R-22 Replacements in Air conditioning Applications – R- 407C and R- 410A: What does the Future Hold ??

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Abstract:
R-407C was rapidly introduced in Europe as a replacement for R-22 in new air-conditioning equipment, as a consequence of the European ODS legislation. Subsequently R-410A has been making inroads into this market segment. This paper compares the physical properties and system performance characteristics of the two new fluids and attempts to answer the question: “Will R-410A Replace R-407C in the future?”. We do not, in this paper, address the question of possible inroads into the use of these HFC refrigerants by not-in-kind technologies.

Background:
The phase-out of R-22 for new installations in Europe which occurred as a consequence of the EU Regulation 2037/2000 came during a period of rapid growth in the use of air conditioning in Europe. As a consequence, the major global manufacturers of air conditioning equipment, who were nearly all active in the rapidly growing European market, had to develop equipment to use non ozone depleting refrigerants. R-407C was initially the refrigerant of choice to meet the new European requirements in domestic and light commercial air conditioning and heat pump systems. This was because, due to R-407C’s physical similarity to R-22, minimal development work was needed to adapt existing R-22 system designs to use R-407C.

Meanwhile, in the US market where the phase out of R-22 was more than a decade away, product development was focusing on energy efficiency spurred on by the DOE regulations which set energy efficiency standards for air-conditioning systems. Development work in the US was focusing on R-410A which showed promise of enabling systems to meet the new DOE standards for the residential segment more easily than R-407C.
Recently R-410A systems have been introduced into the European market with some manufacturers announcing that they were converting their entire product range to R-410A.

Physical Characteristics of R-407C and R-410A

The two fluids are significantly different in their basic thermo-physical characteristics. R-410A has a substantially higher saturation pressure, over the normal working temperature range than R-407C, and its volumetric refrigeration capacity is also substantially higher. Each fluid requires specific system design – R-410A cannot be used in systems designed for R-407C from a safety (pressure rating) consideration alone. Even if the system were of an adequate pressure rating the performance characteristics are sufficiently different that system performance would not be optimal. Similarly R-407C would not operate properly if used in a system designed for R-410A.

A comparison of the physical properties of R-407C and R-410A with those of R-22 is shown in Table 1.

Table 1
Physical Property Comparison
(pressures are absolute)

	R-22	**R-407C**	**R-410A**
Critical Temperature (°C)	96.2	86.1	71.4
Critical Pressure (bar)	49.9	46.3	47.7
Pressure at 50°C (bar)	19.4	22.1	30.6

The much higher saturation pressures of R-410A (compared with R-407C and R-22) is immediately apparent, and explains the reason why R-410A cannot be used in equipment designed for R-407C. The higher pressures of R-410A result in higher superheated vapour densities at typical compressor suction conditions. This contributes to R-410A having higher volumetric refrigeration capacities relative to R-22 (and to R-407C) as shown in Table 2.

Table 2
Theoretical Refrigeration Cycle Comparison
(10°C Evaporation, 45°C Condensing)

	R-22	**R-407C**	**R-410A**
Pressure Ratio	2.54	2.66	2.51
Relative Volumetric Capacity	1.00	0.99	1.43

It is important to note at this point that, while the higher volumetric capacity of R-410A implies the need for a substantially reduced compressor displacement relative to R-407C for a given cooling load, the power consumed by the compressor (and therefore the size of the electric motor driving the compressor) is a function also of the system COP. As is shown below the COP of R-410A systems, while higher than that of many R-407C systems, is not sufficiently different to result in a substantially smaller compressor power draw. The physical dimensions of hermetic and semi-hermetic compressors used for small commercial and domestic R-410A systems will not be very much smaller than those used for equivalent R-407C systems. The story does not end there, however.

System Performance

The energy efficiency of refrigeration (and air conditioning) systems is becoming ever more important as efforts to reduce climate change intensify. Refrigeration and air conditioning systems are significant consumers of electrical energy and consequently energy efficiency is one of the major drivers for system development.

A comparison of the theoretical energy efficiency performance (the theoretical reverse Rankine cycle) of R-410A opposite that of R-407C is given in Table 3.

Table 3
Comparison of a Theoretical Refrigeration Cycle
(Evaporating 10°C, Condensing 45°C)
Relative to R-22

	R-407C	**R-410A**
Net Refrigeration Effect	0.99	1.00
Refrigerant Mass Flow	1.01	1.01
COP	0.96	0.93

R-410A does not look attractive at first sight. Initial performance tests with R-410A, however, showed an interesting energy efficiency improvement over R-22 (and R-407C when used in conventional DX air cooled systems) in air conditioning applications [Ref. 1]. The reasons for the observed improved energy efficiency over R-22 lie in the Transport Properties of R-410A. (See Table 4)

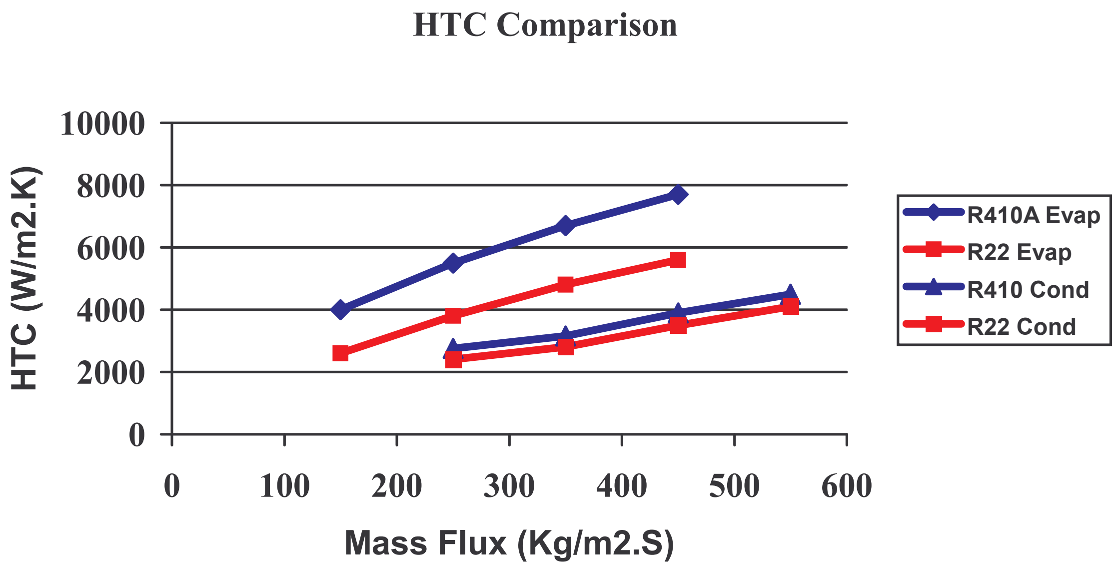
Table 4
Transport Properties of R-410A
(Liquid phase at 10°C)

	R-22	**R-407C**	**R-410A**
Density (kg/cu.m)	1247	1199	1130
Viscosity (μPa.S)	196	185	147
Therm. Cond. (W/m.K)	0.090	0.096	0.108

R-410A has a significantly better Heat transfer coefficient than R-22 (or R-407C), particularly in the evaporator as shown in Fig. 1 (Ref. 2). R-410A also suffers lower pressure drop than R-407C for equivalent mass flow in both vapour and liquid transfer lines. R-410A air-air DX systems have been reported

(Ref. 1) as having around 5% lower energy consumption than equivalent R-22 systems.

Figure 1



Other implications

One important consequence of the different physical characteristics (as described by their Transport Properties) of R-407C and R-410A is manifested in the design requirements for air-conditioning or heat pump systems. R-410A systems require smaller pipe sizes than those for R-407C systems with similar duty. Heat exchanger (evaporator and condenser) piping diameters can be reduced leading to improved heat exchange performance, and in some instances, more compact unit design (Ref. 3).

As an example a heat pump system which might require 1 3/8in. feed pipe to the compressor suction with R-407C would use 1 1/8in. pipe with R-410A (assuming the same refrigeration duty and overall line pressure loss).

A direct consequence of the relatively high composition shift (as well as its temperature glide) of R-407C is its unsuitability for use in centrifugal chillers or in chiller systems which use flooded evaporators or condensers. R-410A does not suffer from these constraints.

So far everything we have discussed seems to point to very clear advantages of R-410A over R-407C, however this does not tell the full story.

R-410A, as has been discussed, is a substantially higher pressure refrigerant than R-407C. Even though, for a given equipment capacity, required tube diameters for R-410A systems are lower than for R-407C, design pressure constraints limit the use of currently available conventional copper refrigeration piping (Ref. 4) to around 1 3/8in (35mm) for R-410A systems. This limit value is very dependent on the specific application conditions. This constraint might effectively limit the design capacity of field installed split air-conditioning systems using R-410A to around 100 kW. R-407C can be used in substantially larger systems before the pressure limitations of current commercially available copper refrigeration piping is reached.

System Performance Enhancements arising from the use of R-407C

One of the much publicised supposed draw-backs of R-407C is its temperature glide. (The issues are really a consequence of the composition shifting possible with R-407C, as discussed in other publications.) The temperature glide itself can, in systems which are designed to make use of this property, result in significant system energy efficiency improvements. The use of counterflow heat exchangers can allow much smaller approach temperatures for a given heat transfer surface area, and thus higher system evaporating temperatures. This translates directly into COP improvements. Improvements in COP of around 6% in counterflow water chillers have been demonstrated (Ref. 1). For air evaporators effective counterflow designs have yet to be developed.

Conclusions

Although R-410A appears to have several advantages over R-407C in terms of its energy efficiency in certain system configurations, it is by no means certain that it will be used in preference to R-407C in new equipment for every application. R-407C and R-410A will co-exist in the future, providing system OEMs options to design the most cost efficient and safe air conditioning and heat-pump systems for a wide range of applications.

References

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