Evaluation of HCFC Alternative Refrigerants

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Introduction

It is well-known that HCFC refrigerants widely used in today's air conditioning and refrigeration (AC&R) industry will soon be phased out, mainly due to their ozone depletion potentials (ODPs) and global warming potentials (GWPs). The timetable established through international agreement and national legislation calls for a 65% reduction of HCFC consumption based on 1989 level by January 1, 2010 in developed countries. In the United States, no new production of HCFC-22 equipment will be allowed by that date. Searching for or converting to R22 alternatives, therefore, has become an unavoidable task that AC&R equipment manufacturers must face sooner or later.

R22 is a typical refrigerant currently used in Heatcraft Refrigeration Products LLC's medium temperature commercial refrigeration product lines. To meet the R22 phase-out schedule, Heatcraft began evaluating R22 alternatives in 2004. This paper summarizes the impact of thermo-physical properties on refrigerant selection for two primary R22 replacement candidates, namely HFC-404a and HFC-410a—both of which have zero ODP. Although the consideration of these impacts may not be sufficient for a complete assessment, this approach provides an effective way for initial refrigerant evaluation and guidance for next steps. Additional parameters, such as component/system efficiency and safety aspects, may be included in detailed analyses as a next step to finalize the refrigerant selection.

Refrigeration System and Operating Conditions

A simplified refrigeration system consisting of four major components, namely compressor, condenser, expansion valve (TXV) and evaporator, as shown in Figure 1, below.

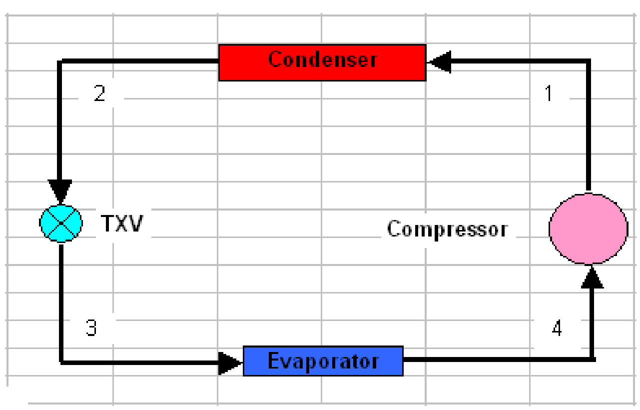

Figure 1: Refrigeration System

Assuming a refrigeration cycle starts at compressor outlet, it goes through a condenser, an expansion valve, an evaporator and comes back to compressor inlet to complete a cycle as shown by points 1 to 4 in Figure 1. This cycle can also be represented by a pressure-enthalpy diagram (p-h diagram) as shown in Figure 2, below, where all values are corresponding to R22 refrigerant as a baseline under so-called medium temperature (MT) operating conditions (e.g., 125°F condensing temperature and 25°F evaporating temperature). It should be noted here that the condensing temperature in Figure 2 is at its high end to represent more severe conditions.

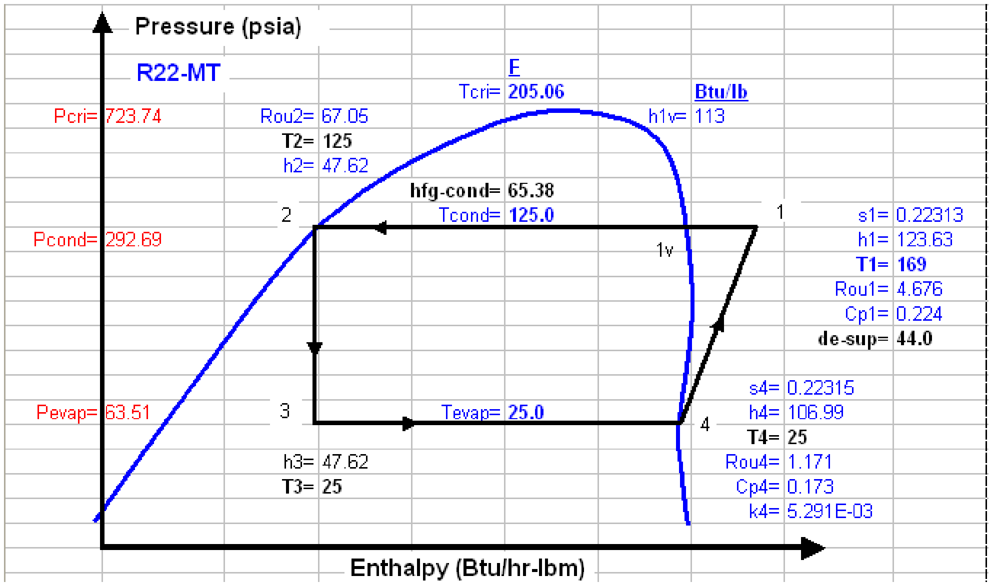

Figure 2: R22 p-h Diagram Under Medium Temperature Conditions

Further, zero superheat (point 4 in Figure 2) and sub-cooling (point 2 in Figure 2) are assumed to occur at evaporation temperature and condensing temperature, respectively. An isentropic process is also assumed for vapor compression. These assumptions are made to simplify the evaluation procedures without compromising the discussion results presented here. All values are generated using the NIST refrigerant property program REFPROP-V7 in English units. These conditions form a base for the discussions in the rest of this report.

System Design Considerations

Two of Heatcraft's refrigeration components are shown in Figure 3, where (a) is a condensing unit and (b) is a unit cooler or evaporator unit. R22 has been used in these units for medium temperature applications.

(a) Condensing unit (b) Unit cooler

Figure 3: Major Refrigeration System Components

Over the years, quite a few refrigerants have been studied and proposed as the R22 replacement by research groups and chemical companies from all over the world [1]–[5]. Among a list of candidates, HCFC-404a and HCFC-410a have become a popular choice by major U.S. AC&R equipment manufacturers. Given that refrigerant properties have a profound influence on refrigeration component design and system performance, Table 1 lists selected thermo-physical properties of R404a and R410a in comparison with R22 under typical operation conditions for medium temperature refrigeration applications.

Table 1: Refrigerant Property Comparison

Refrigerant Property (MT Cycle)	R22	R404a	R410a
Evaporation temperature (Tevap), F	25	25	25
Condensing temperature (Tcond), F	125	125	125
Heat content at 25F (h4-h3), Btu/lbm	59.37	35.80	62.14
Vapor density at 25F (Rou4), lbm/ft^3	1.171	1.677	1.681
Specific heat at 25F (cp4), Btu/lbm-F	0.173	0.234	0.263
Conductivity at 25F (k4), Btu/hr-ft-F	5.291E-03	8.180E-03	6.918E-03
Discharge temperature (T1), F	169	138	168
Discharge pressure (Pcond), psia	292.69	345.86	461.51
Liquid density at 125F (Rou2), lbm/ft^3	67.05	55.35	55.79
Critical temperature (Tcri), F	205.06	161.68	160.44
Critical pressure (Pcri), psia	723.74	540.82	711.07
Compression ratio (Pcond/Pevap)	4.61	4.54	4.52
Cycle COP (h4-h3)/(h1-h4)	3.57	2.84	3.45

Discussion is provided below to analyze the impacts of these properties on (1) cycle performance, (2) component design, (3) manufacturing processes, and (4) the environment. All of these aspects must be taken into account when considering an alternative refrigerant for a refrigeration system.

1. Cycle Performance

The two main performance parameters are cycle cooling capacity and Coefficient of Performance (COP). Cycle cooling capacity per refrigerant mass is determined by the phase change heat content at evaporation temperature (i.e., [h4 – h3]), while cycle COP is calculated from this capacity divided by compressor work (i.e., [h4 – h3] / [h1 – h4]. The evaporation heat content of R404a is significantly lower (60% less) than the baseline R22 value, while that of R410a is slightly higher. The cycle COP of R404a is about 20% lower than the baseline value, indicating that this refrigerant does not match the baseline R22 cycle performance on equal mass base. Conversely, both R404a and R410a have about 43% higher vapor density than R22 (Rou4), as well as 55% and 31% higher vapor thermal conductivity (k4), and 35% and 52% higher specific heat (cp4), respectively. These characteristics imply that both R404a and R410a refrigerants have better heat transfer ability and higher cooling capacity on equal volumetric flow base when a compressor with similar displacement and coil tubing is used as compared to R22. Increased vapor density for R404a and R410a may also lead to smaller compressor size and coil tubing that could result in less system power consumption and more efficient component design to compensate the lower cycle COP. Overall, however, a comparable system COP is possible for R404a, and even a moderate system efficiency improvement might be expected for R410a for a certain cooling load.

System COP is also affected by compressor volumetric efficiency, which is a function of compression ratio (Pcond/Pevap) and compressor isentropic efficiency, which could be affected by other transport properties, as well as system design.

2. Component Design

Impact on system design may involve component design change or re-selection to cope with different operation pressure and refrigerant mass flow rate. Both R404a and R410a have higher discharge pressures than R22. Notably, the discharge pressure of R410a is about 60% higher. Design change becomes necessary when increased discharge pressure (Pcond) and temperature (T1) are encountered with a new refrigerant. Specifically:

- Higher working pressure generally requires a heavier compressor shell and thicker tubing materials.
- The discharge temperature, which is related to vapor specific heat (cp4) and other transport properties, may affect compressor lubricant selection.

- Altered saturation pressure-temperature relation could also mean that a different expansion device is required for proper system operation.
- A larger receiver and liquid piping are expected if refrigerant liquid density (Rou2) is low.

Higher working pressure also requires evaluation from a safety standpoint. A high discharge temperature may have adverse effect on motor bearing safety. Any component attached to the system, such as heat transfer coils, headers and piping, must be able to withstand the higher working pressures. Any system protection components (e.g., filter drier, oil separator, sight glass and relief valve) and any system control components (e.g., head pressure valves, hot gas bypass valves, high pressure switches and fan cycling switches) all need to be rated and functional at the higher working pressures.

Both refrigerants under consideration are more tolerant of pressure changes. For example, in an R22 condenser operating at 120°F (260 psig), a coil refrigerant pressure drop of 10 psig equates to a 3°F temperature change. In a similar R410A condenser, to see the same 3°F temperature change, the coil pressure drop becomes 16.4 psig. In application, this means that the R410a condenser can be designed with more efficient circuiting and increased performance or could be designed with smaller diameter tubes with lower cost and still produce the same net effect.

3. Manufacturing Processes

Impacts on manufacturing processes and on environment should also be considered in order to estimate implementation cost and to ensure production and operation safety. With increased working pressure for HFC alternatives, leak detection equipment must be capable and sensitive enough to sense HFC refrigerants. Any service and maintenance equipment, such as gage sets and hoses, need to be rated for higher working pressures. If design changes are made (such as new tube diameters), there will be a capital expense associated with new equipment. Also, the new design may make changes to the process flow of product through the factory necessary.

4. Environment

A refrigeration system affects the environment through two distinct ways: (1) by its ozone depletion potential (ODP) and (2) by its global-warming potential (GWP). Table 2 lists ODP and GWP values for several refrigerants.

Table 2: Refrigerant ODP & GWP Values

Refrigerant Type	Name	ODP	GWP (100 year horizons)
HCFC	R22	0.055	1700
HFC	R404a	0	3784
HFC	R410a	0	1975
HC	R290	0	20

The use of HFC refrigerants eliminates the ozone-depleting impact of refrigerants. However, both R404a and R410a refrigerants have higher GWPs than R22. Hydrocarbon (HC) R290 has the lowest environment impact among these refrigerants, but it is flammable. The flammability of hydrocarbon refrigerants has been a major concern for large systems such as those seen in commercial refrigeration applications.

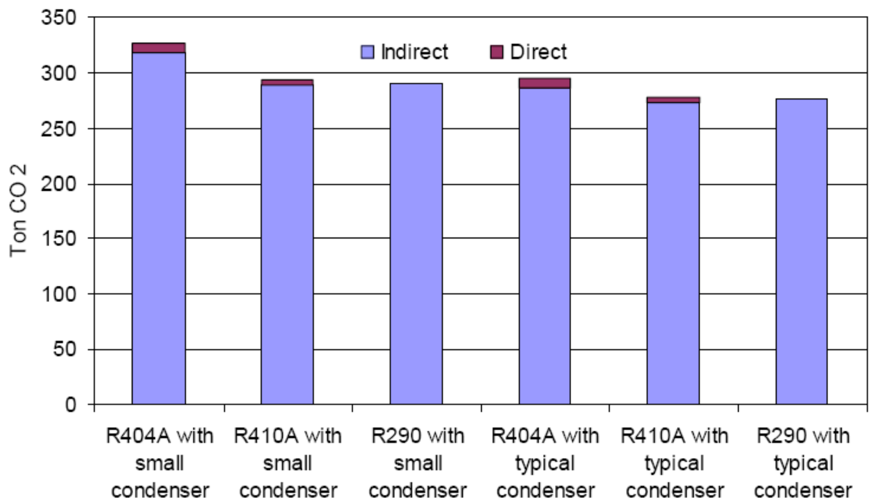

Figure 4: Life Cycle Climate Performance (LCCP) Comparison

According to Yunho Hwang et. al. [4], a Life Cycle Climate Performance (LCCP) analysis for R404a, R410a, and R290 showed that over 90% of equivalent CO_2 emission from a typical refrigeration system is due to electric power consumption (i.e., indirect impact). Only a small portion of the total equivalent CO_2 emissions (i.e., direct impact) is due to refrigerant leakage over the entire service life of the system (see Figure 4). Thus, improvement of energy efficiency for a refrigeration system can largely reduce the environment impact.

Final Remarks

Discussions provided in this report reflect the thoughts and considerations of Heatcraft for initial evaluation of alternative refrigerants as replacements for HCFC-22. Among all the candidates considered, R404a and R410a represent a good balance of system performance, product safety and environmental impact. Furthermore, R410a may have higher performance potential and lower environment impact (LCCP) when compared to R404a for the medium temperature range.

It should be mentioned that component availability is also a non-trivial factor for decision-making. Due to the limited availability of R410a compressor models for commercial refrigeration applications, R404a needs to be made available to satisfy current market needs.

References

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