

General Information



TO: Distribution

DATE: February 28, 2003

FROM: Joseph W. Pillis

SUBJECT: Refrigerant Issues Update – Revised Update February 2003

Purpose:

The purpose of this document is to sort out the relevant questions about the use of various refrigerants that could have a significant impact on the refrigeration business and therefore should be addressed strategically. This document is issued for informational purposes only.

Defining Issues:

The primary issues driving refrigerant choice are as follows.

1. Ozone Depletion Potential, (ODP): Effect on the ozone hole, dependent on the presence of chlorine in chloroflourocarbons.
2. Global Warming Potential, (GWP): Is it a greenhouse gas? Still not much of a legislative issue in the U.S. but growing in importance in Europe, and could eventually lead to phase out of R-134a along with all HFC's .
3. Total Environmental Warming Impact, (TEWI): This measure gives credit for the energy efficiency of a refrigerant in addition to its direct environmental impact if leaked to the atmosphere.
4. Capacity per displaced volume, (tons refrigeration per CFM displacement, or KW capacity / m3/hr). While R-22 and NH3 are approximately the same capacity per displaced volume, R-134a is about 35% lower. This makes R-134a systems more expensive per delivered unit of refrigeration capacity, particularly with positive displacement compressors.
5. Operating pressures should ideally be positive pressure at most common evaporating temperatures, and not over current compressor design pressures at normal condensing temperatures.
6. Azeotropic behavior. Many of the new alternatives for R-22 are zeotropic blends, which means that at a given pressure they evaporate over a range

of temperatures, not at one fixed temperature like R-22. This can work acceptably in direct expansion evaporators but is not acceptable in flooded evaporators or pump recirculated evaporators because the refrigerant tends to “fractionate” into a different mixture of its constituents in the vapor space compared to the liquid space. The constituents of the blend that tend to boil at higher temperature will be a higher percentage in the vapor than what was charged into the system. This means that if a leak develops in the vapor space, the high boiler constituent will be leaked out in a disproportionate amount. Over time, if this leak continues, the makeup of the blend can be changed significantly from the initial charge, with a resultant change in thermodynamic properties, performance of the system, and in the extreme perhaps in the flammability of the mixture. This has huge implications for servicing of systems that have leaked. Does the technician have to measure the current make-up of the blend and try to recharge back to the original make-up? Will the constituents even be available? In large systems it is not realistic to expect replacement of the entire charge as being proposed in small systems. This issue eliminates most of the 400 series blends for use in flooded evaporator systems, (exceptions are R-404A and 410A which have about 1 degree F glide), even though they are the likely replacements for R-22 in unitary A/C and DX chillers.

7. Changes in regulatory requirements. While NH₃ and propane are often excellent refrigerant choices from a performance standpoint, the safety issues of flammability and toxicity drive their acceptability in completely different manner in Europe compared to the U.S. New US requirements for Risk Management Prevention, (Environmental Protection Agency, EPA, reporting requirements) require all plants over 10,000 lbs. of NH₃ to file worst case scenario disaster plans to local regulatory agencies. These plans can look very bad for large quantities of NH₃ in heavily populated areas. We see some companies that do not want their names associated with a report that says they could kill a large population in a worst case spill. Some feel compelled to get away from NH₃. This issue will drive some portion of the U.S. market to NH₃ alternatives or to system designs that minimize NH₃ charge quantities. For many plants located in heavily populated areas, the cost of compliance with all of the regulations required for NH₃ usage make other solutions economically viable when the cost of compliance is included.
8. The Green movement centered in Germany, Sweden, and a few other European countries is so powerful that NH₃ or other “Natural Refrigerants” are the only acceptable alternatives, even in A/C. Hydrocarbons are being used in refrigerators. When NH₃ is the only acceptable alternative, cost competitiveness of NH₃ chillers vs. R22 chillers is not an issue, so acceptable A/C equipment in these areas is totally different than the rest of the world where lowest cost is still the primary issue. In industrial refrigeration there is little difference in cost between NH₃ and R22 systems

primarily because most heat transfer surfaces are steel or aluminum instead of copper as used in R22 A/C systems.

9. The impact on U.S. regulatory and code agencies of the lobbying effect from ARI, and the large A/C and refrigerant suppliers has a tremendous effect on keeping the replacement blends as the only acceptable alternative for A/C in the U.S. While this group's primary interest is A/C, the zeal of this effort can make NH₃ a more and more expensive proposition in U.S. plants. No group representing refrigeration is nearly as well organized or well capitalized to compete with this continuous effort.

The refrigerant change issue has been a huge issue for A/C applications primarily because of the dependence on R-12 in large centrifugal chillers. This was temporarily substituted with R-123 in the same size equipment. A/C companies have redesigned centrifugals for R-22, and R134a in large sizes and introduced screws in smaller sizes on R-22 and R-134a. Longer term R-134a centrifugal chillers will be used in large sizes for flooded evaporators, screws on R-407c or R-417A in DX systems, and screws on R-134a in flooded evaporator systems.

Legislative Movements Driving Change

Several Legislative bodies have published schedules for the phase-out of HCFC compounds. R-22 is the most widely used compound under the HCFC classification, R-123 also falls under this classification.

(Please refer to "HCFC Phasing Out Program" chart on the following page.)

HCFC Phasing Out Program

Montreal Protocol 7th Meeting in Vienna December 1995		EU Decree No. 2037/2000		
		Production	Use – import or own production	Ban on use in the following applications
1996	Reference: 2.8% of 1989 CFC use + 1989 HCFC use, ODP weighted			
1997		Reference year		
1999			Reference: 2.6% of 1989 CFC use + 1989 HCFC use, ODP weighted	
2000		Freeze acc. to reference year		Public cold stores /warehouses. Plants with shaft power \geq 150 kW
2001			Reference: 2% of 1989 CFC use + 1989 HCFC use, ODP weighted	All stationary refrigeration and AC systems yet
2002			Reduction to 85%	01 July: AC systems with capacity < 100 kW
2003			Reduction to 45%	
2004	Reduction to 65%		Reduction to 30%	Reversible AC and heat pump systems
2008		Reduction to 35%	Reduction to 25%	
2010	Reduction to 35%		End of import and production	Service of existing systems with new HCFC
2014		Reduction to 20%		
2015	Reduction to 10%			Service of existing systems with recycled HCFC
2020	Reduction to 0.5%	Reduction to 15%		
2025		End of production		
2030	End of production			

Possible Scenarios for Refrigeration

The range of possible scenarios for field erected refrigeration systems is as follows.

1. Use NH₃ wherever local codes and regulations allow. This will certainly continue in the majority of large food plants for the immediate future.
2. Apply NH₃ with more innovative system designs that allow charge reduction where possible, to get below charge limits and thus minimize the cost of compliance. This trend could accelerate in the short term, requiring non-thermosiphon oil cooling, more use of plate evaporators, possibly NH₃ plate chillers with pumped secondary brines, to keep the NH₃ in the engine room. It is possible that the EPA 10,000 lb limit on NH₃ will be changed to a lower quantity, requiring continuing innovation in plant design.
3. Keep using R-22 where it is allowed, in locations where NH₃ is not acceptable. This is based on local requirements, but R-22 new systems can currently be sold through 2010 and serviced through 2030 in the US. These dates will likely be phased in sooner based on ongoing negotiations. R-22 is already banned in much of Europe for refrigeration applications. Japan has now said it will cease supplying new R-22 equipment after 2004. It is clear that many customers today are reluctant to install new R-22 systems if they have any other viable alternative.
4. Use new refrigerants of the HFC family. This primarily means R-134a, R-507, R-404A, R-410A, R-407C, R-417A, R-23 or R-508 for low temperature.
5. Use natural fluids. This area encompasses using CO₂, air, or water as a refrigerant, as well as non vapor compression systems like absorption.
6. There are not many good choices today for high temperature heat pumps. R-124 is probably the best choice in the R-114 range, (up to 250F saturated condensing temperatures), but it is an HCFC. R-123 or R-134a may be usable in some applications.

Possible HFC Substitutes

R-134a is a viable refrigerant for evaporator temps from about 0 F up to +40 F. While not truly an R-22 substitute because its properties are quite different, it is a possible alternative to R-22 in some applications. Its lower latent heat than R-22 requires more compressor displacement for given tons which means larger and more expensive compression equipment. Below approx. -20 F its efficiency is falling rather rapidly as it goes below atmospheric pressure and delivered capacity per displaced volume becomes prohibitive. It is the only HFC substitute

viable for high temperature condensing above 140 F because of the low critical points of the other substitutes. This makes 134a an attractive choice for heat pumps up to perhaps 200 F condensing. It is proven for industrial usage, well known, and a pure substance which avoids any of the fractionation questions. GWP is low at 0.26. Because of low operating pressures today's equipment is generally over-designed for R-134a pressures. The total pressure increase in an R-134a system is lower than R-22, so the effect of system pressure drop has more of an impact on efficiency in a 134a system.

R-507 is a blend of R-125 and R-143a. It is the only blend classified as azeotropic in the HFC based R-22 replacements. It was originally targeted as a replacement for R-502 and as such has primarily been applied as a recip. compressor refrigerant in supermarkets, where it today enjoys heavy usage. It is slightly higher in pressure than R-22, approx 45 psi at condensing temperature but this is not enough to make it impractical. Its GWP is not very good, ~ 1.0. Its efficiency is approximately 12-20 % worse than R-22 but benefits tremendously from economizing with screws. With the economizing effect it is still 7-13% worse than R-22 or NH3 in the +10F evaporating range, but is still growing in favor in plants worried about NH3 regulations and R-22 phase out. R-507 becomes much more attractive in efficiency against NH3 or R-22 at low evaporating temperatures. At -40F to 95F single stage and economized, R-507 is **MORE** efficient than either NH3 or R-22. At -40F/95F NH3 would be at almost 19:1 compression ratio, and R-507 is only at 11:1. This lower compression ratio allows a higher efficiency to be realized in the system that helps overcome the inherently poorer thermodynamics of this blend.

R-507 is beginning to be viewed as one of very few practical conventional alternatives to NH3 or R-22 in large plants with flooded evaporators and is being applied in an increasing number of systems.

R-507 is extremely dense. This can be a problem to handle in screw compressors at suction pressures much above 20 F, (-7C) because the discharge ports become too restrictive. Also the economizing effect with R-507 requires very high flash gas flow to the compressor side port at low evaporating temperatures. While today's screws will work OK on R-507 from -40 F to +10 F, special economizer ports with increased flow areas would be more optimum for low temperature applications, (the RWF design incorporates increased economizer flow areas with R-507 in mind). Special rotor profiles that give larger discharge port flow areas would be necessary for efficient operation much above +20 F evaporator temperature, on large compressors.

R-507 also produces extremely low discharge temperatures. This is caused by a combination of low heat of compression and high density. This is not really an advantage in a screw compressor because the oil separator will run very cold. On boosters it may be 40 F, (4 C) or so. On high stage maybe 110F, (43 C) or

so. This can cause very high levels of refrigerant dilution in the oil on typical applications. Some compressor manufacturers will not apply compressors on R-507 for this reason because they are worried about very low oil viscosity causing sleeve bearing failures. Using anti-friction bearings and low pressure bearing cavities we have proven our compressors will work acceptably on this viscosity level in about 60 systems to date.

R-404a is classified as a zeotropic mixture of R-143a and R-125, with 4% R-134a. It is very similar to R-507 in properties except it has slightly lower pressures, closer to R-22, and it has a small (1.0 F) glide in the evaporator. The existence of this glide raises concerns about fractionation and for this reason R-404a does not look to offer any benefit over R-507 in flooded evaporators. Because the glide is low, the fractionation concerns may be basically unfounded, but this raises concerns with no particular benefit. We see more interest in R-404a in Europe than in the US, presumably because the domestic European refrigerant manufacturers have more incentive to promote it over R-507. GWP is ~ .94 which is slightly better than R-507.

R-407C has a high glide ~7F at evap. temperatures making it unacceptable for flooded evaporators. Its pressure level is the closest to R-22 of the blends and its cycle efficiency is almost as good as R-22. With special DX evaporators designed to take advantage of the considerable glide it may actually beat R-22 efficiency in small chillers. The glide rules it completely out on flooded evaporators and fractionation concerns also rule it out on large systems.

R-410A is a quasi-azeotrope of R-125 and R-32 with pressures much higher than R-22. Its cycle efficiency is about 10% worse than R-22 but better than R-507. It gives much higher capacity per displaced volume than R-22 which gives a potential for lower cost systems, however compressor design pressures of approximately 500 psi would be required to get to 120 F ambient temperature safely. Because the operating pressures are higher than R-22 and the compression ratios generally lower, some gains in compressor efficiency are generally realized on 410A systems. Also the effect of pressure drop on system efficiency is less due to the higher overall discharge pressure level. It seems unlikely that large field erected systems at 500 psi operating pressures will be built if any other alternative is available. However, many applications with water cooled condensers have been supplied on packaged chillers where the piping runs and charge quantities can be minimized. 410A is fairly attractive in small systems and often cost effective in first cost and efficiency in systems with high pressure drop. At the present time, with standard equipment 410A is not viable in air-cooled systems or systems that could shut down at high ambient. York has installed a number of water cooled 410a shipboard screw chillers with good success. These generally show lower first cost and smaller equipment size than other alternatives. GWP is fair (0.5). R-410a could be considered as a good

refrigerant for the low side of a cascade system down to perhaps -75 F with another compound for the high side.

R-417a - (NU-22) - R-417a (NU-22) is a zeotropic, blend of 50% R-134a, 46.6% R-125, and 3.4% R-600 (butane). The addition of the butane is claimed to allow the use of mineral oils with this blend. This refrigerant has approximately an 8 deg F temperature glide at most evaporator temperatures, and approximately 5 deg. F glide at normal condensing temperatures. This refrigerant is advertised as a possible R-22 replacement. While it might be a possibility in small DX systems, the high glide would make it unattractive in any system with a flooded evaporator, or large systems.

R-23 or R-508A/508B - R-23 has been used extensively as a low temperature cascade refrigerant. R-508A/508B, is claimed to have better efficiency but is newer and has not been used extensively. Either have reasonably good properties for low temp cascade systems to replace R-13 or 13B1 or R-503.

R-124 – This fluid seems to be the best short term choice for high temperature heat pump applications, up to perhaps 250 F. However, it is an HCFC replacement for R-114 and will be phased out with the other HCFC's. It can use alkyl benzene oil if the viscosity level is acceptable for a given compressor. Will likely be replaced by R-134a in most applications needing heat pump temperatures.

Propane – R-290 is an excellent refrigerant in approximately the same temperature range and efficiency level as R-22, of course with the one strong drawback that it is explosive. In chemical plants that are prepared for the cost of explosion proof controls and are accustomed to supplying government reports on other toxic or flammable chemicals in their plants, propane can be a very viable alternative. It is not the sort of refrigerant that food plants are likely to adopt.

Isobutane – R600a is a possible choice for higher evaporation temperatures, as ethane R170 is a possible cascade low temperature refrigerant. Both are hydrocarbons and flammable and may be of interest in chemical plants. R-600a is gaining in popularity in Europe in refrigerators where the charge quantity is very low.

Non-Conventional Refrigerants

There is considerable desire in Europe that the long term refrigerant solution must be natural. This has led to an increasing interest in Water, air and CO₂ as potential refrigerants. Developments in these areas are likely as considerable research and effort is being expended to find natural solutions.

Water - it is possible to use water as a direct refrigerant. A demonstration project was built by Sabroe at the Lego plant in Western Denmark. The plant is operating successfully. The compressor size is quite large for relatively low capacity. It is not possible to achieve evaporation temperatures below 32 F because of the formation of ice. Ideal compressors for this application would be large displacement multistage radial or axial type.

Air - The Brayton cycle has been used for many years for direct air-conditioning using air as the refrigerant. This has generally been used in aircraft where dry compressed air is readily available, heat can be rejected from the air readily, and air conditioning temperature levels are desirable. While not highly efficient, the systems were light in weight and effective in aircraft. There is a renewed interest in low temperature closed air cycle cooling for blast freezing temperatures. Thermodynamically it is not very competitive in efficiency. The overall efficiency will look more attractive when high temperature steam is also needed in the plant and credit can be taken for the overall efficiency in generating cooling and heat simultaneously. The pressures used on the closed air cycle are in the 900 to 1200 psi range. The advantage of closed cycle is that it avoids the necessity to remove moisture from the working fluid if atmospheric air is used, (open cycle). The load required for drying air in an open air cycle is very significant and one of the major drawbacks to its use.

CO₂ - R744 can be used as a direct refrigerant. We have built many systems utilizing CO₂ as the low temp refrigerant in cascade systems, and many compressor systems for CO₂ compression in gas plants. These work quite well and are fairly well known. There is also interest in using CO₂ as a refrigerant up to transcritical levels (above 88 F approx. CO₂ doesn't condense). This would require compressors with working pressures of perhaps two thousand psi and does not appear to be practical with today's compressor types, at least in large sizes. Automotive A/C and some refrigeration display cases are built with transcritical CO₂.

CO₂ does not offer very much range between its critical point and triple point. At the triple point, approximately -69F (-56C) dry ice will form, blocking flow. If the temperature approaches the critical point 88 F(31 C) or exceeds it, (transcritical cycle process) the efficiency drops drastically due to the fall in the enthalpy difference of evaporation.

Thus the primary interest for industrial plants is for the use of CO₂ as the low temperature fluid in a cascade system. Expansion volume in the system should be allowed to accommodate all the liquid in the low side and avoid overpressure, or other methods to prevent loss of the charge on shutdown as on any cascade system. CO₂ shows very good heat transfer coefficients which give possibilities for reduced heat exchanger size. It also has very high capacity per displaced volume giving 8-9 times the capacity of NH₃ in the same compressor size. These

factors are driving considerable interest in CO₂ as a possible lower cost alternative for large plants that can afford the complexity of a cascade system. There is currently considerable work to improve oil management in CO₂ at low temperature to avoid wax formation in evaporators. Today, this is generally done with good oil separators to keep oil out of the low side, often with PAO oils. There has been some interest in the use of polyolester oils which are miscible in CO₂, and it should be possible to return them from low temp. evaporators as their viscosity in the evaporators would still be manageable. However, the long term stability of the polyolester oils does not look promising. Other miscible oil chemistry is being tested, (alkyl naphthene) but does not yet appear to be commercially ready.

Absorption - A variety of salts are available which will absorb NH₃ at low temperature, -80 F or so. Under the presence of heat they will give up the NH₃ to condensing level. This type of absorber system would probably be used in pairs, alternately charging and discharging each unit to maintain a fairly steady evaporator load. So far the manufacturing technology is not well known to determine if this system can ever be cost competitive. It is also unknown if overall efficiency is competitive. Efficiency is a bit difficult to define since heat is the driving force to power the system. If it is waste steam it may be nearly free. If a boiler system is required the issue of cost of energy enters in.

Attachment: Refrigerant Characteristics Data Chart