

PRACTICAL GUIDE
r e f r i g e r a t i o n

CFC to HFC Conversion Issues **Why Not Mineral Oil?**

By Daniel E. Kramer, P.E.
Fellow ASHRAE

With the advent of HFC refrigerants came a requirement that all the mineral oil be removed and replaced with POE (polyol ester) lubricant. Questions have been raised about whether such replacement was always necessary. The issue was complicated when refrigerant manufacturers and formulators recognized that blends containing a large proportion of HCFC-22 (R-401A and R-409A for example¹) exhibit sufficient miscibility in all but ultra-low temperature applications to function like the old HFC/mineral oil systems without changing lubricant.²

This article addresses only HFC refrigerants and blends that are not miscible with mineral oil. It explores factors that favor using or retaining mineral oil when retrofitting existing systems. It also discusses potential problems arising from such use or retention.

Background

The now banned refrigerant CFC-12 and its standard lubricant, mineral oil (MO), formed a highly miscible combination (i.e., they dissolved in each other in all proportions). It was found early on that the approved replacement HFC refrigerants and the old MO lubricant were not highly miscible. There was concern that the reduced miscibility would inhibit oil return to the compressor and would affect heat transfer. Another lubricant, polyol ester (POE), was found to form a highly miscible system with the new HFC refrigerants. Manufacturers and sellers uniformly recommended that only POE be used with the new HFCs. Retrofit instructions mandated not only that the original MO be replaced with POE but that repeated oil (POE) changes were required so the residual MO concentration would be less than 5%.³

These steps proved to be prohibitively costly, especially when applied to smaller systems.

Why Retain Mineral Oil

The following factors favor retaining or using mineral oil in systems with HFC refrigerants:

Lower lubricant cost: POE lubricants cost roughly five times as much per unit volume as either mineral oils or alkyl benzene.

Direct refrigerant replacement: Simply repairing the leak and replacing the lost CFC or HCFC refrigerant with the new HFC without changing the lubricant from mineral oil to POE may well be a viable option in most automotive air conditioners as well as most residential air conditioners and heat pumps. Reports from respected laboratories have confirmed oral reports from service technicians about trouble-free replacement of CFC-12 with HFC-134a in auto air conditioners and icemakers and HCFC-22 with HFC-134a and R-410A (50% HFC-32/50% HFC-125) in residential air conditioners.^{4,5}

Identifying applications where HFC/MO in old and new systems require engineering or design changes is of primary importance. These questions will be addressed in the section on potential problems.

Lower refrigerant solubility: The high miscibility of POE/HFCs carries the same faults as the old high miscibility MO/CFC systems. *Figure 1*⁶ compares the solubility of HFC-134a in R-133-0, a POE, (upper graph) with its solubility in N-70, a low pour point naphthenic mineral oil (lower graph). The dashed horizontal lines indicate percent refrigerant by weight and refer to the y-axis on the right. In both cases, the curves slope upward to the right, so solubility increases as pressure (and therefore temperature) increases. The upper right endpoint for

Dan Kramer, P.E., is former chief engineer of Kramer Trenton Company. He is now a consultant on commercial and industrial refrigeration systems and also is a patent attorney. Kramer has received ASHRAE's Distinguished Service Award.

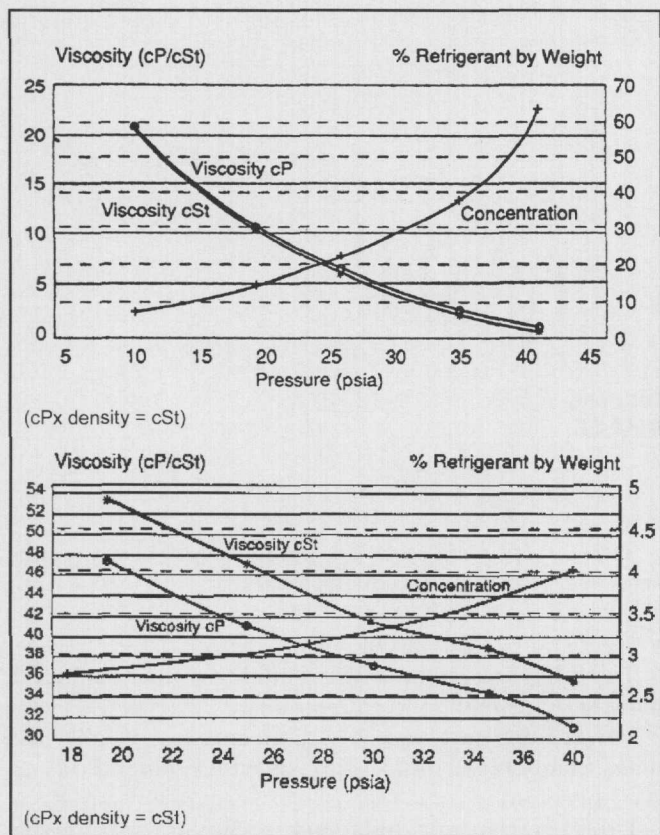


Figure 1: Solubility of HFC-134a in POE (top) and in mineral oil (bottom.)

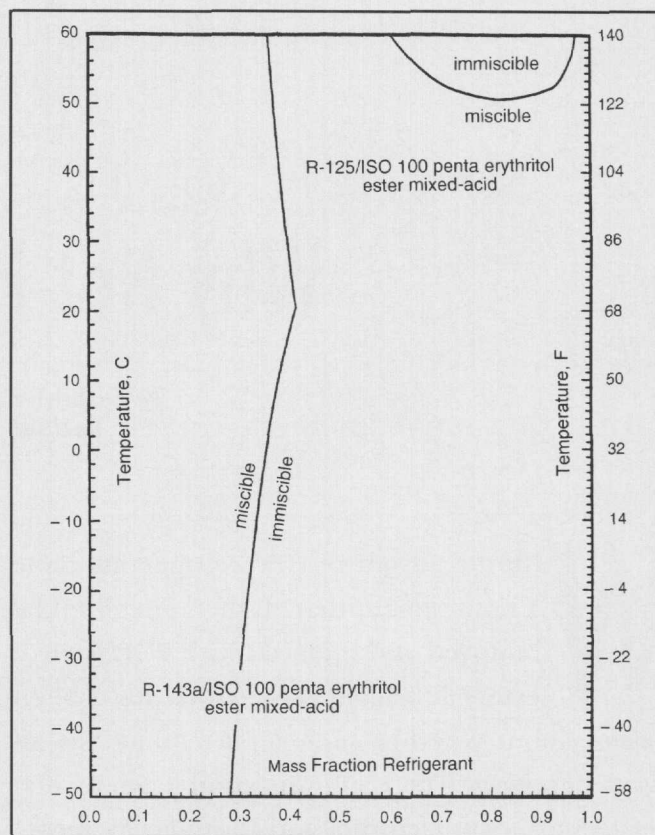


Figure 2: Solubility of R-125 and R-134a.

the curves represents a condition near that occurring in air-conditioner evaporators. At this condition, mineral oil dissolves only about 4% refrigerant. By contrast, the POE holds more than 60% refrigerant.

The sharply lower solubility of HFC refrigerant in mineral oil conveys the following advantages to mineral oil:

Improved working viscosity: High solubility of refrigerant in oil reduces the viscosity of the lubricant, possibly compromising its ability to provide hydrodynamic lubrication. In Figure 1, the solid horizontal lines indicate viscosity and refer to the y-axis on the left. The density of the oils considered is about 0.85. (A note on viscosity: multiply cSt [centistokes] by the density of the fluid to get cP [centipoise]. Multiply cSt by 4.8 to get SUS [Saybolt Universal Seconds].)

Examining the viscosity curves shows a much more aggressive decrease in viscosity of the POE (upper chart) as it is diluted with dissolved refrigerant, much like adding raw gasoline to automotive lubricating oil.

By contrast, the lower chart shows that the MO viscosity drops only slightly, simply because much less HFC-134a refrigerant can dissolve in it, thereby providing higher viscosity oil in the bearings. This observation suggests that an HFC-134a system lubricated with MO that has a working viscosity in the same range as the working viscosity of the miscible POE/HFC-134a mixture would provide comparable bearing wear and compressor lon-

gevity. Tests⁷ strongly support this conclusion. Different oil compositions and the presence or absence of anti-wear additives can affect these results.

Reduced refrigerant charge: At normal compressor sump operating temperatures, the difference between the concentration of HFC refrigerant dissolved in POE and that dissolved in MO may be relatively low. However, the much greater solubility of HFC in POE distributed throughout the remainder of the system suggests that a perceptibly greater refrigerant charge will be required in systems lubricated with POE than in similar systems lubricated with MO. While the contractor building an extended system may not be significantly affected by these differences, to the OEM concerned with production runs of thousands, there may be worthwhile savings, including an eventual reduced burden on global warming.

Faster refrigeration on start: In residential air conditioners and similar systems, when the compressor cools during long off cycles, almost the entire HFC refrigerant charge could reside in the compressor, dissolved in POE oil. As a result, the system behaves at start-up much like an uncharged system. The load on the compressor might be low, and it might take some time for the POE to warm enough to expel its load of refrigerant into the operating circuit. This delay could annoy owners, and the highly diluted POE might briefly have a viscosity too low to lubricate bearings properly. By contrast, mineral oil/HFC systems have only a few percent of the refrigerant charge

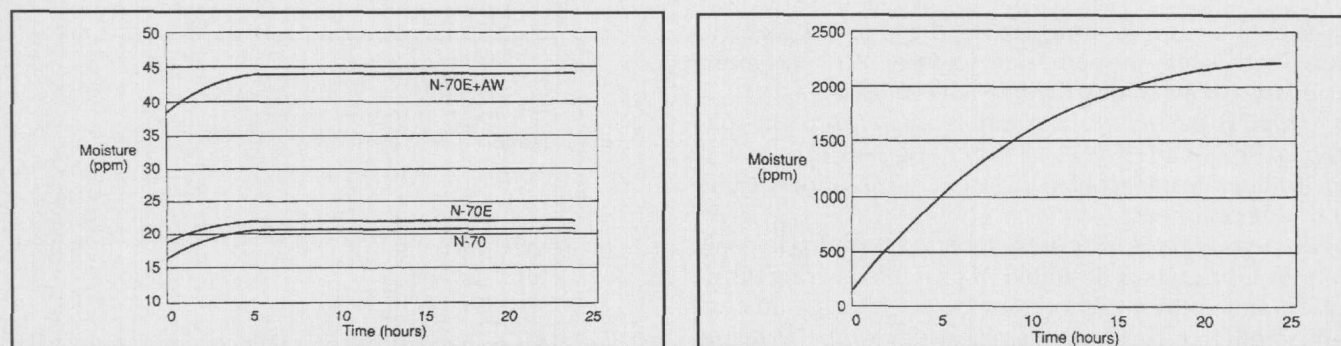


Figure 3: Moisture attractiveness of mineral oil (left) and POE (right).

dissolved in the oil. They will begin effective refrigeration more quickly, and the undiluted oil will provide normal, effective, uninterrupted lubrication. On the other hand, the higher pressure due to refrigerant residing on the high side of the system could be a disadvantage for low voltage starts. See the discussion later on.

Reduced slugging and oil carry-over on start; less need for pump down cycles or heaters: In the HFC/POE case, as with the old CFC/MO case, a sharp reduction in crankcase pressure on start-up can cause violent foaming of the refrigerant-saturated oil in the compressor. This foaming causes oil loss and slugging. Pump down cycles or compressor crankcase heaters are often used to combat this problem. Since HFCs are only slightly soluble in MO, this problem is minimized.

Less distortion of the composition of refrigerant blends: Refrigerant blends such as R-410A or R-507 are mixtures of two or more refrigerants. While some of the refrigerant components are highly miscible with POE, others are only slightly miscible. For example, consider R-507A, an azeotrope having design composition of 50% HFC-143a and 50% HFC-125. Figure 2⁸ shows that the potential solubility of HFC-125 in POE is much greater than the quantity of HFC-143a that the POE can hold in solution. Further, there is the possibility of an effect similar to the *common ion effect* where the solution of the more soluble constituent can negatively influence the solubility of the less soluble constituent. Therefore, in systems having a high ratio of oil to refrigerant, the refrigerant circulated could have an excess of HFC-143a, the less miscible component. A recent study⁹ by Cavestri has quantified an aspect of this situation.

Reduced oil separator flooding: Oil separators normally contain a pool of lubricant. Where there is high lubricant-refrigerant miscibility, refrigerant can dissolve in and increase the volume of the lubricant pool, especially during the off cycle. This increase in volume raises the float and allows the refrigerant-rich lubricant to flow into and flood the compressor crankcase.

Reduced hygroscopicity: Figure 3⁷ illustrates the huge difference between the moisture attractiveness of mineral oil and POE. Merely leaving a POE coated pipe open to the atmosphere over night may generate a moisture level of 1,500 ppm (1.5%) in the POE, a 15-fold increase

in wetness. By contrast, leaving the same pipe (coated with mineral oil) open for the same period would generate a moisture level between about 21 ppm and 44 ppm (0.04%), an increase of only 13% to 30% in wetness over the base level. It is not clear how effectively room temperature evacuation or system-installed driers will reduce a high POE moisture level to an acceptable one. Further, it is not clear if a moisture-indicating element in a sight glass window will effectively report an unacceptable moisture level in the lubricating oil. Proponents of these systems and devices will undoubtedly make this information available.

While the refrigeration circuits of household systems such as refrigerators and window conditioners typically are not opened during their lifetimes, commercial and industrial systems are opened periodically for renovation or service, exposing residual lubricant in pipes to ambient air and its moisture. The moisture-absorbing characteristic of the lubricant may therefore be a factor in system life.

Reduced chemical reactivity: Mineral oils absorb little moisture. By contrast, the potential high moisture levels in POE increase chemical reactivity at higher temperatures leading to formation of materials that plug capillaries, screens, and filter-driers, abrade bearings, and increase the propensity for icing at expansion devices.

Reduced electrical resistivity: POEs can suffer from low electrical resistivity. Low electrical resistivity could prejudice the electrical integrity of hermetic motors. A recent patent¹⁰ suggests a solution to this problem.

Reduced dirt transfer: As recently as 1997,¹¹ small systems employing POE lubricant appeared to have problems with system dirt being conveyed because of the POE's detergent effect. By contrast, mineral oil tends to allow dirt to settle without being entrained and conveyed to another point in the system.

Using Mineral Oil with HFCs

• **Non-sticking suction reeds:** A major compressor manufacturer¹² has reported its need to reduce suction valve seat area in compressors intended for POE lubricants to avoid a problem with suction valves failing to open reliably.

• **Better visual leak detection:** Oil stains near joints,

gaskets or seals have long provided a clue to leak location. With its high attractiveness to water, POE may more readily wash away, destroying signs of leaks.

• **Water solubility and environmental impact:** The substantial solubility of POE in water suggests a potential environmental impact of inadvertent release into streams and water supplies.

• **Improved Foaming Characteristics:** Foaming in compressor lubricants is desirable to promote bearing lubrication and reduce compressor noise. Mineral oils exhibit moderate foaming characteristics with CFCs and HCFCs while POE lubricants have a much reduced propensity to foam with HFCs.⁸ While the reference does not offer data to directly support foaming characteristics in the MO/HFC, there is an inference that the oil in the MO/HFC combination will have superior foaming characteristics to the POE in the POE/HFC combination, thereby better achieving the desired objectives.

Potential MO/HFC Problems

The fact that there may be some advantages in applying HFCs with MO over POE in autos and smaller systems should not suggest that exactly the same considerations apply in larger systems. There are many potential problems waiting to trap the unwary. Some of these will be addressed and possible solutions considered.

Unsatisfactory oil return to the compressor-suction line: Existing suction lines were sized to provide adequate return with the mineral oil, which had a high miscibility characteristic with the old CFC refrigerant. Therefore, the refrigerant/MO mixture had low viscosity, and the old design velocity factors worked fine.

When the old CFC is replaced with an HFC, very much less of the new refrigerant is dissolved in the MO. Therefore, its viscosity is much higher (see *Figure 1*). Under a severe riser situation, oil return difficulty may be expected.

There are three potential solutions:

1. Change the original MO to a MO of a lower viscosity. Biancardi⁵ reports that MO grade 1GS (65 SUS) mimicked the viscosity of POE ISO 32 (150 SUS).
2. Add a few percent diluent such as CFC-12 or n-pentane to reduce oil viscosity.
3. Repipe the suction line to provide a higher velocity with its resultant higher pressure drop.

In systems with long suction lines and many risers, prudence and conservative engineering might also suggest simply using POE lubricant with the new HFC refrigerant.

Unsatisfactory oil return to the compressor-discharge line: Normally, high discharge line temperatures suggest that neither POE nor MO would have dissolved a high concentration of refrigerant and that oil return in risers would be similar for both.

Oil accumulation in the receiver: Oil return through the receiver is a serious concern in low miscibility oil/HFC systems. This is because oil that cannot dissolve fully

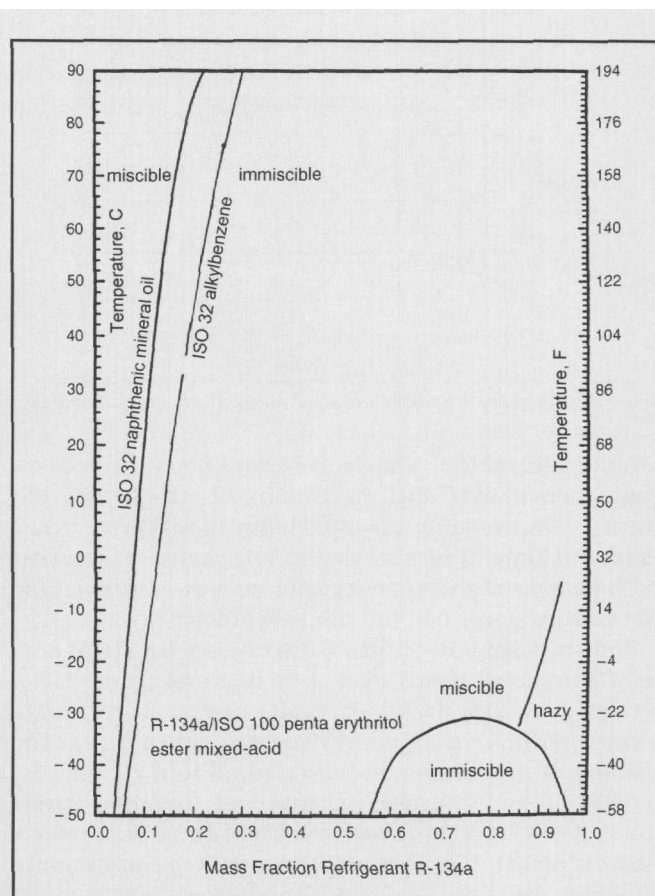


Figure 4: Solubility of R-134a in oil.

in the pool of refrigerant residing in the receiver will float on top of the refrigerant and accumulate. A large receiver thus provides an effectively infinite (compared with the quantity of oil in the compressor) sink for the oil, endangering the compressor oil supply.

*Figure 4*⁸ shows that even at 50°F (10°C) condensing/receiver temperature, HFC-134a can hold in solution about 10% MO, more at higher condensing/receiver temperatures. The issue of concern, of course, is the relation of compressor oil pumping rate compared to its refrigerant pumping rate. It is this relative pumping rate or Oil Concentration Rate (OCR) that determines the oil concentration through a uniformly flowing system. If this rate is within the solubility characteristic of the refrigerant residing in the receiver, little oil will collect in the receiver. Otherwise, there is trouble.

Compressor manufacturers do not publish the OCR of their compressors. While one could postulate that reciprocating compressors might have a low OCR at high back pressures and refrigerant mass flows and a high OCR at low back pressure conditions, more information is needed to design a system.

Possible solutions for oil accumulation in the liquid receiver include:

1. Where possible, design systems without receivers.
2. Switch to alkylbenzene lubricant, which has a somewhat higher solubility in HFCs.

3. Use effective oil separators. ASHRAE published Standard 69, *Methods of Testing Discharge Line Refrigerant-Oil Separators* in 1971, and revised it in 1990. This standard can provide an effective testing procedure when modern oil concentration instruments are used.

4. Encourage compressor manufacturers to provide OCR data at various conditions for both POE and for MO of various viscosities. When compressors are intended for field-erected systems, the oil pumping rates at various conditions should be part of the rating information supplied by compressor manufacturers.

Relative heat transfer in evaporators and condensers: Both the fully miscible POE/HFC system and the low miscibility MO/HFC system exhibit inherent characteristics that affect heat transfer. For instance, in the fully mis-

cible POE/HFC evaporator there is only a single phase throughout, however, as refrigerant evaporates, the POE concentration in the boiling refrigerant increases sharply. According to Raoult's Law, this concentration change increases the boiling point and thereby raises the effective refrigerant source temperature difference thereby reducing the heat transfer potential.

By contrast, with a low solubility lubricant like MO/HFC, there will be two phases throughout the evaporator length and the viscous oil phase is likely to coat the inner tube surface thereby providing a barrier to heat flow. However, the refrigerant phase will remain essentially pure and its boiling point will remain substantially constant throughout the length of the evaporator. This provides greater effective temperature difference than the POE/HFC case

Refrigerant Replacement/Retrofit

By Kenneth M. Elovitz, P.E.
Member ASHRAE

A mechanic calls to say your client's air-conditioning system just blew its entire 300 lb (135 kg) charge of CFC-12 (or R-500) through a cracked elbow in a discharge line. It's the hottest day of the year. Customers are leaving the client's store. Your client wants to know which \$30,000 repair you will authorize.

You tell the mechanic you will reply by the end of the day and start digging out your reference materials on refrigerants. HFC-134a is touted as the replacement of choice for CFC-12 in most applications, but it uses POE lubricant. The literature says that to switch to POEs, the residual mineral oil content should be less than 5% and preferably below 2%. There is a lot of oil out in the system. Simply cleaning out the compressor sump could easily leave as much as 50% mineral oil when you recharge and start back up. The literature says that changing the oil three times and running for 24 to 48 hours between each change will reduce the residual mineral oil content down to an acceptable level. Apart from the cost to buy and dispose of all the POE needed for the changes, the system is not operating—so you have no way to run for 24 to 48 hours between oil changes.

You remember Dan Kramer's article that said that HFC-134a could work with mineral oil in some situations. Your system is not the type discussed, and you are not brave enough to see if his theory can be extrapolated to a 100 ton (350 kW) built-up system like this one. As you ponder whether you will have to explain to an EPA bureaucrat why an unanticipated

cracked fitting that cost your client \$30,000 in repairs plus an unknown amount of lost business does not constitute intentional venting, you consider the following options:

Medium (0°F to 32°F/-18°C to 0°C) Or High (above 32°F/0°C) Temperature System

1. Recharge with the original refrigerant (CFC-12 or R-500). This option would work, but it will be expensive and leaves the client no better off than he is now if another accident occurs. The only advantage of this approach is that you can change to POE lubricant to be ready to convert to HFC-134a next time. That reasoning seems a little foolish because you hope there is no next time.

2. Recharge with HCFC-22. This is a good option, because HCFC-22 is readily available and will be around for a while. There are a few tricks to converting to HCFC-22:

- The same compressor running on HCFC-22 at the same speed and the same suction and discharge temperatures will have about 35% more capacity than R-500 and almost 60% more capacity than CFC-12. Therefore, if the system has an open, direct-drive compressor, changing to HCFC-22 would require changing the drive motor and associated electrical components. You might be lucky, though, if the compressor is now running CFC-12 at 1,750 rpm. Changing to a 1,200 rpm motor of the same horsepower should give approximately the capacity and load on

Ken Elovitz is an engineer and in-house counsel for Energy Economics in Foxboro, Mass. He develops and edits the Practical Guide series for ASHRAE Journal.

and possibly offsetting the resistance of the oil film.

The same analysis in reverse would apply to condensers, except that the viscosity of the oil rich phases would be lower and therefore have less effect on heat transfer.

Therefore, in properly designed evaporators, with a MO selected with the same effective viscosity as the POE, the overall refrigerant-side heat transfer coefficients may be very similar to the coefficient with POE.

Internally finned tubes: Tubes with internal enhancement might present a special problem, especially in low temperature evaporators.

Unreliable low voltage starting: Particularly in single-phase systems that have low compressor starting torque, the higher low-side pressures found after long off-cycles

imposes a greater compressor starting load, possibly causing non-start under low voltage conditions. A starting kit may be required, as a service tool.

Conclusions

Substituting HFC refrigerant for HCFC or CFC refrigerants in residential refrigerator/freezers, auto air conditioners, and residential air conditioner systems with compressors located below the evaporator and no liquid receivers has a high probability of success with the original mineral or alkylbenzene oil.

The application of HFC refrigerants to receiver-based refrigeration systems and systems with suction risers has the greatest probability of success where reduced viscos-

HCFC-22 with no electrical changes required.

- If the system has a belt-drive compressor, it can be slowed down to produce the same capacity with HCFC-22 as it did with CFC-12 or R-500. Since the compressor drives the oil pump, make sure the new compressor speed provides adequate lubrication.

- In either case, change the thermal expansion valve(s).

Reciprocating AC, chiller, or medium temperature (0°F to 32°F/-18°C to 0°C) display case with CFC-12

Recharge with R-401A (53% HCFC-22, 13% HFC-152a, 34% HCFC-124). Capacity, efficiency, and pressures are said to be similar to CFC-12, so R-401A is nearly a drop in replacement except for a need to change to alkylbenzene oil. The HCFC/alkylbenzene system has been shown to work okay with up to 50% residual mineral oil, so repeated flushing is not required. Be sure to relabel the equipment to indicate the new refrigerant. It would be a good idea and helpful to service mechanics to post R-401A pressure-temperature charts in strategic locations, such as at thermal expansion valves and at the compressor.

You might be able to get away without changing the thermal expansion valve. However, products designed for R-401A are now available, and it will be easier to change the TXV now than on a service call later if the old valve doesn't work properly.

Reciprocating AC or Chiller with R-500

This situation is almost the same as the reciprocating system with CFC-12 except the new refrigerant would be R-401B (61% HCFC-22, 11% HFC-152a, 28% HCFC-24). Capacity, efficiency, and pressures are said to be similar to R-500, so R-401B is nearly a drop in replacement except for a need to change to alkylbenzene oil. The HCFC/alkylbenzene system has been shown to work okay with up to 50% residual mineral oil, so repeated flushing is not required. Be sure to relabel the equipment to indicate the new re-

frigerant. It would be a good idea and helpful to service mechanics to post R-401B pressure-temperature charts in strategic locations, such as at thermal expansion valves and at the compressor.

You might be able to get away without changing the thermal expansion valve. However, products designed for R-401B are now available, and it will be easier to change the TXV now than on a service call later if the old valve doesn't work properly.

Low (0°F to -40°F/-18°C to -40°C) and Medium (0°F to 32°F/-18°C to 0°C) Temperature R-502

These systems generally can be recharged with R-402A (38% HCFC-22, 60% HFC-125, 2% propane). Capacity will increase slightly, and efficiency will decrease slightly. The lubricant must be changed to alkylbenzene. Systems that can tolerate a 10°F to 15°F (5° to 8°C) increase in discharge temperature can use R-402B (60% HCFC-22, 38% HFC-125, 2% propane) to obtain a slight increase in efficiency. Ice machines, food service units, and vending machines often fall into this category.

Like the other HCFC-blend retrofits, change the expansion valves, relabel the equipment to identify the refrigerant, and post pressure-temperature charts for convenience in servicing.

All Systems

On all systems, especially those with refrigerant-cooled compressors or motors, check with the manufacturer to verify that the proposed refrigerant blend is compatible with the materials in the refrigeration system, especially seals and motor insulation. The system should be recommissioned after the new refrigerant has been installed.

For additional information on alternative refrigerants, see <http://home.navisoft.com/navyozone/altref.htm> and www.epa.gov/ozone/title6/snap/snaplist.html as well as various refrigerant manufacturers' web sites. ♦

ity alkyl benzene or mineral oils are used along with effective oil separators and suction riser design implementing appropriate refrigerant vapor velocity.

Notes and References

1. R-401A is a blend of 53% HCFC-22, 13% HFC-152a, and 34% HCFC-124. R-409A is a blend of 60% HCFC-22, 15% HFC-142b, and 25% HCFC-124.

2. Allied Signal. Genetron Refrigerant Application Bulletin Tip Sheet #1, *Are Oil Changes Needed for HCFC Blends?*

3. Allied Signal. 1995. *Genetron 404A Retrofit Guidelines*.

4. In addition, system tests using a commercial refrigerator-freezer designed for CFC-12/mineral oil were made replacing CFC-12 with HFC-134a with no other changes. The refrigerator-freezer worked like a charm, including a 10-day run without defrost, which in reality is a simulation of a chest freezer. ASHRAE. 1989. *CFCs: Time of Transition*. Sanvordenker, K.S. "Materials compatibility of R-134a in refrigerant systems." pp. 211-16.

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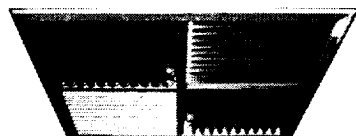
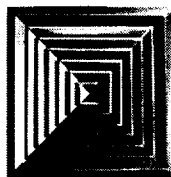
10. U.S. Patent 5,851,968. Dec. 22, 1998. *Increasing the Electrical Resistivity of Ester Lubricants, Especially for Use with Hydrofluorocarbon Refrigerants*.

11. U.S. Patent 5,865,607. Filed Feb. 18, 1997. *Refrigerating Cycle or Compressor Having Foreign Matter Collector*.

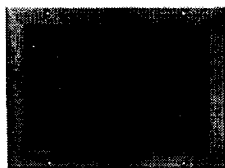
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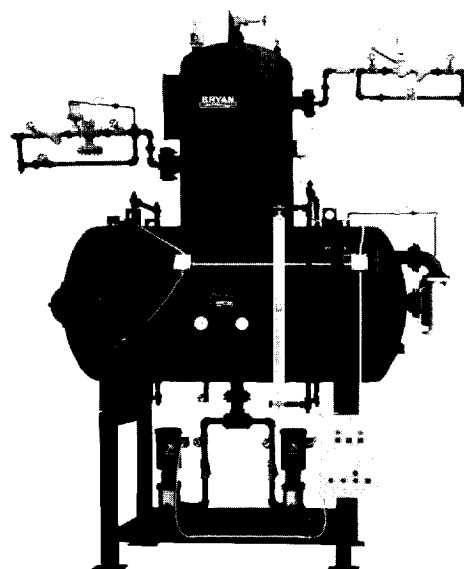
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