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ALTERNATIVES TO OZONE DEPLETING REFRIGERANTS IN TEST EQUIPMENT

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ABSTRACT

This paper describes the initial results of a refrigerant retrofit project at the Aerospace Guidance and Metrology Center (AGMC) at Newark Air Force Base, Ohio. The objective is to convert selected types of test equipment to properly operate on hydrofluorocarbon (HFC) alternative refrigerants, having no ozone depleting potential, without compromising system reliability or durability. This paper discusses the primary technical issues and summarizes the test results for 17 different types of test equipment: ten environmental chambers, two ultralow temperature freezers, two coolant recirculators, one temperature control unit, one vapor degreaser, and one refrigerant recovery system. The post-conversion performance test results have been very encouraging: system capacity and input power remained virtually unchanged. In some cases, the minimum operating temperature increased by a few degrees as a result of the conversion, but never beyond AGMC's functional requirements.

INTRODUCTION

The repair of aircraft inertial navigation and guidance equipment requires the use of environmental chambers, coolant recirculators, and other types of test equipment which contain refrigeration systems. There are more than 70 different types of test equipment used for processing or evaluating the inertial and navigational devices that are repaired at AGMC. Each type uses at least one of the following refrigerants: R-12, R-13, R-500, R-502, and R-503. All of these refrigerants are classified as stratospheric ozone depleting substances under the Montreal Protocol.^{1,2}

This paper describes the interim results of the refrigerant retrofit project at AGMC. The goal is to modify various types of existing test equipment to properly operate on alternative refrigerants that have *no ozone depleting potential* without compromising system reliability or durability. Selecting a replacement refrigerant and lubricant for a given application involves the consideration of several factors including thermodynamic performance (cooling capacity and power consumption), environmental properties, materials compatibility, system reliability and durability, refrigerant and lubricant availability, chemical stability, flammability, and toxicity. Moreover, the equipment conversions must be technically feasible, cost effective, and the converted units must be safe to operate.

At a time when many equipment suppliers are marketing new products using hydrofluorocarbon (HCFC) refrigerants which have low ozone depleting potentials (primarily R-22 and mixtures based on R-22), this project focuses solely on hydrofluorocarbon (HFC) refrigerants that have no ozone depleting potential. This paper describes the technical approach and the primary lessons learned from the conversions completed prior to April 1, 1994.

REFRIGERANTS

CFC Refrigerants

The Montreal Protocol and the subsequent upgrades of this historic international agreement require the near-term phase out of chlorofluorocarbon (CFC) refrigerants including: R-11, R-12, R-113, R-114, and R-115. These same regulations also affect some commercially important azeotropic refrigerant mixtures³:

CFC-500 CFC-12 (74 percent) and HFC-152a (26 percent)

CFC-502 HCFC-22 (49 percent) and CFC-115 (51 percent)

CFC-503 HFC-23 (40 percent) and CFC-13 (60 percent).

HFC Refrigerants

The HFC refrigerant that appears to be the best alternative for both R-12 and R-500 in medium-temperature and high-temperature applications is R-134a. The operating pressures and thermodynamic performance of R-134a are very comparable to R-12 in those temperature regimes. Several compressor manufacturers now market hermetic and semi-hermetic compressors made specifically for R-134a.

Some HFC replacements for R-502 are now available commercially. This project has focused on R-404a (more specifically DuPont SUVA[®] HP62), a near-azeotropic mixture of R-125/143a/134a. DuPont provided sample quantities of SUVA[®] HP62 for use in this project beginning in July, 1993. The properties of R-404a and R-502 are so similar that no significant performance change is expected. However, the higher operating pressures for R-404a has made it necessary to increase the pressure relief valve setting from 325 psig (2.34 kPa absolute) to 350 psig (2.52 kPa absolute).

Refrigerant R-23 has been produced commercially for several years but it has normally been combined with R-13 to create R-503, an azeotropic mixture used in low temperature refrigeration applications. Based upon its thermodynamic properties, R-23 appears to be the best HFC alternative for both R-13 and R-503. The properties of R-23 and R-13 are so similar that no performance change is expected in these cases. However, an increase in the minimum operating temperature is expected when R-23 is substituted for R-503 because there is a 12 F difference in their normal boiling points (-127.6 F [-88.7 C] for R-503 compared to -115.7 F [-82 C] for R-23)⁴.

HCFC Refrigerants

The present regulations concerning HCFC refrigerants allow their use in new equipment until the year 2015 and in existing equipment until 2020. However, it is likely that the phase-out schedule for the HCFCs will be accelerated closer to the year 2000.

On a worldwide basis, the most widely used HCFC refrigerant is R-22 which has a low ozone depletion potential⁵. Candidate alternatives for R-22 are being evaluated by a consortium of manufacturers in a project called *ARI's R-22 Alternative Refrigerants Evaluation Program*⁶. DuPont, Allied Signal, and other refrigerant producers have made sample quantities of various HFC refrigerants candidates for this work. However, it is not yet clear which candidates will eventually become the replacements for R-22 and production quantities of the replacement refrigerants are not expected to be available until 1996. Consequently, there are no plans (within the scope of the present project) to retrofit any test equipment that utilizes R-22.

Proprietary Refrigerants

A few of the equipment types at AGMC operate using a proprietary refrigerant which is a combination of CFC-13, CFC-14, CFC-114 and R-740 (argon). The manufacturer of this equipment has developed a drop-in replacement which is a different proprietary mixture of HCFC, HFC, and hydrocarbon gases that substantially reduces the ozone depletion potential. However, there are no plans to retrofit any of AGMC's test equipment that use this proprietary refrigerant as part of the present project.

LUBRICANTS

The mineral oils normally used with CFC refrigerants are not miscible in the HFC refrigerants. After considering several alternatives of various lubricant types including alkylbenzenes and polyalkylene glycols (PAGs), the leading independent compressor manufacturers selected polyol ester oils (POEs) for use with HFC refrigerants. However, at this point in time, Copeland, Bristol, and Tecumseh each recommend a different polyol ester for use in their respective products. Copeland endorses Mobil's EAL™ Arctic 22 CC, Tecumseh approves Castrol's SW-32, and Bristol favors ICI's RL32S. These compressor manufacturers are now working to qualify additional candidates. For the present work at AGMC, the selection of the polyol ester lubricant is keyed to the compressor manufacturer except for the R-23 applications as described in the paragraph which follows.

The polyol ester that appears to be the best choice for use with refrigerant R-23, regardless of the compressor manufacturer, is CPI's Solest® LT-32. Preliminary tests indicate that Solest® LT-32 can be used with R-23 in low temperature applications *without* the addition of a hydrocarbon (such as propane) that has traditionally been used with mineral oils. Another factor in the decision to select Solest® LT-32 for this project is that procurement regulations make it difficult for the Air Force maintenance staff to obtain propane for these uses. Table 1 summarizes the alternative refrigerants and lubricants applied to the retrofit of AGMC's test equipment.

Table 1. Alternative Refrigerants and Lubricants

CFC Refrigerant	HFC Refrigerant	Polyol Ester Lubricant
R-12	R-134a	Mobil EAL™ Arctic 22 CC (Copeland)
R-500		
R-502	R-404a (SUVA® HP62)	ICI Emkarate® RL-32S (Bristol)
		Castrol Icematic® SW-32 (Tecumseh)
R-503	R-23	CPI Solest® LT-32
R-13		

SYSTEM COMPONENTS

As previously mentioned, compressor manufacturers are beginning to market compressors and condensing units designed specifically for use with R-134a and R-404a. Compressors previously used for applications with R-13 and R-503 can be used with R-23 after the mineral oil is thoroughly removed and replaced with polyol ester oil.

Beyond the compressor and the heat exchangers, the other system components that must be considered include thermostatic expansion valves, capillary tubes, oil separators, suction accumulators, liquid receivers, solenoid valves, hot gas bypass valves, pressure relief valves, and filter-driers (Figure 1). Suppliers of these various components already have products on the market that are intended for use with the HFC alternative refrigerants listed in Table 1.

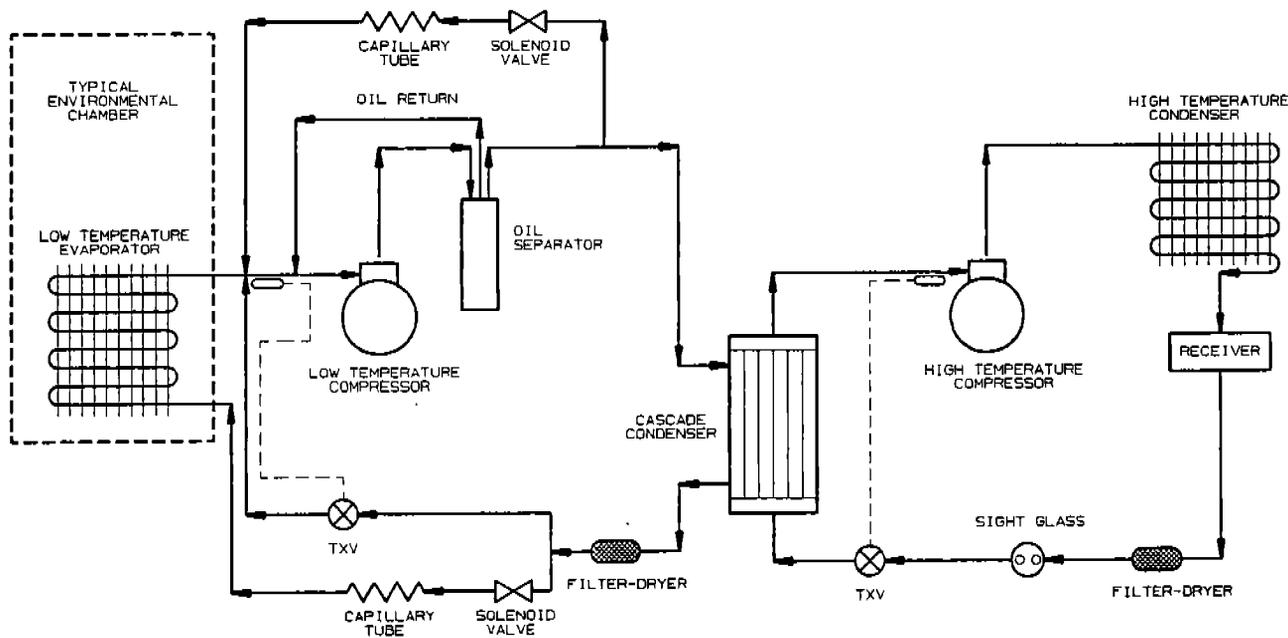


Figure 1. Typical Cascade Refrigeration Circuits

MATERIALS COMPATIBILITY

The most significant research work on materials compatibility regarding alternative refrigerants and lubricants is being done by a consortium called the Air Conditioning and Refrigeration Technology Institute (ARTI). Richard Ernst presented a summary of ARTI's work at the 1993 ASHRAE/NIST Refrigerants Conference that focused on R-22/R-502⁶. ARTI's scope includes three of the HFC alternative refrigerants listed in Table 1: R-134a, R-125, and R-143a (note that R-404a is a blend of R-125/143a/134a). The remaining alternative refrigerant, R-23, is not included. Refrigerant R-23 has been widely used in refrigerant systems for many years and is known to be comparatively benign from a materials compatibility standpoint.

A summary of the results of ARTI's work regarding compatibility of refrigerants and lubricants with motor materials appeared in a recent journal article⁷. The compatibility of elastomers with refrigerant/lubricant mixtures has also been reported⁸. Like their CFC predecessors, the selected HFC refrigerants and lubricants have little effect on the metals found in refrigerant systems (e.g., iron, steel, aluminum, and brass). The results of ARTI's work provides the primary basis for the position that the alternative refrigerants being retrofitted into AGMC's equipment are as compatible with the materials in the refrigeration systems as the original CFC refrigerants.

CONVERSION STEPS

Procurement of the new refrigerant, lubricant, and all replacement components should be completed prior to starting any conversion. One of the more important decisions is whether or not to replace an existing compressor (or condensing unit). The factors to consider are the age of the compressor relative to its expected life, the condition of the equipment prior to the conversion, the system reliability requirements, and the potential labor cost savings associated with changing out the compressor instead of flushing out the mineral oil using the procedures which follow. In general, nearly all of the hermetic and semi-hermetic compressors encountered thus far at AGMC have been replaced with new units, ones specifically designed for the new refrigerant wherever possible.

The conversion steps applied in this project are based on inputs from several sources^{9,10,11}. The major steps for converting each refrigerant circuit are as follows:

1. Recover the CFC refrigerants using EPA-approved equipment.
2. Change out the compressor (if appropriate) and other circuit components (such as relief valves or liquid receivers). Thoroughly drain the lubricant from the compressor, suction accumulator, and other potential collection points.
3. Install a fresh charge of polyol ester oil into the compressor. Replace the filter-drier. Evacuate the circuit to 250 microns maximum, and re-charge the system with the original CFC refrigerant (unless the CFC refrigerant quality had been compromised by a motor burn-out or other event).
4. Run the compressor for at least 4 hours (24 hours is preferable) to allow residual mineral oil to collect in the compressor's sump.
5. Recover the CFC refrigerants, thoroughly drain the oil, and test for residual mineral oil (using a test kit or a refractometer).
6. Repeat Steps 3 through 5 two more times to flush out the residual mineral oil so that there is no more than about 1 percent mineral oil in the circuits.
7. Pressurize the system to 150 psig (1.14 kPa absolute) with dry nitrogen and monitor pressure decay for at least one hour to test for leaks.
8. Evacuate the circuit to 400 microns static vacuum as a preliminary step. Release the vacuum and quickly change the filter-drier and install a fresh charge of polyol ester oil.
9. Evacuate the circuit to 150 microns static vacuum maximum and then charge the circuit with the HFC replacement refrigerant.
10. Operate the unit at steady-state conditions and adjust the refrigerant charges and the thermostatic expansion valves as required.
11. Change the placards to clearly indicate the new refrigerant and oil charges.

The above basic steps are modified as appropriate to suit each different type of test equipment.

STATUS SUMMARY

Prior to April 1, 1994, one sample of 17 different types of test equipment have been converted and functionally tested to validate the changes (Table 2). Included on this list are ten environmental chambers, two ultralow temperature freezer, two coolant recirculators, one specially-built temperature control unit, one vapor degreaser, and one refrigerant recovery system.

The post-conversion performance test results have been very encouraging. In most cases, the minimum set point temperature increased by a few degrees as a result of the conversion, but never beyond the functional requirements. For example, the minimum set point on one environmental chamber increased from -73 C (-99 F) to -71 C (-96 F) which still satisfies the -65 C (-85 F) requirement for this particular equipment type.

Table 2. Refrigerant Conversion Experience at Newark Air Force Base

Equipment Manufacturer	Part Number	Equipment Description	CFC Refrigerants	HFC Refrigerants	Minimum Temperature
Thermotron	WP-666	Environmental Chamber	R-502	R-404a	-30 F (-22 C)
Thermotron	S-32	Environmental Chamber	R-502/R-13	R-404a/R-23	-90 F (-68 C)
Thermotron	S-4	Environmental Chamber	R-502/R-13	R-404a/R-23	-100 F (-73 C)
Russells Technical Products	RB4-1-1	Environmental Chamber	R-502/R-13	R-404a/R-23	-100 F (-73C)
Standard Environmental Systems	TK/5	Environmental Chamber	R-502/R-503	R-404a/R-23	-96 F (-71 C)
Tenney	TTC	Environmental Chamber	R-502/R-503	R-404a/R-23	-100 F (-73 C)
Tenney	T5-100350	Environmental Chamber	R-502/R-503	R-404a/R-23	-100 F (-73 C)
Tenney	TJR	Environmental Chamber	R-12/R-503	R-134a/R-23	-112 F (-80 C)
BMA	TM-5CC	Environmental Chamber	R-502/R-503	R-404a/R-23	-98 F (-72 C)
Bemco	F100/350-8	Environmental Chamber	R-502/R-13	R-404a/R-23	-100 F (-73 C)
Revco	ULT390	Ultralow Temperature Freezer	R-500/R-503	R-134a/R-23	-123 F (-86 C)
So-Low Environmental Equipment	A13-120	Ultralow Temperature Freezer	R-502/R-13	R-404a/R-23	-105 F (-76 C)
Northrop	113050	Coolant Recirculator	R-12	R-134a	Not Applicable
Electro Impulse	30324	Temperature Control Unit	R-12	R-134a	Not Applicable
Neslab	CFT75	Coolant Recirculator	R-12	R-134a	Not Applicable
Branson	B250R	Vapor Degreaser	R-12	R-134a	Not Applicable
Redi/Controls	RRS-503/13	Refrigerant Recovery Unit	R-502	R-404a	Not Applicable

CONCLUSIONS

The primary conclusions drawn from the work consist of the following:

- Suitable HFC alternatives for CFC refrigerants are commercially available.
- The HFC alternative refrigerants are not "drop-in" replacements but the measured performance changes have been small. Replacing R-23 for R-503 creates the largest difference—the minimum operating temperature increases by about 12 F (7 C).
- Lubricant producers have developed polyol ester lubricants which appear to meet the system requirements in terms of miscibility, lubricity, and materials compatibility.
- Compressor manufacturers are developing a data base on many alternative refrigerant/lubricant combinations.
- Suitable filter-driers and other refrigerant system components are currently available.

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