's no surprise, then, that each refrigerant has been chosen by at least one manufacturer to replace HCFC-22 in new DX chillers.

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***GWP differences have such a minuscule impact on TEWI that they can be effectively ignored.***

Unfortunately, having made their refrigerant choice, some chiller manufacturers are bad-mouthing the choices of others. At this early stage of implementing HCFC-22 alternatives, these disparaging claims cause undue confusion and are a disservice to chiller owners and specifiers. The evaluation that follows attempts to give an even-handed analysis of the HCFC-22 alternatives, so chiller owners and specifiers can make informed decisions.

## Properties of HCFC-22 Substitutes

Because all four replacement candidates are HFCs, their molecules do not include chlorine, so their ODP is zero.

As far as GWP, however, the numbers do vary.  According to the Dupont Internet site, the GWP ratings are:

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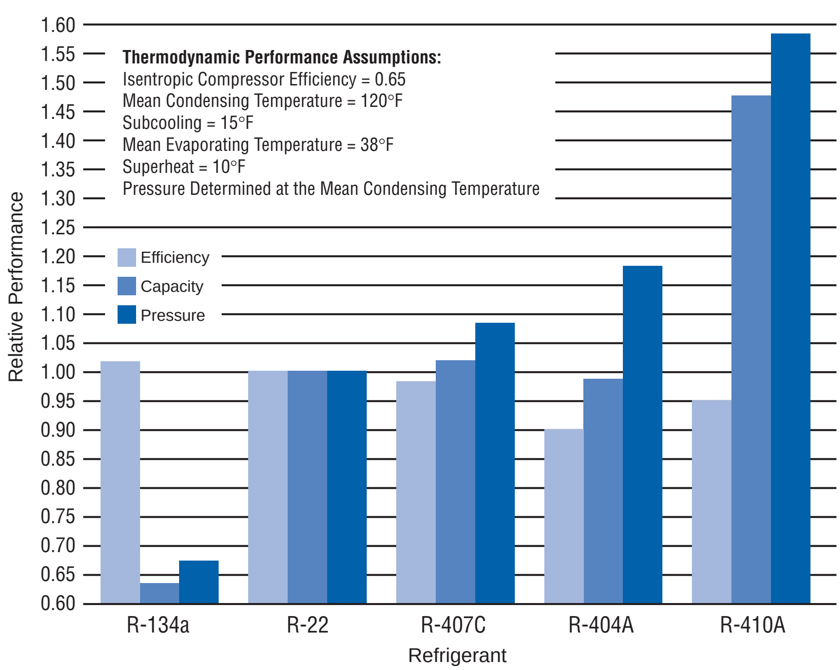
|---|---|
| HFC-134a: | 1300 GWP |
| HFC-407C: | 1600 GWP |
| HCFC-22: | 1700 GWP |
| HFC-410A: | 1890 GWP |
| HFC-404A: | 3750 GWP |

While there is a variance in these numbers, it is not significant. According to the TEWI (Total Equivalent Warming Impact) formula being proposed by GWP researchers, there are two ways in which a water chiller can affect global warming: refrigerant leaks and electric-energy consumption. Of the two factors, electric-energy consumption (or more specifically, the $CO_2$ created by the power plant supplying the electricity) is far more significant, accounting for 98 to 99% of a chiller's TEWI. So the refrigerant GWP differences shown above have such a minuscule impact on TEWI that they can be effectively ignored.

According to refrigerant manufacturers, all HCFC-22 substitutes will be available for the long-term. All are non-flammable and have low toxicities like HCFC-22. However, their capacities, efficiencies, and pressures vary, which affects their application.

**Figure 1: Thermodynamic Characteristics of HFC-134a, HFC-407C, HFC-404A, and HFC-410A Relative to HCFC-22**




## Retrofitting Existing Chillers

To be successful in a retrofit situation, a replacement refrigerant needs to have capacity, efficiency, and pressure comparable to HCFC-22. These thermodynamic characteristics will ensure satisfactory equipment capacity and efficiency.

How do the replacement candidates measure up thermodynamically? Figure 1 shows their efficiency, capacity, and pressure as compared to HCFC-22.

HFC-407C is very similar to HCFC-22 in all thermodynamic respects, which makes it a good retrofit candidate. Consequently, HFC-407C is being used for retrofits in some areas now.

The capacity of HFC-134a is much lower than HCFC-22, so it is not a good retrofit candidate.

The pressures of HFC-404A and HFC-410A are much higher than HCFC-22, so they are not good retrofit candidates either.

## Designing New Chillers

Because new chillers can be designed around a refrigerant's properties, all of the above refrigerants are candidates for use in new DX-chiller designs. Obviously, the chiller design will differ from HCFC-22 chillers to a greater or lesser degree, according to the properties of the particular refrigerant choice.

For HFC-134a DX chillers, the design is affected by the refrigerant's lower capacity and pressure. Lower capacity means more refrigerant will have to be circulated, which necessitates larger or faster compressors. Lower pressure means that cost can be taken out of some chiller components because they don't have to be built as ruggedly.

For HFC-410A DX chillers, the designer must deal with much higher refrigerant pressure. As a result, heat exchangers and compressors will have to be designed to withstand that pressure. The higher pressure also means the refrigerant gas will be more dense. Higher density means less gas will have to be circulated to provide the same amount of refrigeration. So compared to HCFC-22 chillers, smaller or slower compressors can be used.

For HFC-404A DX chillers, there is a lower refrigerant efficiency and higher refrigerant pressure to deal with. To counter the lower efficiency, bigger heat exchangers may be required. The higher pressure may require that the heat exchangers and relief devices be redesigned.

For HFC-407C DX chillers, the design preferred by YORK, the refrigerant's slightly higher pressure is not high enough to require different chiller components than used for HCFC-22 chillers. The refrigerant's capacity and efficiency are very similar to HCFC-22. There are, however, intriguing design implications for one unique feature of HFC-407C – the property known as "temperature glide."

## Temperature Glide Explained

HFC-407C, HFC-404A, and HFC-410A are all blends of other refrigerants.

HFC-407C is a ternary blend, comprised of HFC-32, HFC-125 and HFC-134a, with a composition by weight of 23%, 25% and 52% respectively. HFC-404A is ternary blend of HFC-125 (44%), HFC-143a (52%), and HFC-134a (4%). HFC-410A is a binary blend of HFC-32 and HFC-125 in a 50%-50% ratio.

Each of these HCFC-22 alternatives is a zeotropic blend, meaning that the resulting blend does not react as a single substance. At a given pressure, they evaporate and condense over a range of temperatures, rather than at a single temperature. The expression "temperature glide" was coined to describe this phenomenon.

HFC-410A and 404A have temperature glides of 1°F or less, which is small enough that we can overlook the effect. However, HFC-407C has a temperature glide of 7 to 8°F.

## Impact of Temperature Glide

The phenomenon of temperature glide, when fully understood, holds tremendous promise for chiller designers and customers as a means of improving chiller efficiency. Unfortunately, some manufacturers using other HFCs are obscuring this benefit by spreading several misconceptions.

***Misconception # 1:*** *Any refrigerant leak will alter the blend percentages of the remaining HFC-407C and degrade chiller performance.*

As stated above, the components of a zeotropic blend evaporate at different temperatures for a given pressure. Consequently, it is perceived that an HFC-407C refrigerant leak will cause the more volatile components — HFC-32 and HFC-125 — to escape first. This phenomenon is known as fractionation.

But it is wrongly thought that a refrigerant leak invariably changes the proportion of the remaining constituents, thereby degrading chiller performance. In real-world applications, there are few conditions where fractionation is a factor. During chiller operation, any refrigerant-gas or refrigerant-liquid leaks will not result in fractionation because the refrigerant blend is still thoroughly mixed.

Only if there is a refrigerant-gas leak during chiller shutdown will the more volatile components escape first. But calculations and tests show that the effect on performance is slight.

To empirically test the impact of refrigerant-gas leaks during shutdown, an independent test laboratory (Intertek Testing Services, formerly ETL) ran an experiment on a 100-ton chiller. During chiller shutdown, 35% of the HFC-407C gas was purposefully leaked from the point in the system where the fractionation effect would be most pronounced.

The leaked refrigerant was replaced with a make-up quantity of fresh HFC-407C. This leakage/recharge cycle was repeated 4 times. In the end, the amount of gas lost and replaced simulated a refrigerant leak of 140% of the original charge. While such repeated, massive leaks would be highly unusual in real-life, they do serve as an extreme test of fractionation.

What was the impact on chiller performance? In spite of massive refrigerant leakage and replacement, the laboratory found that capacity went down only 4.5%, while efficiency went up 1.1%.

This test illustrates that it would take a near-catastrophic refrigerant leak to produce any discernable loss in capacity, at which point the seriousness of the leak would far overshadow the performance issues.

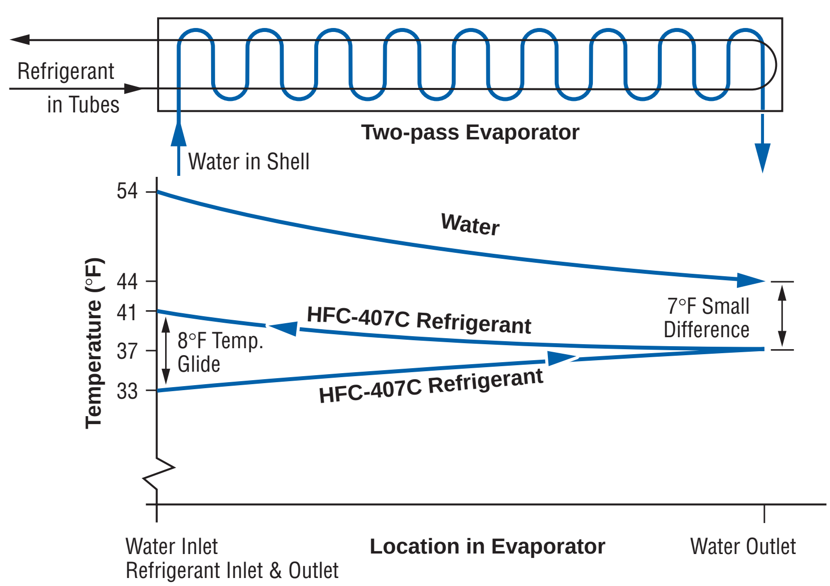
***Misconception # 2:*** *The temperature glide of HFC-407C will result in refrigerant temperatures below 32°F, which will freeze the chilled water.*

A typical DX evaporator has a 7°F small difference, which is defined as chilled-water temperature minus refrigerant temperature at the evaporator location where the temperature difference is smallest (usually where the refrigerant and water exit the evaporator, but not always). Now charge this evaporator with HFC-407C, with its temperature glide of 7 to 8°F. At first glance, it would appear that this combination might expose the chilled water to near-freezing temperatures. As shown in Figure 2, if the design leaving-chiller-water temperature is 44°F, then the HFC-407C refrigerant might enter the evaporator at 33°F.

But actual applications show there is no freezing problem. Most major HVAC equipment suppliers already allow their HCFC-22 DX evaporators to operate with refrigerant-inlet temperatures below 32°F, and there are no freezing problems.

***Temperature glide holds tremendous promise as a means of improving chiller efficiency.***

**Figure 2: HFC-407C Temperatures in a Two-pass Evaporator**



The reasons are simple. First, the coldest refrigerant is typically in contact with the warmest water, as shown in Figure 2. Secondly, ice-crystal formation is inhibited by the high velocity and turbulence present in the water side of the evaporator. If ice crystals did form on the tube or tubesheet surfaces, the scrubbing action of the turbulence would pull them back into the warm bulk flow.

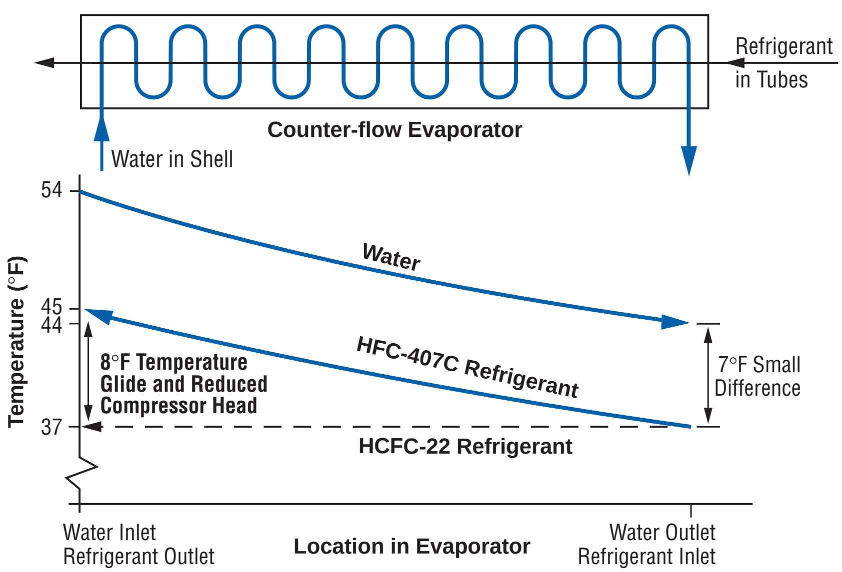
***We hope this paper results in a speedy acceptance of all HCFC-22 alternatives.***

### Benefit of Temperature Glide

At first glance, the phenomenon of temperature glide looks like an unwanted side effect in an HCFC-22 substitute. However, closer examination reveals that the temperature glide of HFC-407C holds a promising benefit — major improvement in chiller efficiency.

If the DX evaporator is designed as a counter-flow heat exchanger, then the refrigerant and the water enter at opposite ends, as shown in Figure 3. In this configuration, the leaving refrigerant temperature is 45°F. Compare this temperature with an HCFC-22 chiller using the same evaporator. The leaving refrigerant temperature would be 37°F.

**Figure 3: HFC-407C Temperatures in a Counter-flow Evaporator**




The higher leaving-refrigerant temperature with a counter-flow evaporator and HFC-407C means the compressor does less work to raise the refrigerant to the condensing temperature. And less compressor work means lower energy consumption.

Thanks to temperature glide, HFC-407C promises to be an outstanding HCFC-22 substitute, not just from the perspective of ODP and GWP, but from an efficiency viewpoint as well.

### Conclusion

A variety of HFC refrigerants have been developed as alternatives to HCFC-22 in DX chillers. All are viable candidates, and all are being used by one or more chiller manufacturers. YORK has chosen HFC-407C because of its performance characteristics in real-world applications. Its capacity, efficiency, and pressure similarities to HCFC-22 make it a logical choice for retrofits. And its temperature glide promises significant efficiency improvements in new chillers.

When the HVAC industry eliminated its use of CFC refrigerants, some chiller manufacturers confused owners and specifiers with claims and counter-claims as to which was the "best" replacement refrigerant. In the end, several refrigerants turned out to be worthy replacements, and the focus of chiller evaluations turned away from refrigerants and toward the more important factors of value and performance. At YORK, we hope this paper has cleared up some misconceptions, and results in a speedy acceptance of all HCFC-22 alternatives.