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**INVESTIGATION OF FLUSHING AND CLEAN-OUT METHODS FOR
REFRIGERATION EQUIPMENT TO ENSURE SYSTEM COMPATIBILITY**

Final Report

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Executive Summary

Integral Sciences Incorporated has completed ARTI Contract No. 660-52502 assessing methods for removing contaminants from a refrigeration system. For systems being retrofitted from CFC-12 to HFC-134a, several environmentally acceptable mineral oil removal methods have been advanced. These methods may manifest considerable reduction in cost and waste from the current practice of three lubricant changes with polyolester.

Mineral oil removal techniques were tested on laboratory and field refrigeration equipment. System sizes varied from three ton, single evaporator models to a 30 ton, dual compressor system with seven evaporators. After each field retrofit, the mineral oil content in the system lubricant was less than five percent.

No laboratory or field tests were conducted to assess these techniques for burnout contaminant removal, as the techniques developed were applicable to mineral oil removal but not to cleaning per se. In addition, currently prevailing burnout service practice was determined to be effective and mature.

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Part 1: The State of the Art

Introduction

SECTION 608 of the Clean Air Act Amendments has altered much of the refrigeration service contracting industry. MCLR Project Number 660-52502 was established to examine two areas where the Amendments are influencing contractors to determine if more cost-effective service procedures might be developed.

One area where existing service procedures are being revisited involves the removal of contaminants from a refrigeration system after a motor burnout. At one time, a Class I substance such as CFC-11 or CFC-113 was used as a flushing agent for cleaning a system after a burnout. On large systems, the compressor was disassembled, and the parts were cleaned using 1,1,1-trichloroethane (TCA) or a TCA-containing mixture. Such alternatives are seldom possible today, as the manufacture of Class I substances was banned on January 1, 1996.

A second area of concern arises as a result of equipment retrofits from CFC-12 to HFC-134a; this new refrigerant is immiscible with the system's original lubricant. As a result, the mineral oil which was previously used in the system must be almost completely removed and replaced with a polyolester- or alkylbenzene-based synthetic lubricant. The current "triple flush" procedure for mineral oil removal is often time inefficient and costly; removal is accomplished by repeatedly changing the compressor oil with polyolester lubricant. The system must be operated for at least 24 hours between lubricant changes to allow migration of mineral oil from remote places in the system.

Refrigerant producers and equipment manufacturers have studied oil removal methods for HFC-134a retrofits for several years. Two perspectives have emerged from this work. The more conservative perspective looks for a method which consistently removes mineral oil for nearly all applications. The strengths of this conservative perspective include simplicity of the flushing procedure and high probability of success. The drawback is that at times more expense is incurred than necessary; in these cases it may be possible to reduce the labor, solvent, and waste disposal needs of the process.

Advice published by manufacturers and producers draws on this conservative perspective, because efforts to reduce retrofit costs may conflict with the primary need of safely retrofitting a refrigeration system. The equipment owner, system manufacturer, and compressor manufacturer risk losing the system if a retrofit fails; furthermore, manufacturers may be reluctant to honor warranties on systems which have been modified. The published literature therefore instructs that although multiple changes of lubricant with polyolester are usually appropriate, the system and compressor manufacturers should be consulted before attempting any retrofit.

The second perspective might be called a minimal element approach. It takes advantage of two facts. First, most systems tolerate a certain amount of residual mineral oil after being retrofitted; concentrations up to one percent by weight are generally considered acceptable by original equipment manufacturers. Some manufacturers allow as much as five percent mineral oil to remain in the new lubricant, and higher levels might be

workable in some applications. Second, the effort required to remove the required amount of mineral oil may be significantly less than three oil changes with polyolester. It may be possible to develop specific guidelines which identify mineral oil tolerant systems.

When evaluating the minimal element perspective, the primary consideration is miscibility of the remaining lubricant. At least three problems result from inadequate miscibility; the first is lack of oil return to the compressor. As mineral oil is carried through the evaporator by the refrigerant, it tends to separate from HFC-134a as a result of both the refrigerant's evaporation and reduced miscibility at low temperatures. This increases the lubricant's viscosity and prevents the mineral oil from returning to the compressor. Eventually the compressor could be left with insufficient lubricant.

A second problem is that the trapped oil interferes with both refrigerant flow and heat transfer through the tubing and reduces the capacity and efficiency of the refrigeration system. This causes the compressor to cycle more frequently than necessary. In addition to oil becoming trapped, wax deposits can be formed in low temperature portions of the system when miscibility with the refrigerant is poor.¹²

Third, the immiscibility of the HFC-134a and mineral oil at the compressor results in increased startup pressures. A compressor designed for the lower startup pressures of a CFC or HCFC, which has partially dissolved in mineral oil, may lack sufficient torque to start if HFC-134a is used with the same lubricant.¹⁷

All flushing methods contain elements of both the minimal element and conservative perspectives. The conservative approach increases a retrofit's cost but also promotes long term stability by reducing the risks incurred. The minimal element approach reduces short term costs, but it can result in large deferred expenses because of the risks incurred by the system.

Process Alternatives for Mineral Oil Removal

Information about current mineral oil removal practices for HFC-134a retrofits spans a wide range of sources. Although much retrofit literature is available, information addressing mineral oil removal in these articles is scant. Most of these references simply indicate that the mineral oil concentration in the polyolester lubricant must be reduced to no more than a few percent, and multiple compressor oil changes with polyolester will accomplish this if the system is run for several hours between changes. Residual mineral oil targets generally fall between 1 and 5 percent.

Further information proceeded from discussions with refrigerant producers, compressor and system manufacturers, and service contractors. All have studied the mineral oil removal problem to some extent, and several innovative approaches have emerged. Some of those interviewed are beginning to move away from the "triple flush" procedure.

The “Triple Flush” HFC-134a Retrofit Method

The “triple flush” method provides a straightforward and universally applicable mechanism for removing mineral oil from a refrigeration system—at the expense of potentially requiring more time and lubricant than absolutely needed. The mineral oil at the compressor (and perhaps oil separator) is drained and replaced with polyolester lubricant. This procedure is repeated several times with the system run between each lubricant change to remove the oil which has collected in points which cannot be drained.

From the service technician’s perspective, the “triple flush” method consists of:

1. Pump down the CFC-12 system. Refrigerant will be isolated on the high side.
2. Drain and measure the compressor lubricant. Add an equal amount of polyolester lubricant to the system. If the system has an oil separator, its lubricant should also be changed if possible. Some hermetic compressors may need to be drained through the suction stub. Note that some mineral oil will remain in other parts of the system after the lubricant is changed.
3. Operate the system with CFC-12 to allow the remaining mineral oil to be mixed with the polyolester. The compressor or system manufacturer should be consulted for guidelines on how long the system should be run. Typically the system is run for 24 hours.
4. Sample the compressor oil and measure the mineral oil content in the POE using a field test kit or an oil analysis service.
5. If the mineral oil level is not yet below the system manufacturer’s guidelines for HFC-134a retrofits, repeat steps 1 through 4. Three to four flushes may be required.
6. Recover the CFC-12 from the system.
7. Modify the system to operate using HFC-134a. This may require adjustments to the expansion valve, gear ratio, and (for centrifugal systems) impeller. Filter/driers should be changed in accordance with the system manufacturer’s recommendations for HFC-134a. Certain seals may also be incompatible with HFC-134a and should be replaced as specified by the compressor manufacturer.
8. Charge the system with HFC-134a and return it to service. The new refrigerant charge will be approximately 90% of the weight of the original CFC-12 charge.

Variations on the "Triple Flush" Method

A few variations of the "triple flush" oil removal procedure are in use which in some instances can reduce costs and labor.

Some contractors prefer to change the system over to HFC-134a prior to changing the lubricant. If the "triple flush" process is done using HFC-134a instead of CFC-12, additional mixing time may be required to return the mineral oil to the compressor. This eliminates the need to check the system for leaks after the "triple flush" process, because all leaks which might occur as a result of the retrofit are repaired before the lubricant is changed. It helps to check for and repair any leaks before the retrofit is started; in this way the contractor can ensure that the system can operate properly after the retrofit.

Another variation on "triple flush" has been employed by at least one contractor. Instead of using polyolester lubricant for all three flushes, alkylbenzene lubricant is used for the first two flushes. Alkylbenzene is considerably less expensive than polyolester, has suggested cleaning properties, and may be tolerated in the system at higher levels than mineral oil.

Problems Associated with "Triple Flush"

For smaller refrigeration systems such as supermarket display cases, the overall labor, materials, and disposal costs of the triple flush procedure are high¹, making mineral oil removal the most expensive portion of an HFC-134a retrofit. In many cases, the contractor must return to the site several times to pump down the system, sample and test the lubricant, and change the lubricant.

In addition to the labor charges incurred, considerable quantities of new polyolester lubricant must be provided at prices as high as \$35.00/gallon [\$9.00 / l], and an equal amount of CFC-contaminated waste lubricant must be disposed of. Many contractors contacted also appeared to be unfamiliar with the oil disposal regulations promulgated in 40 CFR 266 and 40 CFR 279.

The repeated interruptions to the refrigeration system to pump down the system and change the lubricant is also of concern to system owners and service contractors. If a supermarket display case cannot be kept cold enough during a retrofit, problems arise with food spoilage.

Advantages of "Triple Flush"

The "triple flush" process stands unchallenged in its simplicity and its applicability to a wide variety of systems. The overall efficiency of the mineral oil removal is known when the retrofit is completed because this procedure calls for sampling and testing the compressor oil.

¹ This is especially true when only one system at the site is being retrofitted.

Although the system must be repeatedly shut down during the retrofit, food can often be left in the display case because these shutdowns do not usually last a long time. Compatibility concerns for this means of mineral oil removal are minimized because no substances are added to the system which will not normally be present.

Flushing Mobile Air-Conditioning Systems with CFC-12

A survey of retrofit literature across the air-conditioning and refrigeration industry shows the "triple flush" method to be in nearly universal use. One exception was found, however, in mobile air-conditioning retrofit procedures.

At least one refrigerant producer recommends flushing the evaporator, condenser, and lines with liquid CFC-12. If the system has a thermal expansion valve, heat can be applied to fully open it. At that point the components can be flushed simultaneously; they do not require isolation. From the technician's standpoint, the procedure involves five essential steps:

1. Recover the original CFC-12 charge from the vehicle.
2. Draw a 29 inch vacuum on the air-conditioning system for 5 minutes.
3. Replace the compressor lubricant with polyolester.
4. Using a recovery/recycle device, push/pull liquid CFC-12 through the system for 30 minutes.
5. The CFC-12 used to flush the system can either be recycled for reuse as a flushing solvent or reclaimed for reuse as a refrigerant.

This mineral oil removal procedure is complete in less than one hour, uses materials and equipment already available to the service technician, and leaves all waste disposal considerations to a reclaimer. The obvious drawback of this approach is that a Class I substance is used in the process.

Terpene Flushing Solvents for Automobile Retrofits

At least one firm sells a zero ozone depleting fluid for flushing mobile air-conditioning systems. The composition of this fluid is protected as a trade secret, but the physical properties listed in Table 1 suggest a substance similar to β -pinene.

Table 1: Physical Properties of a Terpene Flushing Fluid

Appearance:	Clear liquid
Molecular weight:	138
Density:	0.851 at 25° C
Boiling point:	165° C
Flash point:	40° C
Vapor pressure:	2-3 mm Hg at 20° C

A liquid pump is used to circulate one gallon of solvent through the lines, evaporator, and condenser separately. The solvent, which does not readily evaporate, is then blown out of the system using a large amount of dry shop air.

The primary drawback of solvents of this nature is the amount of time and air required to remove the fluid from the system. Table 2 summarizes these needs as specified by the firm marketing the fluid.

Table 2: Time and Air Needs for Terpene Automotive Flush

	Flush time, minutes	Purge time, minutes	Total time, minutes	Purge air, cu. ft., at 90-120 PSI
Evaporator	10	30	40	600
Condenser	10	30	40	600
Lines	10	30	40	600
Total	30	90	120	1800

For an automotive system, this flushing fluid requires three times the amount of time required for flushing the system with CFC-12. Nearly 2000 cubic feet of dry compressed air must be supplied to remove the material. A special pump must be purchased by the technician. In addition, the fluid requires disposal in a chemical waste landfill or incinerator as a result of its lubricant contamination.

From a safety standpoint, the fluid is a volatile organic compound, can be harmful when inhaled, and is combustible. Although the pure substance is biodegradable and should not cause problems in a municipal water treatment system, the lubricant, wear metals, and other deposits mixed in during the flushing process require separate handling. The terpene can be recycled in a vacuum still or in solvent reclamation equipment, but service personnel may be hard pressed to find a vendor who offers this service at cost-effective rates.

Although preliminary indications show this solvent may be compatible with compressor materials at low levels without compromising lubricity, no data was found which addresses compatibility with engineering plastics, elastomers, and gasket materials.

Industry Comments on Small HFC-134a Retrofits

Mineral oil removal is by far the most expensive segment of HFC-134a retrofits for small systems, and the "triple flush" procedure is especially time inefficient and costly, particularly when only one system at a site is being retrofitted. On many systems, including the laboratory test system at ISI, four flushes are required. On such systems, the retrofit requires the contractor to come to the site five times.

The result is that contractors are uncomfortable with HFC-134a retrofits from a procedure and cost standpoint, especially for supermarket applications. Many contractors are simply choosing to retrofit with blends containing Class II substances which can tolerate high levels of residual mineral oil. Other contractors are advising equipment owners not to retrofit systems at all. As previously mentioned, contractors are often poorly informed regarding proper disposal practice for CFC-contaminated oil.

Refrigeration system owners are sensitive to downtime; food spoilage considerations make shorter interruptions preferable. Both system owners and contractors are interested in finding a procedure which can be completed in a single Sunday evening while the supermarket is closed, or during a similar time when store traffic is low. System owners are also concerned about potential for efficiency loss.

Industry Comments on Centrifugal System Retrofits

Retrofits for large centrifugal systems are proceeding well. From a time and materials perspective, the "triple flush" procedure is effective and efficient. While still a moderately expensive process, mineral oil removal is a considerably smaller fraction of the retrofit cost in large systems. Other costs such as new HFC-134a and system disassembly outweigh the mineral oil removal expense.

The use of a flushing solvent in place of the "triple flush" process is not suitable for centrifugal systems. A flooded evaporator is often employed in these systems; water-carrying tubes pass through a tank with several hundred pounds—or more—of evaporating refrigerant. Flushing this evaporator would require prohibitive amounts of solvent, resulting in emissions, shipping costs, solvent costs, and disposal costs that are expensive and unnecessary.

Because the compressor is disassembled during the retrofit, a proven, non-ozone depleting, standardized solvent would be useful for cleaning motor parts. At the present time Class I and Class II substances are frequently employed.

Process Alternatives for Servicing Burnouts

Procedures for servicing motor burnouts are more developed than procedures for removing mineral oil for HFC-134a retrofits. This is because motor burnout repairs have been a routine service practice for at least fifty years longer than HFC-134a retrofits have.

For small systems, procedures similar to the one in the ASHRAE refrigeration handbook have been in use for a long time.

Description of System Burnouts

When a motor burnout occurs in a refrigeration system, the resulting contaminants include water, acids, carbonaceous sludge, differing types of refrigerants, metal fragments, insulation material, and other burned material. These materials migrate into the refrigeration system before the compressor stops operating.

On small systems, most of the burnout materials are removed from the system by replacement of the compressor. Additional steps must be taken to remove the contaminants remaining elsewhere in the system; otherwise they will return to the new compressor and repeat burnout will occur.

Servicing any burnout involves two functions: repairing or replacing the defective compressor, and trapping burnout contaminants in filter/driers to prevent them from returning to the new compressor and causing repeat burnout. Burnouts are classified by the location of the resulting contaminants.

Mild Burnout Service

In a mild burnout, the contaminants are restricted to the compressor, condenser, liquid line filter/drier, and associated tubing. The burnout is serviced by replacing the compressor and liquid line filter/drier. If the system does not have a liquid line filter/drier, one is added. The new filter/drier is oversized to accommodate the high level of contamination without unduly restricting refrigerant flow.

Because the new drier is downstream of all burnout contaminants, little migration can occur past the filter/drier back to the compressor; potential for repeat burnout is thus diminished. Over time, the contaminants in the condenser and tubing tend to be trapped in the liquid line filter/drier.

Severe Burnout Service

In a severe burnout, the contaminants have migrated beyond the liquid line filter/drier and toward the expansion valve, evaporator, and suction side of the compressor. In addition to replacing the compressor and replacing (or adding) the liquid line filter/drier, contaminants downstream of the filter/drier must be trapped before returning to the compressor. This is accomplished by adding an oversized suction line filter/drier immediately preceding the new compressor.

Large System Burnout Practice

Although the above principles apply when servicing burnouts on large centrifugal refrigeration systems, the task tends to be more complex. In many cases, disassembly and repair of the compressor is more affordable than replacement.

For burnouts on large systems, the compressor is either disassembled and cleaned or replaced. Individual motor components are cleaned or replaced as necessary. Parts are generally cleaned by either immersion in a cleaning solvent or wiping with a cloth. The refrigerant is recycled before it is returned to the system.

As with compressor service for large system retrofits, a need exists to examine solvents used for cleaning motor parts. Most of the fluids in use today for this purpose are being phased out under the terms of the Montreal Protocol.

Industry Comments on Burnouts

The current ASHRAE handbook procedure for servicing motor burnout is generally effective for small systems. Although no significant procedural changes are anticipated for large systems, a long term environmentally safe alternative refrigerant is needed for cleaning compressor parts. Concern about a replacement solvent in the industry is high, and compressor and system manufacturer studies have not yet recommended an alternative fluid. A solvent may also be helpful for flushing small systems in some cases.

Solvents for System Flushing

Requirements of Flushing Solvents

The two flushing fluids already discussed for automotive air-conditioning use have immediately evident drawbacks; CFC-12 is a Class I substance, and the terpene product is particularly difficult to remove from the system after use. The refrigeration industry has placed considerable emphasis on the search for an alternative solvent for flushing systems. The direct guidelines provided by ARTI for this contract call for:

1. Low cost.
2. Low toxicity.
3. Low flammability.
4. Zero ozone depletion potential.
5. Low waste.
6. Compatibility with system materials.

A similar set of requirements emerged from discussions with the refrigeration industry:

1. Must be compatible with system materials.
2. For retrofits, must cost less than the POE "triple flush".
3. Flammable solvents are unacceptable.
4. The procedure must demonstrate effectiveness and time efficiency.
5. The procedure must work in the vast majority of cases.
6. For supermarkets, downtime must be minimized to avoid food spoilage.
7. The solvent must be miscible with mineral oil.

Work performed at Integral Sciences Incorporated has identified additional parameters needed when screening flushing solvents. First, a low boiling point is required to allow the solvent to be removed from the system. Experiments at ISI indicate that boiling points above 50° F [10° C] will not be time or cost effective in flushing applications. Additional evaporation rate data appear on pages 53-55. All known commercially available cleaning solvents fail one or more of the ARTI requirements or this boiling point criteria.

An additional 119 organic compounds were examined with boiling points under 50° F [10° C], and each failed at least one of the ARTI and industry criteria.

Potential Methods of Solvent Removal

Few methods are available for removing liquid phase solvent from dead spots in a refrigeration system. The following methods were eliminated from consideration.

Mechanical methods such as wiping and isolated component cleaning were rejected for accessibility, time, and cost considerations. Removing the solvent by flushing with a second solvent with a lower boiling point was also rejected. The second solvent adds time, cost, and waste to the process without substantive gains. If this second solvent were miscible with mineral oil, it would be chosen as the primary solvent. If it were not miscible, removal of the primary solvent mixed with mineral oil may be in question anyway.

The only feasible means identified for removing a flushing liquid from the refrigeration system is to evaporate the fluid. The resulting vapor can be removed from the system either by using a vacuum pump or by blowing the vapor out of the system with dry nitrogen. All solvents examined by ISI require more time to remove from the system than to flush the mineral oil out of the system. For this reason, the time required for the solvent to evaporate has more influence on the cost of a small system retrofit than any other factor. For additional data on the evaporation rates of specific classes of solvents, refer to pages 53-55.

Sources of Solvent Candidates

Several sources were consulted during the search for candidate solvents which meet the requirements for refrigeration system flushing fluids. A list of organic compounds indexed by boiling point presented no previously unconsidered materials with boiling points below 50° F [10° C]. Substances referenced in either the EPA's Solvent Alternatives Guide (SAGE) or EPA's Significant New Alternatives Policy (SNAP) rulings were considered and are discussed in detail below.

Refrigerants as Solvents

The requirements for a refrigeration system flushing fluid are substantially the same as those desired in new refrigerants—low boiling point, zero ozone depletion potential, compatibility with system materials, minimal combustibility, low toxicity, and (ideally) miscibility with mineral oil. For this reason, replacement refrigerants and halons were screened as solvent candidates.

Two refrigerants emerged as leading candidates. Iodotrifluoromethane, a substance not available at affordable prices for this application, appears to show no ozone depletion potential, good miscibility with mineral oil, no flammability, and a boiling point of -8.5° F [-22.5° C]. The problems with iodotrifluoromethane are that toxicity studies are not yet complete, further compatibility testing is needed, prices are currently too high, and future availability will depend on the compound's acceptance in other applications for fire extinguishing, cleaning, refrigeration, and air-conditioning.

A more probable refrigerant, HCFC-22, will remain widely available during the phaseout of CFC-12, is inexpensive, and meets every requirement except zero ozone depletion potential. The repercussions of HCFC-22's ozone depletion potential when used as a system flushing solvent are discussed on page 26. Because the amount of HCFC-22 remaining in the system after flushing is small, compatibility concerns are diminished.

The use of HFC-134a with a surfactant as a flushing solvent was considered but is not incorporated in this proposal; removal and materials compatibility concerns would be greater with this approach than with any other method advanced by ISI. Industry should continue to evaluate potential surfactant applications in refrigeration, however. Imagination Resources, Inc., of Columbus, Ohio, has developed an additive which may allow the use of mineral oil in HFC-134a applications. This additive is being evaluated by the US EPA for mobile air-conditioning system retrofits⁸.

EPA's Solvent Alternatives Guide (SAGE)

The US EPA publishes a computer program called Solvent Alternatives Guide (SAGE) as an informative tool for suggesting alternatives to part cleaning with chlorinated solvents. The program asks a series of questions about the part to be cleaned and recommends process and chemical alternatives for the task.

The chemical alternatives that can be identified by SAGE are listed in Table 3. As the table indicates, SAGE manifests a high tolerance for aqueous and flammable substances; these materials are not acceptable to the refrigeration industry. Acceptable solvents that are not flammable are aqueous, semi-aqueous, high pressure (supercritical fluids), have high boiling points, or demand ultrasound, high pressure spraying, or other mechanical separation devices which would preclude their use for this application.

**Table 3: Chemical Alternatives
Identified by SAGE**

Water
Neutral aqueous solutions
Alkaline aqueous solutions
Acidic aqueous solutions
Semi-aqueous solutions
Aqueous chemistry additives*
Acetone
Terpenes
Dibasic esters
Glycol ethers
Alcohols
Petroleum distillates
Ethyl lactate
N-methyl pyrrolidone
*Surfactants, builders, etc.

The process alternatives that can be suggested by SAGE are listed in Table 4. As SAGE's thrust is primarily toward cleaning parts prior to assembly, all of these alternatives presume accessibility which is not offered in a refrigeration system. In addition, most of these process alternatives are unfamiliar to service contractors and would require large expenditures in new equipment.

Table 4: Process Alternatives Identified by SAGE

Low pressure sprays	Steam
High pressure sprays	CO ₂ snow
Power washers	CO ₂ pellets
Immersion cleaning	Plasma cleaning
Ultrasonics	Laser ablation
Megasonics	UV/ozone cleaning
Brushing	Supercritical CO ₂
Wiping	Xenon flash lamp
Abrasives	Hot alkaline immersion
Heat stripping	Molten salt baths
No cleaning	Abrasive blasting

EPA's Significant New Alternatives Policy (SNAP)

Replacements for chlorinated refrigerants, halons, solvents, foam blowing agents, and miscellaneous substances are screened and regulated under the US EPA's Significant New Alternatives Policy (SNAP). Preliminary decisions on candidate replacements for ozone depleting substances were published in the Federal Register on May 12, 1993; the EPA has issued several revisions since that date.

Table 5: SNAP Acceptable Solvents

Aqueous solutions
Semi-aqueous solutions
Terpenes
Alcohols
Trichloroethylene
Perchloroethylene
Perfluorocarbons*
Ethers
Esters
Methylene chloride
Hydrocarbons
Vanishing oils
Volatile methyl siloxanes
Trans-1,2-dichloroethylene
HCFC 123

*in limited use applications

The cleaning solvents which the EPA has proposed as acceptable under SNAP are listed in Table 5. Like the SAGE solvents, the SNAP decisions also have a high tolerance for flammable solvents. The remaining solvents are aqueous, semi-aqueous, or have boiling points higher 300° F [149° C], or are halogenated hydrocarbons of suspected short-term use.

Any solvent selected for clean-out and flushing of refrigeration systems will require an "acceptable" ruling from SNAP before it can be generally used. The review process takes at least 90 days.

Verbal communications between ISI and the US EPA have brought favorable review for using either Class II substances or HFCs as flushing solvents provided the process is used in closed-loop applications and does not result in venting any fluid.

Commercial Metal Cleaning Solvents

Producers of metal cleaning solvents were contacted to determine if any commercially available product might meet the requirements for a system flushing fluid. A summary of commercial products appears in Table 6. While it is hoped that this list represents the general types of metal cleaning solvents on the market today, it may not be exhaustive.

None of the commercial products mentioned meet the full set of criteria needed. The products offered are either flammable, aqueous, have high boiling points, or (in the case of supercritical CO₂) have working pressures that are too high.

Table 6: Commercially Available Metal Cleaning Solvents

Aliphatic hydrocarbons C ₁₀ - C ₁₃ + diisobutyl ester
Aliphatic hydrocarbons C ₁₀ - C ₁₃ + ethylene glycol ether
Aliphatic hydrocarbons C ₁₀ - C ₁₃ + propylene glycol ether
Aqueous + hydrocarbon emulsion
Aqueous + surfactant
Aromatic hydrocarbons
β-Pinene
C ₃ - C ₈ hydrocarbons
d-Limonene
Dipropylene glycol methyl ether
Ethyl lactate
HCFC-141b
HCFC-141b + CO ₂
HCFC-141b + methanol
HCFC-141b + perchloroethylene
Ketones
Low molecular weight alcohols
Methylene chloride
Mineral spirits
Mixed aliphatic esters
Mixed aliphatic hydrocarbons (highly paraffinic available)
Naptha
Perchloroethylene
Perfluorocarbons
Sulfur hexafluoride
Supercritical CO ₂
Trichloroethylene

Solvents for Motor Parts Cleaning

The Need for Solvents for Cleaning Disassembled Motor Parts

The high cost of large centrifugal equipment necessitates occasional compressor disassembly for retrofit or repair. Motor parts have historically been cleaned using chlorinated solvents. Some contractors still use CFC-11, CFC-113, or trichloroethane. Another solvent in common use contains trichloroethane, trichloroethylene, naptha, and mineral spirits.

Of these cleaning fluids, trichloroethane, CFC-11, and CFC-113 are no longer domestically produced. In addition users of trichloroethylene and perchloroethylene must

meet stringent Clean Air Act requirements, and the EPA may eventually place further restrictions on these compounds.

Contractors require guidance from the refrigeration industry if they are to replace these disappearing cleaners with effective substitutes. Without this assistance, the balance of system reliability, technician safety, and compatibility with the system and the environment are likely to be compromised.

Requirements of Motor Part Cleaning Solvents

While the requirements of motor cleaning fluids are similar to those for system flushing fluids, the relative priorities of the requirements differ. Because the solvent is vented during cleaning and drying, no tolerance of ozone depletion potential is permissible.

Although a moderately low boiling point is desirable to assure good evaporation rates of the solvent after cleaning, this boiling point must be high enough to allow convenient, economical, and safe cleaning at atmospheric pressure. Furthermore, solvents with especially low boiling points would be prone to self-cooling, which tends to reduce cleaning effectiveness. The motor parts are typically immersed by the technician, wiped off, and allowed to air dry.

For metal parts cleaning, solvents with boiling points in excess of 300° F [149° C] will be needed to achieve a flash point above 100° F [38° C]. Flash points above 140° F [60° C] reduce handling complexities imposed by the Department of Transportation. To achieve this, however, boiling points in excess of 300° F [149° C] are necessary.

Toxicity considerations are of particular importance in choosing a solvent because service personnel will be exposed to small quantities during use. Skin contact and vapor inhalation concerns must be addressed first by choosing a substance which meets OSHA and other regulatory requirements and second through use of proper ventilation, eye protection, clothing, and handling procedures.

Compatibility testing is needed to assure that the cleaning solvent does not damage the refrigeration system either during or after cleaning. The compatibility requirements for cleaning solvents may be less stringent than those for flushing fluids because the motor is disassembled for cleaning, and residual solvent removal is straightforward.

The strength of the solvent also requires balance; an ideal cleaning fluid would be strong enough to remove all contaminants without dissolving motor materials. Solvency strength may be rated by a fluid's Kauri-Butanol (K-B) number (trichloroethane = 137). While a higher K-B number raises compatibility concerns, a lower value reduces the effectiveness of soil, deposit, and other contaminant removal.

Products Meeting ARTI and Industry Criteria

Solvents which are currently available to the industry are listed in Table 6. The choice of a solvent for a particular field application will rely on complete compatibility studies of each

offering. Table 7 lists commercially available solvents meeting each of ARTI's requirements except this compatibility requirement.

It should be noted that current ASHRAE Refrigeration Handbook guidelines do allow the use of mineral spirits (with boiling points between 300° F and 380° F) as well as naptha in air-conditioning and refrigeration applications. Some solvents which are presently in use contain substantial portions of mineral spirits which may have high aromatic content.

While aliphatic hydrocarbons are likely to threaten system elastomers, highly paraffinnic C₁₀ - C₁₃ hydrocarbon base solvents may reduce these concerns while maintaining low cost and low flammability. The addition of glycol ethers, dibasic esters, terpenes, alcohols, and the like to these solvents with lower Kauri-Butanol values will enhance solvent activity, although this same addition will increase compatibility concerns. To balance these considerations, Integral Sciences Incorporated suggests the addition of these polar constituents at 10% levels as a starting point for the identification of a solvent for motor parts cleaning.

Table 7: SAGE / SNAP / Commercial Products with Potential Use for Cleaning Motor Parts

Aliphatic hydrocarbons / DBE*
Aliphatic hydrocarbons / low molecular weight alcohols*
Aliphatic hydrocarbons / propylene glycol ether*
β-Pinene
d-Limonene
Highly paraffinnic aliphatic hydrocarbons
Mineral spirits
Mixed aliphatic esters
Naptha
Octyl acetate
*usually 90% / 10%

ISI did not test any of these materials during this contract, which focused on flushing fluids and techniques for retrofits and motor burnouts. At the same time, this project suggested a need for methods and cleaning agents for motor parts cleaning which ARTI may elect to pursue at a future date.

Part 2: Consideration of Advanced Methods

HFC-134a Flush with Polyolester "Cosolvent"

Benefits and Drawbacks of HFC-134a as a Flushing Solvent

As a flushing solvent, HFC-134a is one of the most benign possible. Not flammable in air at atmospheric pressure and in ASHRAE safety group A1, HFC-134a poses few safety risks to experienced service personnel. The refrigerant has an atmospheric lifetime of 15 years and does not cause damage to the ozone layer. Although this solvent does not necessarily require removal from the system, it is easy to remove. HFC-134a is also inexpensive, available to the contractor, and easily reclaimed for future use.

These advantages are offset by the fact that HFC-134a is virtually immiscible with mineral oil. Two phases can be observed at room temperature once the mineral oil level rises to approximately 0.25%. In addition, laboratory system experiments at ISI show that when HFC-134a is used alone as a flushing solvent, the mineral oil level is approximately 0.25% in the HFC-134a leaving the system.

From these results, one can infer that at least 400 pounds of HFC-134a would be required to remove one pound of mineral oil from the system. For this reason, HFC-134a was ruled out as a pure flushing solvent.

The use of a recovery/recycle device in a loop to clean and reuse the refrigerant during an HFC-134a flush was also rejected. Most recovery/recycle devices available to service technicians cannot process more than two pounds of refrigerant per minute, and there may be several hundred pounds or more to process.

Alternative techniques were sought which would allow inexpensive and rapid removal of mineral oil from liquid HFC-134a. Processes considered included the use of alumina driers for oil absorption, oil imbiber beads, and low temperature phase separation of the refrigerant and oil. No promising methods emerged from this list. ISI's approach to HFC-134a flushing, therefore, moved toward searching for methods which allow for the immiscibility of mineral oil with this refrigerant.

Effect of Polyolester on Mineral Oil Miscibility with HFC-134a

Recent studies at Dupont¹⁰ confirm that adding polyolester to HFC-134a does not significantly improve the fluid's miscibility with mineral oil. Without the refrigerant present, however, polyolester and mineral oil are fully miscible. Although clean polyolester lubricant might be an effective flushing material which does not require complete removal, the high cost of polyolester prohibits its use as a flushing agent.

The use of polyolester as a "cosolvent" with HFC-134a for mineral oil removal was considered for two reasons. First, mineral oil miscibility with HFC-134a does increase slightly in the presence of polyolester. Second, indications from the field are that the polyolester and HFC-134a may have a "fronting" effect on mineral oil. A contractor's

observation of "double" the amount of lubricant at the compressor after replacing the lubricant with polyolester and running for two hours suggests migration beyond that possible by miscibility with the refrigerant alone. This "fronting" effect may also contribute to mineral oil removal in the "triple flush" process.

Areas of Concern

The suggested procedure contradicts the current understanding that residual mineral oil does not circulate adequately after a "drop in" retrofit with HFC-134a and POE. Had this method worked, this same "fronting" effect would also preclude the need for mineral oil removal in the first place.

At the same time, the contractor's observation of the extra lubricant appearing at the compressor early in "triple flush" retrofits suggests an important and useful phenomenon. As Part 4 of this paper shows, ISI was able to reproduce this behavior in both laboratory and field refrigeration systems. Furthermore, these observations contributed significantly to the method which was ultimately considered.

Other concerns supported a decision against testing an HFC-134a / polyolester flush. Because the refrigeration system must be liquid-filled with HFC-134a, more refrigerant would be needed than a contractor normally brings to the site. Approximately three times this amount would be needed for the flushing procedure alone.

It may be possible to use a less expensive (not refrigeration grade) polyolester lubricant for this flushing procedure. Although this might save the contractor money, compatibility concerns increase due to the lubricant which remains behind after the retrofit's completion. In addition, a contractor who is encouraged to use a lower grade polyolester in a system flushing process might be tempted to use the lower grade as a refrigeration system lubricant or become confused about the types of lubricant available.

Alkylbenzene Lubricant in the Triple Flush Process

Effect of Polyolester on Alkylbenzene Miscibility with HFC-134a

As with mineral oil, alkylbenzene lubricant is virtually insoluble in HFC-134a. For this reason, it is not an appropriate primary lubricant for HFC-134a retrofits.

The tolerance for alkylbenzene in a system increases significantly, however, in a system containing polyolester lubricant with HFC-134a. Recent studies show that even at 2° F [-17° C], HFC-134a and lubricant exhibit miscibility when 25% of the lubricant is alkylbenzene by weight.^{9, 10} Studies with 2.5% alkylbenzene and 7.5% polyolester in HFC-134a show full miscibility at 2° F [-17° C].

Cost and Cleaning Benefits of Alkylbenzene Lubricant

This method was not intended to displace the "triple flush" process currently in use, or to reduce the amount of waste generated by "triple flush". It was instead considered as an alternative to using polyolester in the first one or two flushes of the system.

Alkylbenzene is considerably less expensive than polyolester. In larger systems, the resultant cost savings may be attractive. Suggested cleaning properties of alkylbenzene may give added benefit.

Areas of Concern

ISI did not elect to test this method, because stronger candidate procedures were eventually developed. Although lubricant costs are less using this method, the labor requirement and waste disposal needs are not reduced.

Field test kits which determine the mineral oil level in a lubricant blend become unreliable when more than 2 lubricants are mixed. These kits generally measure a single property of the lubricant, such as its refractive index, and use linear interpolation from measurements of pure lubricants to determine the blend composition. As a three-lubricant blend has 2 degrees of freedom in its composition, little can be determined by taking a single measurement.

HCFC-22 Flush

Stratospheric Ozone Depletion and HCFC-22 as a Flushing Solvent

HCFC-22, a Class II substance, has many advantages similar to those offered by HFC-134a. In addition to these, it is fully miscible with mineral oil at temperatures of interest and provides an effective flushing procedure which takes about two hours on ISI's laboratory system.

In a few decades, HCFC-22 will be an entirely unavailable option for system flushing as a result of the Montreal Protocol. In the United States, there is already an excise tax on HCFC-22. This refrigerant's availability, however, will survive longer than CFC-12's. As a result, contractors retrofitting refrigeration systems from CFC-12 or R-500 to HFC-134a will probably be able to obtain HCFC-22 at reasonable prices.

As HCFC-22 is an ozone depleting substance, it would not be advanced as a flushing fluid for retrofits if an equally effective, non-ozone depleting fluid were available. This unfortunately is not the case. Noncombustible in air at atmospheric pressure, inexpensive, reusable, miscible in mineral oil, familiar to refrigeration contractors, in ASHRAE safety group A1, benign to system components, and easily removed from a system after use, HCFC-22 had to be considered as a refrigeration system flushing fluid for HFC-134a retrofits.

It is difficult to determine the ozone depletion implications of flushing systems with HCFC-22. At first glance, the "triple flush" procedure might appear to be more ecologically sound. This probably is not the case, because the mineral oil drained from a CFC-12 system is contaminated with refrigerant, and subsequent emissions are unavoidable. The ozone depletion potential of HCFC-22 is just one-eighteenth of that of CFC-12. This is supported by the regulatory climate in the United States, where HCFC-22 is viewed as a low-cost, low-ODP transition fluid away from Class I substances.

Areas of Concern

Because less objectionable candidate techniques were available, ISI did not test this method in the field. Notwithstanding, this method was used successfully in several experiments on ISI's laboratory system; in fact, it became the method of choice for removing all lubricant from the system between tests. The process typically required 120 pounds of refrigerant and two hours. Most of this time was used to recover residual HCFC-22 after the flush was complete.

A primary drawback of this method is that a third refrigerant (HCFC-22) must be brought to the site as a flushing solvent. This refrigerant would require the use of a recovery/recycle device and separate storage cylinders. Because the system must be liquid filled with HCFC-22, several times more refrigerant is needed than a normal charge system charge holds. The risk of cross-contamination as well as system compatibility problems may also increase if this fluid is selected.

In addition to these concerns, many organizations have already started distancing themselves from using or recommending Class II substances. Furthermore, HCFC-22 will go out of production in developed countries by the year 2029 under the terms of the Montreal Protocol.

Low Side Oil Separation and Removal

Impact of "Triple Flush" on Compressor Oil Level

Some participants interviewed by ISI reported a rapid rise in compressor oil level when using the "triple flush" retrofit procedure. This rise occurs when the system is started after the first lubricant change.

Although no detailed studies of this phenomenon were found, it appeared that mineral oil sometimes returns to the compressor rapidly when the "triple flush" procedure is used. It was wondered if this accelerated return might result in an effective flushing procedure.

Lubricant Mixing in the "Triple Flush" Procedure

If, after the first lubricant change during a retrofit, the lubricant returning from the evaporator to the compressor initially has a high concentration of mineral oil (more than 50%) and this concentration remains high until most of the mineral oil returns to the compressor crankcase, an opportunity exists to conveniently remove this lubricant. The

"triple flush" method does not take advantage of this uneven lubricant circulation; instead, the mineral oil returns to the compressor and mixes with new polyolester lubricant.

To prevent the mineral oil from returning to the compressor and contaminating the new polyolester, a suction separator can be installed on the compressor suction line to remove the mineral oil from the system. By draining this separator at suitable intervals, most of the mineral oil can be removed at relatively high concentrations. This reduces the amount of polyolester which would be discarded as a result of contamination with mineral oil.

Flushing Procedure Overview

The flushing procedure as it was originally tested required two oil separators and no more than two site visits. First, the refrigeration system was pumped down for service. A suction line oil separator was installed to separate the mineral oil from the cold refrigerant vapor. This lubricant was drained to a point outside the system as the refrigerant proceeded to the compressor. Prior to starting the system, the compressor lubricant was replaced with polyolester.

The polyolester level at the compressor was protected by the installation of a discharge separator in conjunction with a commercially available oil control system. This after-market mechanical device, when added to the compressor, was to monitor the compressor's lubricant level. When the oil level dropped below a preset level, a valve opens and polyolester returns from the discharge separator to the compressor. The valve closes when the oil level was sufficiently high.

The system was operated with CFC-12 and polyolester lubricant until the mineral oil content of the system was sufficiently low. As the "triple flush" procedure appeared to fully mix a system's lubricant over 24 hours, it was suspected that the mineral oil and polyolester might be kept essentially separate by running the system for a shorter time. The CFC-12 was then recovered and the suction line oil separator was removed. The discharge separator and oil control system were removed after these tests; however, they could have been left in the system as an addition if desired.

Advantages of the Procedure

This method presented several procedural advantages. First, no new compounds would be added to the system. This would minimize compatibility concerns and keep the waste stream as chemically simple as possible. The waste would also contain little excess lubricant.

Parts for this method were expected to be inexpensive, easy to install, and reusable. In addition, the system's run time would not exceed that required for a single flush of the "triple flush" method.

Modern oil separators can remove almost all lubricant that is present in refrigerant vapor. For some models, less than 0.007% of the fluid which passes through the separator is

lubricant. It was assumed that in systems with refrigerant vapor speeds of 5 pounds per minute, less than 0.5 pounds of polyolester would be lost over 24 hours.

Areas of Concern

The systems retrofitted in the course of this study circulate refrigerant at rates ranging from 65 to 400 pounds per minute. Even with 99.993% separator effectiveness, a technician must be present to add polyolester to the system during prolonged runs. This problem was addressed by procedural improvements further on in the study.

Another concern with this technique was that it provides no means of determining when the mineral oil has been completely removed. Although refractive index measurements were considered, there was no point in the system where a truly representative sample could be drawn during the procedure. As with the flushing methods in use today, a minimum of 24 hours of system operation would be needed after the procedure before the residual mineral oil concentration can be assessed.

Cleaning with the Original CFC-12 Charge

CFC-12 as a Flushing Solvent

Like HCFC-22, CFC-12 is an effective fluid for flushing refrigeration systems; clean CFC-12 can remove almost all of the mineral oil from many refrigeration systems in the space of a few minutes. In addition to its effectiveness, this fluid boasts no flammability, low toxicity, good compatibility with motor materials, easy removal, and established disposal procedures. Price, ozone depletion potential, and availability concerns, however, necessitate a method which requires only the CFC-12 existing in the system.

At first, this appears to be a challenge. One problem is that the CFC-12 in the system is already contaminated with mineral oil; in some systems the level can be 20% or more. Another problem is the size of the CFC-12 charge—it's large enough to liquid fill the high side of the system, but not the low side which uses larger tubing. Even if enough refrigerant were available to liquid fill the low side separately, it's still quicker and easier to flush all components simultaneously.

The solution to this apparent shortage is that both liquid and vapor refrigerant are effective at removing mineral oil from the system. Liquid phase CFC-12 is commonly used to flush mobile systems. For stationary equipment, the "triple flush" process provides a cold vapor degreasing mechanism in the evaporator, and the mineral oil is advanced by the moving vapor over a 24 hour period.

Flushing Procedure Overview

This procedure requires connection of a recovery/recycle device in place of the system's compressor. Some refrigeration systems have usable high and low side service valves to connect the recovery/recycle unit, and if a service valve is available to close either the suction or discharge line to the compressor, it may not be necessary to remove the

CFC-12 from the system while these connections are being made. Otherwise the refrigerant must be removed briefly while appropriate valves are installed.

The system's thermal expansion valve or capillary tube is bypassed during this procedure; this saves time in two ways. First, refrigerant flow through the system is faster without this restriction. Second, a phase change in the evaporator is undesirable; oil migration toward the recovery/recycle device would be greatly reduced if the mineral oil's viscosity increased as a result of a cold evaporator.

The recovery/recycle device must be capable of transferring either liquid or vapor phase refrigerant while removing oil in the process. Devices which are fitted with a thermal expansion valve before the compressor may work properly without special attention. Devices with no expansion valve must be throttled manually with a valve and pressure gauge in the suction line. Caution must be taken to prevent liquid refrigerant from entering the compressor of the recovery/recycle unit.

The recovery/recycle device is then turned on, circulating refrigerant through the system in the customary direction; i.e., high side to low side. The fans on the system being serviced should be off during this procedure. Two events then happen. First, the refrigerant is cleaned; this may spare recycling efforts later. Second, the circulating refrigerant causes the mineral oil in the system to migrate to the recovery/recycle device and be removed. It is important to drain the recovery/recycle device's oil separator regularly during this procedure.

Once it becomes evident that the circulating refrigerant is clean and oil is no longer collecting in the recovery/recycle device, the device is used to recover the CFC-12 from the system, and the procedure is complete. The switch from flushing to recovery can be made without breaking a connection or shutting the recovery/recycle device off if the connections are thought out carefully in advance.

Areas of Concern

Although this method might provide adequate mineral oil removal in a one or two hour period, the time depends partially on evaporator temperature. Evaporators located in refrigerated display cases may require a long time to warm up. Disabling the condenser fan on the recovery/recycle device would help by raising the refrigerant's temperature and reduce the time required; however, the fan will need to be restarted in order to recover the refrigerant.

Because the evaporator is heated during this procedure, refrigerated products must be relocated during the retrofit. This is a serious concern for many installations, and in the end ISI did not pursue field testing of this technique.

Part 3: Laboratory Retrofit Tests

Laboratory and Field Testing Methodology

EACH of the proposed methods underwent preliminary testing using ISI's laboratory refrigeration system during Part I of this contract. These informal tests were used both to screen the candidate methods and to familiarize ISI personnel with some of the practical issues surrounding system flushing. For all but the low side oil separation approach, the proposed methods can be completed in approximately 2 hours on the ISI system. The technician was directly involved for about half of this time.

No methods were proposed which introduce primary solvents with boiling points higher than 0° F [-18° C]. This ensured that methods did not emerge with prohibitive time requirements for solvent removal.

To verify this position, ISI's refrigeration system was flushed with CFC-113. Although this fluid's 118° F [48° C] boiling point is moderately high, it is still far below the high boiling points required by many of the hydrocarbon and terpene alternatives. Most of the liquid phase CFC-113 was recovered by purging the system with air. Following this, the vapor was removed with a high speed recovery device incorporating a vacuum pump. This unit had been tested and certified to meet the applicable final recovery vacuum level prescribed by the US EPA. Even selecting a unit with recovery rates well in excess of that used by most contractors, several hours were added to the flushing procedure as a result of using CFC-113.

Most of the proposed methods stayed within a conservative approach to flushing. None of the advanced methods required the introduction of unusual compounds to the system being serviced or retrofitted. No methods required the contractor to obtain specialized or non-HVAC related equipment. Finally, none of the procedures relied on technology that had yet to be demonstrated or commercialized.

The Need for Laboratory System Testing

At the conclusion of ISI's literature search and proposal of advanced methods for testing, no methods were ready for evaluation on an operating refrigeration system that could not tolerate extended outages. In contrast, the laboratory system at Integral Sciences Incorporated had no schedule or usage constraints. Prior to asking an equipment owner to share facilities for field testing, the proposed method required full laboratory evaluation.

At ARTI's request, testing was only conducted on the low side oil separation technique.

It was not feasible to obtain access to an actual burnout of a field system for enough time to fully develop procedures for removing burnout contaminants. Similarly, no reasonable system owner would have allowed deliberate introduction of burnout materials to their systems. For this reason the initial plan was to use ISI's laboratory refrigeration system for burnout simulations with mock contaminants.

Once the low side oil separation approach was selected as the only method to be tested, the burnout test plan was abandoned. As this method provides for mineral oil removal but not for cleaning per se, the method's effectiveness in servicing burnouts was not investigated. Part I research also found that existing practices for handling burnouts are both mature and effective.

Description of ISI Laboratory System

Integral Sciences Incorporated has installed at its engineering facility a 3 ton refrigeration system which is characteristic of a supermarket display case.

A single 3 horsepower bolted hermetic reciprocating compressor drives the system. A 3 ton air-cooled condenser is also mounted to the chassis. This condenser contains a total of 200 ft [61 m] of tubing in 3 identical parallel circuits. A core type liquid line filter/drier, receiver, and sight glass follow the condenser.

150 ft [46 m] of $\frac{5}{8}$ inch [16 mm] outer diameter soft copper refrigeration tubing runs from the system's high side into the room housing the evaporator. Several low spots are strategically placed in the system. A thermostatic expansion valve of the proper size attaches the evaporator to the high side tubing. The evaporator tubing is divided by a distributor into 10 identical parallel circuits which total 600 feet in length. Air is forced over the evaporator fins by two fans.

Another 150 ft [46 m] of tubing run from the evaporator to the compressor's suction port. The outer diameter of this tubing is $\frac{9}{8}$ inches [29 mm]. A large number of bends occur in this tubing, and two pronounced low points are equipped with access valves and sight glasses to evaluate oil removal at these points.

Retrofit Evaluation Criteria

The degree of mineral oil removal attained in laboratory retrofits was measured by analysis of the system lubricant after the retrofit. When necessary, these results were verified by direct measurements of the amount of mineral oil in the laboratory system at Integral Sciences Incorporated immediately after the system is flushed. This was done by flushing the system again with clean HCFC-22 for an extended period and then analyzing the refrigerant.

Although poor oil return can affect a refrigeration system's capacity and efficiency, thermodynamic measurements of the refrigeration systems used for this study were not made. In an operating supermarket, lack of instrumentation and load variations make it impossible to accurately measure a system's capacity and efficiency. In addition, several independent parties already have measured capacity and efficiency changes associated with specific retrofits from CFC-12 to HFC-134a.

Even if capacity and efficiency data of each system had been available before and after each retrofit, the field systems would not have been identical, and the data would not have been directly comparable. In addition, many small system retrofits—particularly those

which involve hermetic compressors—do not involve changes in gear ratio or impeller design. This may result in capacity and efficiency losses with HFC-134a which might be misattributed to poor lubricant return.

Preparation of Test Systems

Testing of the proposed methods on field systems required no special advance preparation; by definition these systems are already representative of refrigeration systems which a contractor might retrofit to HFC-134a.

Before each laboratory test was conducted, the system was prepared by isolating the compressor and reverse flushing the high and low sides with reclaimed CFC-12 for four hours. The compressor was disassembled, cleaned with hexane, dried, reassembled, and charged with Suniso 3GS as specified by the compressor manufacturer. The system was then run with CFC-12 until the compressor oil level was stable for a 48 hour period. The total amount of lubricant in the system (i.e. in the evaporator, condenser, and tubing—not including the compressor or any oil separators) consistently measured between 12 and 14 ounces [350 and 400 grams] of mineral oil.

Lubricant Analysis

An Atago N-3000 hand refractometer, frequently the choice of AC&R field service personnel, was used to determine the level of mineral oil remaining in the polyolester lubricant. Even after carefully degassing the lubricant and allowing the temperature to stabilize, this instrument tended to understate the amount of mineral oil remaining in the polyolester by as much as 5% of full scale. These problems were most apparent at low mineral oil levels.

As these measurements were taken by laboratory personnel, results from refractometers used by service technicians should be interpreted cautiously. A 12° F [7° C] change in ambient temperature between readings can sway the refractometer's result by 5% or more of full scale, thereby making the instrument useless. In all cases, the ambient temperature should be stable, recorded, and corrected for in each measurement.

ISI concurrently determined the mineral oil content of the polyolester by liquid chromatography; the results in this report are derived from this method as they are more easily reproduced.

Laboratory System Retrofits

Method Description: Advanced Method

Integral Sciences Incorporated has advanced and tested a method which improves on mineral oil removal from the hundreds (or thousands) of feet of tubing in the evaporator, condenser, and lines. A discharge separator is temporarily installed in the compressor discharge line. This prevents all but a small amount of polyolester from leaving the compressor and entering the system, and ensures proper lubrication of the compressor

during the procedure. As a result, all of the oil migration in the refrigeration system will be from the high and low side back to the compressor. Nearly all of this migration will be mineral oil, and this mineral oil is trapped in an oil separator that is temporarily installed on the compressor's suction line.

The discharge separator is selected by the size of the compressor and discharge line. Manufacturers of these devices were quite helpful in recommending the proper separator. For the tests performed at Integral Sciences, a model 922 Temprite oil separator with a #4 mesh filter was selected because of its efficiency rating for oil separation (99.994%), its size, and the added feature of particle filtration from the refrigerant at the compressor discharge. Tube size of the inlet and outlet of the separator was $\frac{5}{8}$ inches [1.6 cm] OD.

The suction separator is actually a discharge separator which has been installed on the suction line. The oil return mechanism of this component is not used since its function is to simply remove oil from the system. Selection of the suction separator was based on the size of the suction line; undersizing this component will result in unsatisfactory pressure drops. For the laboratory tests, an AC&R Components model S-5588 was used. Tube size of the inlet and outlet of the suction separator was $\frac{9}{8}$ inches [2.9 cm] OD.

From the service technician's perspective, the advanced method consists of :

1. Pump down the CFC-12 system. Refrigerant will be isolated on the high side.
2. Drain and measure the compressor lubricant. Add an equal amount of polyolester lubricant to the system. If the system has a discharge separator, it should be removed unless its efficiency is at least 99.994%. In either case its lubricant should be drained and changed. Some hermetic compressors may need to be drained through the suction stub; a hoist may be required.
3. Install an appropriately sized discharge separator rated to 99.994% efficiency to the compressor discharge line. The discharge separator should be charged with POE to the separator manufacturer's recommendations.
4. Install an appropriately sized "low side" oil separator to the suction line.
5. Operate the system with CFC-12 to allow the remaining system mineral oil to be removed by the separator on the low side of the system. The system is run a minimum of 24 hours.
6. Pump down and recover the CFC-12 from the system.
7. Remove the high and suction separators.
8. Sample the compressor oil and measure the mineral oil concentration using a field test kit or an oil analysis service.

9. If the mineral oil level is not yet below the system manufacturer's guidelines for HFC-134a retrofits, drain and add POE to "new system" levels as prescribed by the compressor manufacturer. This is necessary because the system will be virtually oil-free and will follow a new system's lubricant circulation pattern.

If the % mineral oil attenuation meets the system manufacturer's retrofit guideline, an additional partial charge of POE (to new system levels) will be needed for the same reasons described above.

10. Modify the system to operate using HFC-134a as appropriate. Filter/driers are changed in accordance with the system manufacturer's recommendations for HFC-134a. Certain seals may also be incompatible with HFC-134a and are replaced as specified by the compressor manufacturer.
11. Charge the system with HFC-134a and return it to service. The new refrigerant charge will be approximately 90% of the weight of the original CFC-12 charge.
12. Test the lubricant after 48 hours of operation to ensure the mineral oil level is below the system manufacturer's recommendations.

If a suction accumulator is present in the system, the suction separator is installed after the accumulator. If this is not possible, it is installed before the accumulator. However, if there is evidence of liquid refrigerant at the accumulator, this must be remedied before proceeding with the retrofit procedure. In addition, it may be necessary to drain the compressor oil a second time in order to obtain acceptable final mineral oil levels because of the accumulator's mineral oil charge. This will surely be necessary if the accumulator is not able to be drained before performing the retrofit. Accumulators were not tested as part of Part II of this contract, but they are not seen as a potential drawback to the advanced method.

By running the system for 24 hours, virtually all of the mineral oil can be effectively removed from the high and low side. In the laboratory system at ISI, less than 50 grams [1.8 oz] of mineral oil remained in the system after the procedure—the compressor oil fill capacity was 2200 grams [78 oz] of POE. The oil trapped in the suction separator was 70% / 30% mineral oil / POE by weight. Red dye was added to the high side before each test and never appeared in the compressor oil; no dye escaped the suction separator.

One drawback to this method is the effort required to install and remove the additional components; this is a task that requires considerable effort. However, their addition eliminates two site visits currently needed for the triple flush procedure.

Another more serious drawback is that one of the discharge separators used for testing unexpectedly lost most of its oil to the system during the retrofit procedure. The separator was appropriately rated at 99.9% efficient. Calculations showed, and our test verified, that over a 24 hour period three quarters of the compressor oil are lost to the

system if such a separator is used. To remedy this, a second separator was substituted that was rated to 99.994% efficient and subsequently was tested to this rating.

Baseline Test: "Triple Flush" Method

For comparison with the new approach, the laboratory refrigeration system was retrofitted from CFC-12 to HFC-134a using the "triple flush" method to remove the mineral oil from the system. Four changes of lubricant were required. The system was operated for 24 hours between each lubricant change. The residual mineral oil was measured at 27.4%, 13.2%, 7.0%, and 2.6% in polyolester between flushes, respectively. Had this been a field retrofit, four site visits would have been required to produce a level as low as 2.6%, but a fifth visit would be needed to document the final mineral oil value. As Table 8 shows, material and labor charges for this retrofit are estimated at \$743. Table 9 documents the waste generated from this procedure.

The baseline test employing the "triple flush" procedure required the least amount of on-site labor, but was the most expensive of the laboratory tests performed, generated the largest amount of waste oil and required the most site visits. It was believed that the advanced methods would yield even greater savings during retrofits of larger systems. This would seem reasonable in light of the fact that on-site requirements do not increase with the advanced method; installation and removal of the separators are discrete time allowances that should not appreciably change. However, it was thought that the amount of time for the oil-drain step would increase as system size was increased, and that the amount of POE used for the "triple flush" retrofit would also measurably increase.

Advanced Method: Variations

Because the advanced method has variations that can result from decisions and compromises made by field service personnel, Integral Sciences employed three tests to bring definition to the outcomes these decisions might produce in the field. In Method I, the compressor was drained by the use of a hoist as suggested by the compressor manufacturer. As this step may be inconvenient or impossible when the location of the compressor is such that a hoist cannot be used, Method II shows the result of this compromise to the method. Method III remedies this using a second lubricant change.

Method I

The CFC-12 was pumped down and the compressor mineral oil was drained during the first site visit. The compressor is never flushed or washed by the method being tested, so care was taken to remove as much mineral oil as possible from the compressor in advance. The compressor's winding cover and bottom plate were removed and wiped down to ensure that all accessible mineral oil was removed. Because the laboratory system employed a bolted hermetic compressor, it was tilted and drained through the suction stub. Polyolester lubricant (Mobil Arctic EALTM 22) was then added to the compressor and discharge separator according to the manufacturer's instructions.

The temporary oil separators were then installed on the high and low side of the system. The system was run for a brief period while system parameters were monitored to verify proper system function before leaving the site. The system was run for 24 hours to remove the remaining mineral oil from the system.

On return, the system was pumped down and the CFC-12 was removed by a recovery device. The temporary oil separators were also removed. As the tubing in the lines, evaporator, and condenser contain little oil at this time, extra polyolester was added to the system to compensate. A new filter/drier was installed and the system checked for leaks before it was charged with HFC-134a.

The system was then run for an additional 48 hours; after this time, the lubricant was tested, and the system was checked for overall performance. On this third visit, the mineral oil content of the lubricant was measured at 3.8% by liquid chromatography. As the system was functional in all other aspects as well, this can be considered a successful retrofit.

Cost and labor issues require consideration and are summarized in Table 8. The discharge and suction separators are not included in the total retrofit cost analysis because they represent one time costs and will be reused. These components can be purchased for approximately \$350.

The laboratory retrofit was timed as if it were two separate site visits.² The first site visit required five hours and included one hour for travel, 30 minutes for setup and 30 minutes to tear down when the work was complete. Most of the time needed for this visit was used to drain the compressor.

The second site visit, including travel, setup, and tear down, consumed 3 hours. The bulk of this time was spent removing the two oil separators, recovering the CFC-12, and adding the HFC-134a. The mineral oil level at the compressor did not change appreciably after the second visit in any of the laboratory tests; this is one indication of the suction separator's efficiency in removing mineral oil.

Method I produced 2420 grams [86 oz] of waste lubricant that will require disposal. A comparative summary of the amount of waste generated for each procedure is listed in Table 9. This experiment was the more labor intensive of the laboratory tests tried, but it still required fewer site visits, generated less waste, and cost less than the current retrofit practice.

Method II

While the proper compressor oil drain procedure is that outlined in Method I, inaccessibility, time constraints, or other problems sometimes make the recommended procedure impractical. For this reason, a second test was conducted to determine the

² The third visit was needed for purposes of checking the final mineral oil level for this study, but conceivably would not be required for field retrofits.

effect of not dismantling or lifting the compressor while the mineral oil is being drained. The result of this compromise is that an additional oil drain is necessary after completion of the flush procedure if more than 5% mineral oil is in polyolester. Method II shows the result of this compromise to the method. Method III resolves this by simply employing a second lubricant drain if the analysis reveals excessive mineral oil levels at the completion of Method II.

Except for the change to the compressor oil drain procedure, this test was conducted incorporating the identical test methodology described in Method I. Instead of hoisting the compressor and allowing a 90 minute compressor drain, the compressor was drained for about 30 minutes without the removal of the winding cover or bottom plate. A standard oil suction kit was used to remove oil from the compressor. More than 90 minutes were cut out of the first site visit, which had employed a hoist.

These procedural changes from Method I had an adverse effect on the mineral oil level; 48 hours after the retrofit was complete, oil analysis showed that the polyolester still contained 5.7% mineral oil by weight. This is above the desired amount recommended by most compressor and system manufacturers.

Method III

Method II was repeated. On the second site visit, the compressor oil was drained a second time after analysis revealed the mineral oil levels were above 5%. Both oil separators were removed from the system. Polyolester was added to the compressor per the manufacturer's recommendations for new systems. This added 20 minutes and 1720 grams [61 oz] of polyolester to the retrofit's expense. The compressor oil was retested after 48 hours of additional operation with R-134a and found to contain 1.6% mineral oil in POE.

This method (as a furtherance of Method II) is the least labor intensive of the flush procedures tested and represents significant reductions in expense, site visits, and waste lubricant over the triple flush procedure. In addition, the mineral oil concentration at the end of the retrofit is significantly lower than the other alternatives provide—a fifth site visit would have been required to achieve this result by the triple flush method on ISI's laboratory system.

Table 8: Material and Labor Costs for Laboratory Procedures				
Item	"Triple Flush"	Method I	Method II	Method III
Final mineral oil level	2.6%	3.8%	5.7%	1.6%
Polyolester	\$ 68	\$ 32	\$ 28	\$ 43
Travel labor	\$200	\$100	\$100	\$100
On-site labor	\$250	\$340	\$273	\$287
Copper fittings	\$ 0	\$ 10	\$ 10	\$ 10
HFC-134a	\$165	\$165	\$165	\$165
Filter-drier	\$ 10	\$ 10	\$ 10	\$ 10
Total cost	\$693	\$657	\$586	\$615
Lubricant waste generated	6050 g	2420 g	2350 g	4040 g
Cost Assumptions:				
\$35.00 / gallon [\$9.25 / liter] for polyolester lubricant				
\$50.00 / visit for travel labor				
\$40.00 / hour for on-site labor				

Table 9: Summary of Laboratory Methods				
	Mineral Oil Level	Retrofit Cost	Waste Generated	Site Visits
"Triple Flush"	2.6 %	\$693	6050 g	4
Method I	3.8 %	\$657	2420 g	2
Method II	5.7 %	\$586	2350 g	2
Method III	1.6 %	\$615	4040 g	2

Part 4: Field Retrofit Tests

The First Field Retrofit

System Description

THE first field retrofit was of a single-compressor medium temperature supermarket refrigeration system in Columbus, Ohio. The compressor was a Copelametic model number MRB1-0500-TFC. This unit is rated at 5 horsepower [3.7 kW] and 18 CFM [8.5 l s⁻¹]. The unit cooled a single 24 foot [7.3 m] dairy case and contained a thermostatic expansion valve. A 1⁵/₈ inch [4.1 cm] outer diameter suction line is employed; this line reduces to 1³/₈ inches [3.5 cm] to accommodate a Sporlan SF4811T filter. The discharge line is ⁵/₈ inches [1.6 cm] and includes a Sporlan C-305 filter.

The compressor and first condenser were located in a mechanical room in the rear of the building on the main floor; this room housed an additional 19 compressors. A second condenser was located on the roof approximately 50 feet [15 m] from the compressor and served as part of the building heating system. All refrigeration lines leading to and from the evaporator were suspended approximately 15 feet [4.5 m] above the floor. The compressor and first condenser were mounted approximately 50 inches [1.3 m] above the floor on a Hussman chassis bearing model number HICA0531F. The system operated using 38 pounds [17 kg] of CFC-12.

The compressor normally cycled on and off under the control of a temperature sensor in the display case. In a typical period, the compressor would run for six minutes and shut off for seven minutes. Although the system was equipped with a timer to run the defrost cycle for 40 minutes every eight hours, the timer was found to be defective and was replaced.

Materials Required

Table 10: Materials Used for First Field Retrofit

Suction separator, Temprite model 928, 1 ⁵ / ₈ inch [4.1 cm] connections
Discharge separator, Temprite model 922, ⁵ / ₈ inch [1.6 cm] connections
Brazing kit
Gauge manifold set and hoses
Recovery device, Watsco WC-2 (ARI certified)
Vacuum pump, Varian Evac 200, 7 CFM [3 l s ⁻¹]
HFC-134a, 38 pounds [17 kg]
Mobil Arctic EAL TM 22 polyolester lubricant, 2 gallons [8 l]
Replacement suction filter/drier: Sporlan model SF4811T
Replacement discharge filter/drier: Sporlan model C-305
Hand-held refractometer, Atago model N-3000.
Liquid chromatograph, Varian Vista 5500
Assorted wrenches and other tools
Assorted copper fittings and short sections of copper line

The materials used during the retrofit are listed in Table 10. This table should not be construed as an endorsement of any product or brand name, and equivalents may be substituted.

Site Visit I

The retrofit work was divided into two site visits. It was anticipated that 24 hours would be required between the visits to remove 95% of the mineral oil from the system as required. This assumption was based on laboratory system testing at ISI (pp. 34 ff.).

The first day's work comprised:

1. Pumping down the refrigeration system and recovering the small amount of refrigerant which remained in the discharge line between the compressor and condenser.
2. Thoroughly draining the compressor oil with a suction pump and tube.
3. Installation of a suction oil separator prior to the suction filter.
4. Installation of a discharge oil separator prior to the condenser.
5. Installation of an oil return line from the discharge oil separator to the compressor.
6. System evacuation.
7. Addition of POE to the compressor.
8. Reintroduction of the refrigerant which was removed in step 1.
9. Restarting and monitoring of the system.

ISI anticipated that the system would be down for 90 minutes during the first day, but the procedure took longer than expected. The system was shut off for 130 minutes. There were two reasons for the delay. First, it had been expected that the suction and discharge separators could be installed simultaneously. This turned out to be infeasible on account of space restraints in the mechanical room. Second, although the compressor had an oil drain valve, 12 ounces of mineral oil would not drain and had to be removed with a suction pump.

As anticipated, the discharge separator was not able to keep adequate lubricant in the compressor for a 24 hour period.³ Approximately one pound [500 g] of POE was added to the compressor every five hours to maintain the compressor lubricant between the $\frac{1}{4}$ and $\frac{2}{3}$ level in the sight glass. A total of five pounds [2300 g] of polyolester was added during the 24 hour test. The compressor was allowed to cycle on and off as it does in normal service. The suction separator was drained periodically to observe the method's

³ see also page 29.

progress in removing mineral oil from the system. The collected lubricant was weighed and tested for mineral oil content using both the hand refractometer and by liquid chromatography. These measurements appear in Table 11.

Table 11: Lubricant Removed From Suction Separator During First Retrofit				
Elapsed Time, Hours	Grams Drained	% Mineral Oil, Refractometer	% Mineral Oil, Liq. Chrom.	Grams M.O. Removed
1	125	100	97.3	122
2.5	207	80	85.2	176
4	161	40	32.3	52
6	253	23	20.0	51
9	399	15	15.3	61
14	526	11	10.3	54
19	543	5	6.9	37
21.5	260	3	6.2	16
24	208	< 2.5	4.8	10
Totals	2682	N/A	21.6	579

The refractometer measurements in Table 11 should be interpreted cautiously. The amount of CFC-12 dissolved in the lubricant which was removed was not determined. In addition to increasing the quantity of lubricant reported, this may also cause some of the difficulties with the refractometer's accuracy. In addition the resolution of the refractometer used was only 2.6%.

Site Visit II

The following tasks were performed the second day:

1. The system was pumped down and the CFC-12 was removed permanently.
2. Both oil separators were removed from the system.
3. The compressor lubricant was sampled and measured by refractometer at 4.2% mineral oil. As this was less than the 5% objective and the lubricant entering the suction separator contained even less mineral oil, the compressor oil was not changed the second day.
4. An additional pound [450 g] of POE was added to bring the lubricant to new system levels. Use of the discharge separator had resulted in less than the normal amount of lubricant in the evaporator and condenser.
5. The system was evacuated and charged with HFC-134a.
6. The system was monitored to assure proper operation.

The second day's procedure took 100 minutes. The system ran normally for the next 48 hours, at which time a final compressor oil sample was taken and analyzed by liquid chromatography. The mineral oil concentration in this sample was 3.9% by weight.

Retrofit Economics

The greatest difficulty with the procedure used for this retrofit was that the discharge separator could not maintain sufficient lubricant at the compressor. A technician was needed to remain with the system for 24 hours while the mineral oil was being removed. This drawback renders the procedure too expensive for commercial application. Table 12 summarizes the costs associated with this retrofit. In addition to the costs in Table 12, approximately 2 gallons [8 l] of off-specification waste oil required disposal.

Table 12: Cost Breakdown and Assumptions of First Field Retrofit

Item	Assumption	Price
2 trips to site	\$50 each	\$ 100
4 hours technician labor	\$45 / hour	180
24 hours "watch" technician	\$45 / hour	1080
2 gal. Mobil Arctic EAL™ 22	\$40 / gallon	80
38 pounds HFC-134a	\$4 / pound	152
Copper fittings and tubing	\$20 total	20
Replacement filter/driers	\$64 total	64
Total		\$ 1676
The \$350 (wholesale) cost for the 2 reusable oil separators is not included. The list price for these was \$808.		

The Second Field Retrofit

Procedure Revisions Considered

Reports of rapid oil migration in systems being retrofitted using the "triple flush" method (see page 25), along with the comparatively slow circulation observed in the first field retrofit, suggested a new procedure requiring only one site visit. The objective was to use a substantial dose of polyolester lubricant to flush mineral oil out of the high and low sides as the system was run. The proposed method involved adding an additional half compressor charge of polyolester to the high side, and using a suction separator to collect mineral oil which would be expelled as the system operated.

This revised method was screened on ISI's laboratory refrigeration system. The system was charged and operated with CFC-12 and mineral oil until the compressor oil level was constant for a 24 hour period. Following this, the compressor lubricant was replaced with polyolester. This removed 76% of the mineral oil from the system immediately. An additional 12% was removed by operating the system for one hour while employing the proposed flushing procedure with a low side separator and 1/2 compressor charge of POE

added to the high side. This left 12% mineral oil in the system; changing the compressor lubricant at that time would have reduced this level to approximately 3%.⁴ The procedure then needed to be demonstrated on a suitable field system.

System Description

The work statement for this project called for at least one field retrofit of a multiple evaporator system. Accordingly, a supermarket system with seven evaporators and two compressors was retrofitted in Chicago, Illinois for this test. The evaporators were attached to a common header located approximately 3 feet [1 m] above the compressors. A 2 ⁵/₈ inch [6.7 cm] common suction line divided after the suction filter into two 1 ³/₈ inch [3.5 cm] lines to the individual compressors.

Both compressors were Copeland model 1500-TSK, each rated at 15 horsepower [11 kW]. The rack was a Hill model AD4H3000RCM1-T. The system did not have an oil control device to regulate the compressor oil level; however, an equalization line was present which kept the oil level about the same in each compressor.

The system had a discharge separator with its original equipment. This separator did not have an oil drain or reservoir, but instead fed the collected oil directly back into the low side manifold. Because this manifold was placed ahead of the suction separator, the suction separator collected lubricant from both the compressor and the part of the system which was being flushed. This changed how measurements on the drained lubricant samples would have to be interpreted, as more POE appeared than otherwise. In addition, this increased the rate of oil loss from the compressor.

Defrost Cycle Considerations

Because the polyolester overcharge displaces the system's mineral oil rapidly after startup, it was important that all evaporators would receive flow when the system was started. After an initial surge of oil returning to the suction separator within the first 30 minutes, the oil flow would decrease to the normal rate over the next 30 minutes. At the end of the hour, the system would be essentially devoid of mineral oil and ready for the next step of the procedure.

Although the system did release more than 50% of its remaining mineral oil in the first 10 minutes and the flow did ease back to the normal oil circulation rate by the end of an hour, two evaporators were not cleared of mineral oil at first because their defrost cycle was in progress. The system was equipped with a hot gas bypass-type defrost mechanism. In this implementation, warm refrigerant is circulated through two evaporators at a time in the reverse direction to defrost the coils. This kept polyolester from entering these evaporators until their defrost cycle ended.

⁴ This was not done during the screening test; instead, the system was run for an additional 17 ¹/₂ hours to obtain additional data.

Approximately 80 minutes into the test, the defrost cycle was modified to cycle through all of the evaporators, two at a time for about 10 minutes each. This appeared to be the cause of a sharp increase in oil at the suction separator approximately 100 minutes into the test. This lubricant exhibited a marked rise in its mineral oil concentration. It is reasonable to believe that had the defrost cycle been properly accounted for prior to running the test, the mineral oil recovery would have been essentially complete after the first hour.

Materials Required

The materials used during the retrofit are listed in Table 13. This table should not be construed as an endorsement of any product or brand name, and equivalents may be substituted.

Table 13: Materials Used for Second Field Retrofit

Suction separator, Temprite model 928, 1 ⁵ / ₈ inch [4.1 cm] connections
Gauge manifold set and hoses
Recovery device
Vacuum pump
HFC-134a
Mobil Arctic EAL™ 22 polyolester lubricant, 2 gallons [8 l]
Castrol Icematic® polyolester lubricant, 2 gallons [8 l]
Virginia KMP Emkarate™ polyolester lubricant, 2 gallons [8 l]
Hand-held refractometer, Atago model N-3000.
Liquid chromatograph, Varian Vista 5500
Assorted wrenches and other tools
Copper pipe, 2 ⁵ / ₈ inch [6.7 cm], 10 feet [3 m]
4 Repair couplings, 2 ⁵ / ₈ inch [6.7 cm]
10 LR 90° elbows, 2 ⁵ / ₈ inch [6.7 cm]
3 LR street elbows, 2 ⁵ / ₈ inch [6.7 cm]
15% Silfos solder, 2 pounds [1 kg]
45% Safety-Silver, 2 pounds [1 kg]
Couplings, ³ / ₈ inch [1 cm], 2
Sanding cloth
Filter core, Sporlan RPE-48-BD

System Preparation

The mineral oil was removed in a single site visit. The system was run for two weeks after this visit before the CFC-12 was replaced with HFC-134a. The compressor lubricant was sampled during this later visit and analyzed by ISI. Although normal circumstances would permit the refrigerant to be changed immediately after the mineral oil is removed, the contractor's schedule required the changeover to be done at a later time.

The site visit work was performed by two service technicians from the Chicago area. Because new methods were being employed on an expensive system, a senior manager

from the contracting firm was also at the site. ISI's engineering manager attended to record observations and clarify instructions.

Prior to removing the system from service, lines were measured, cut, and brazed to the suction separator. The system pumpdown began 110 minutes into the retrofit; by 140 minutes the system had been taken off-line and the compressor lubricant had been replaced with polyolester. By 200 minutes, the suction separator was in place.

One gallon [4 l] of polyolester was then pumped into the high side line after the receiver and high side filter. It's possible that on a system this size, using more polyolester would have increased the rate of mineral oil return. At 209 minutes into the retrofit, the system was started; it had been off 99 minutes.

Mineral Oil Removal

The system was run for 157 minutes. 71 minutes into the run, one half gallon [2 l] of polyolester was added to each compressor; this was necessary because in this configuration all lubricant leaving the compressor wound up in the suction separator (see page 46). It was not necessary to interrupt the system's operation while adding the lubricant. Both compressors were low again at the end of the run, but rather than adding lubricant to them the lubricant in both compressors was changed entirely a second time.

The suction separator was drained periodically. The volume of the drained lubricant was measured and its mineral oil concentration was determined using the refractometer. These samples were reanalyzed a few days later by liquid chromatography. These measurements appear in Table 14.

Table 14: Lubricant Removed from Suction Separator During Second Retrofit						
Run Time Minutes	Ounces ⁵ Drained	Refractometer		Liquid Chromatograph		
		Reading	% MO	% MO	Ounces MO	Cumulative
10	104	4620	51	41	42.6	42.6
20	16	4600	46	33	5.3	47.9
30	12	4560	37	30	3.6	51.5
40	10	4555	35	28	2.8	54.3
50	10	4550	34	27	2.7	57.0
60	8	4530	29	25	2.0	59.0
70	8	4520	27	23	1.8	60.8
85	12	4510	24	20	2.4	63.2
100	64	4485	18	18	11.5	74.7
115	16	4480	17	17	2.7	77.4
130	8	4480	17	15	1.2	78.6
145	8	4470	15	15	1.2	79.8
155	6	4470	15	14	0.8	80.6

The run was terminated after 157 minutes of system operation; this was 366 minutes into the retrofit. The system was pumped down, the suction separator was removed from the system, and the lubricant was changed in both compressors. As mentioned previously, these compressors were running short of lubricant by that time. Measurements pertaining to the lubricant removed from the compressors appears in Table 15. These tasks took 59 minutes, and the system was restarted 425 minutes into the retrofit and monitored briefly. The defrost timer was reset, and the system was allowed to operate with CFC-12 and polyolester for two weeks.

Table 15: Lubricant Drained From Compressors After Suction Separator Removal			
	Amount Drained	% MO by Liq. Chrom.	MO Removed
Compressor #1	96 oz.	8%	8 oz.
Compressor #2	96 oz.	7%	7 oz.
Totals	192 oz.	7.5%	15 oz.

After two weeks of system operation, the lubricant was sampled from both compressors. They each contained 2.8% mineral oil by weight in polyolester. The refrigerant was changed over to HFC-134a after these samples were drawn.

Retrofit Economics

As Table 16 shows, a considerable portion of the retrofit's cost was in copper fittings. These are eventually removed from the system and can be reused on another job. The

⁵ One fluid ounce $\cong$ 29.57 ml.

suction separator is another fixed asset necessary for the task; it can be reused for many retrofits. In addition to the costs in Table 16, the disposal of 6 gallons of off-specification waste oil was also required.

Table 16: Cost Breakdown and Assumptions of Second Field Retrofit

Item	Assumption	Price
19 hours technician labor	\$46 / hour	\$ 874
6 gallons POE	\$40 / gallon	240
200 pounds HFC-134a	\$4 / pound	800
Filter core, RPE-48-BD	\$20 each	20
10' Copper pipe, 2 ⁵ / ₈ "	\$10 / foot	100
4 Repair couplings, 2 ⁵ / ₈ "	\$8 each	32
10 LR 90° elbows, 2 ⁵ / ₈ "	\$29 each	290
3 LR street elbows, 2 ⁵ / ₈ "	\$30 each	90
2 lb. Silfos solder, 15%	\$40 / pound	80
2 lb. Safety-Silver, 45%	\$13 / pound	26
2 Couplings, ³ / ₈ "	\$0.50 each	1
Total		\$ 2553
The \$300 (wholesale) cost for the oil separator is not included.		
The list price was \$559.		

Several changes to this procedure would lower its cost considerably. The separator used for this retrofit was sized to allow a minimal pressure drop on the low side. Since this separator is only used for a short time and is not a permanent addition to the system, a smaller separator which would cause some pressure drop could be used. The use of hoses to attach the suction separator to the low side would reduce the copper fitting need, brazing time, and consumables used. These hoses would be reusable for other retrofits.

More POE could be used to flush the system. Clearly if no POE is added to the high side, mineral oil return from the evaporator would take considerably longer. Some optimal amount of POE may further reduce the total retrofit cost in terms of labor and materials.

Finally, this procedure could be applied to several systems in a single day. This would reduce technician time at the site significantly. At the store where this retrofit was done, there were five systems which could have been retrofitted concurrently; this would result in labor savings on the order of 30%.

Because this system is considerably larger than the one retrofitted in the first field retrofit, the prices given for these retrofits are not directly comparable. Table 17 compares the costs of both field retrofits on a tonnage basis against the least expensive of the laboratory system retrofits. Although the large system retrofit was not inexpensive, it did show an impressive economy of scale; this retrofit cost 58% less than any other when normalized by system capacity.

Table 17: Comparative Costs of System Retrofits			
Retrofit	Compressor Horsepower ⁶	Retrofit Cost	Cost Per Horsepower
Lab, using "triple flush"	3	\$ 693	\$ 231
Lab (Method III)	3	615	205
Field Single Evaporator	5	1676	335
Field Multiple Evaporator	30	2553	85

Comparison of New and Old Methods

This work was undertaken in hopes that significant cost reductions could be applied to current mineral oil removal practices. Areas where savings were hoped for were in materials required, waste generated, the number of site visits required, and the level of effort expended by the service contractor.

For small system retrofits involving only one or two refrigeration systems, the new procedure may reduce the total retrofit cost by 15 to 30 percent. Most of this savings takes the form of the reduction to a single site visit.

This savings for small systems does not appear in Table 17, however. This is because for the first field retrofit, a "watch" technician remained at the site for 24 hours to maintain the compressor lubricant at a safe level. This nearly tripled the cost of the first field retrofit. Had the procedure which was used for the second field retrofit been used, this first field retrofit would have cost approximately \$600, or \$120 per horsepower.

For retrofits of larger systems, and for any retrofits involving a large number of systems at a single site, further savings may be attainable. This results from the service contractor's ability to perform the procedure on several systems simultaneously. Further savings would result from reductions in the amount of polyolester lubricant required.

⁶ One horsepower $\cong$ 746 W. As a general rule, refrigeration systems have one compressor horsepower for each ton of refrigeration capacity. One ton of refrigeration $\cong$ 3506 W of heat removal capacity.

Part 5: Appendix

Relative Difficulty of Solvent Evaporation

BECAUSE the retrofit's cost is primarily determined by the solvent's evaporation rate, and the evaporation rates vary especially widely between solvents, it is necessary to develop a rating system for classifying evaporation speeds.

An evaporating solvent will condense immediately if sufficient space for the vapor is not provided. For example, one pound of saturated water vapor at 40° F [4° C] occupies 2443.5 cubic feet. If the vapor is not saturated, even more space is required. Also at 40° F [4° C], one pound of HCFC-123 vapor occupies at least 5.9215 cubic feet.

Insufficient space is available inside the tubing of a refrigeration system to evaporate any liquid flushing solvent. To facilitate evaporation, vapor is removed from the system to the atmosphere by either a vacuum pump or by purging with dry nitrogen. The "volume of vacuum" (vacuum pumps are rated in cubic feet per minute with no differential pressure) or volume of nitrogen provided varies directly with the volume of vapor removed. At 40° F [4° C], neglecting subcooling effects which depend on system geometry and the surrounding temperature, a vacuum pump which can remove one pound of HCFC-123 from the system in one hour would require $(1703 / 5.92)$ or 288 hours to remove one pound of water.

The relative difficulty of solvent removal can therefore be approximated by the volume occupied by one pound of saturated vapor. ISI has chosen 40° F [4° C] for the temperature; subcooling effects, cold outside weather, and display case temperature considerations make this seem to be a logical choice.

Figures 1 and 2 plot the comparative difficulty of removing certain classes of solvents from the system. The fluids listed are not meant to be advanced as solvent alternatives; they are chosen only to be representative of certain solvent types including aqueous solvents, high and low pressure refrigerants, high pressure flammable hydrocarbons, and biodegradable products with zero ozone depletion potential and very low vapor pressure. Water, β -pinene, and d-limonene are removed from Figure 2 to allow easier reading of the remaining fluids.

As Figure 2 shows, one of the easiest fluids to remove is HCFC-22. A Class II substance with an ozone depletion potential of 0.055 (CFC-12 = 1.0), HCFC-22 can be removed from a supermarket system in approximately 2 hours with a small recovery device. Given that one pound of saturated vapor at 40° F [4° C] occupies only 0.66 cubic feet, even one of the more volatile hydrocarbons such as hexane would require a week to remove with a vacuum pump. Water, β -pinene, and d-limonene would require nearly a year.

Reserved Page: Figure 1.

Reserved Page: Figure 2.

Bibliography and Abstracts

Bibliographies and Resource Directories

1. **Refrigerant Database**, Calm, J. M., February 1995.

Available in both print and computerized editions, this database provides bibliographic citations for over 2,200 documents along with summaries of 270 refrigerants and blends. Supported in part by the US Department of Energy grant number DE-FG02-91CE23810, *Materials Compatibility and Lubricant Research (MCLR) on CFC-Refrigerant Substitutes* and other sources, this database is the best single source of references concerning new alternative refrigerants and their applications.

2. **Alternatives to Vapor Degreasing for Cleaning Metal Parts**, Minnesota Technical Assistance Program (MnTAP), Minnesota Office of Waste Management, April 1992.

A bibliography of cleaning methods that may replace vapor degreasing for metal parts cleaning. 197 references.

3. **Stratospheric Ozone Protection Resources—Air Conditioning and Refrigeration**, United States Environmental Protection Agency, Air and Radiation, EPA-430-F-93-005, February 1993.

This 2 page resource directory provides points of contact with trade and professional associations, air-conditioning manufacturers, refrigeration manufacturers, and chemical producers, along with a list of pertinent EPA fact sheets and Federal Register notices. This list provides a start toward identifying information sources in the refrigeration industry, but it tends to overlook the service contractors and reclaimers who are often on the front line when a system is being cleaned out or retrofitted.

Lubrication and Oil Return

4. **HFC-134a as a Substitute Refrigerant for CFC-12**, Spauschus, H. O. (Georgia Technical Research Institute), *International Journal of Refrigeration*, Vol. 11, November 1988.

The emergence of HFC-134a as a candidate for CFC-12 substitution is discussed. Considerable attention is given to this replacement's lack of solubility with mineral oil and alkylbenzene lubricants. Solubility of the refrigerant and lubricant increases bearing lubrication and assists in oil return to the compressor.

5. **Lubricants in Refrigerant Systems**, TC 3.4, Lubrication, 1994 Refrigeration Handbook, American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), pp. 7.1 - 7.23.

A discussion of lubrication requirements, lubricants, and refrigerant-lubricant mixtures. Physical properties of lubricants are discussed along with solubility and miscibility relationships with refrigerants, water, and air, oil return from evaporators, wax separation, and refrigeration oil evaluation techniques.

6. **Viscosity of Refrigerant-Oil Mixtures at Evaporator Conditions**, Parmelee, H. M., Transactions, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Vol. 70, 1964, pp. 173-180.

The process of oil return from the evaporator in a refrigeration system to the compressor crankcase is discussed in detail in the introduction. The balance of the paper presents measurements of the viscosity of R-13, R-13B1, R-22, and R-502 with a 150 SUS naphthenic oil at low temperatures under superheated conditions.

7. **Fundamentals of Lubrication in Refrigeration Systems and Heat Pumps**, Kruse, H. H. and Schroeder, M. (Department of Refrigeration, University of Hannover, Hannover FRG), ASHRAE Journal, American Society of Heating, Air-Conditioning, and Refrigeration Engineers, Vol. 26 No. 5, May 1984, pp. 5-9. (The copy obtained by Integral Sciences Incorporated is longer than the one published in the ASHRAE Journal, and appears in pages 763-783 of an unknown source.)

In addition to containing an overview of lubrication principles in refrigeration systems, this article summarizes problems caused by lubricants at a system's oil separator, condenser, expansion device, and evaporator.

8. **Retrofitting with HFC-134a, Additives, and Mineral Oil**, Jetter, J. J. (US EPA Air and Energy Engineering Research Laboratory), MACS Action Newsletter, December 4, 1993.

Richard C. Cavestri, Ph.D. (Imagination Resources, Inc.) has developed proprietary lubricant additives that change the properties of mineral oil to allow its dispersion in HFC-134a vapor. If tests at the EPA's Air and Energy Engineering Research Laboratory prove to be favorable, it may be possible to retrofit systems from CFC-12 to HFC-134a without any need to replace the original system lubricant.

9. **Private Communication**, Beckler, P. (Shrieve Chemical Products, Inc.), April 1994.
10. **Refrigerant/Lubricant Miscibility Studies**, Leck, T. J. (Dupont Fluorochemicals Laboratory), presentation to ASHRAE, January 1994.

Miscibilities of several polyolesters, mineral oil, and alkylbenzene are reported at varying concentrations in several replacement refrigerants that are manufactured by Dupont. Small amounts of mineral oil in POE lubricants significantly reduces their miscibility with HFC refrigerants. The effect on mineral oil on the miscibility of alkylbenzene and HFC refrigerant, however, is considerably less. Also, residual alkylbenzene in a solution of polyolester and HFC refrigerant has a smaller effect on miscibility than mineral oil does.

11. **Lubricating Oils for Refrigerant R-134a**, Doya, K., Aoki, Y., and Onoyama, M. (Showa Shell Seiyu Company Ltd., Japan), Reito, Japan, vol. 65 no. 10, 1990, pp. 1047-1052.

This paper considers several lubricants for use with HFC-134a in refrigeration, and includes some miscibility data for mixtures of lubricants (i.e., mineral oil and polyalkylene glycol and ester) with HFC-134a. Generally speaking, these mixtures are not miscible with HFC-134a.

12. **Evaluation of Lubricants for Refrigeration and Air-Conditioning Compressors**, Spauschus, H. O., Transactions, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Vol. 90 Part 2B, 1984, pp. 784-798.

The special properties required of lubricants for refrigeration and air-conditioning compressors are discussed in chapter 32 of the *ASHRAE Handbook—1980 Systems*. This paper reviews laboratory and compressor screening and methods of evaluation for qualifying and controlling the quality of these lubricants. Important factors that determine functional requirements include the type of refrigerant, operating conditions, and compressor design considerations; which factors, in turn, define the lubricity, stability, solubility, and low-temperature properties that a successful lubricant must provide. The evaluation of petroleum-base stocks, synthetic fluids, blends, and additives in refrigeration lubricant formations is discussed. The importance of relating bench tests to compressor tests and field experience is stressed. [Author abstract]

Retrofit Studies

13. **SUVA® 134a (SUVA® Cold MP, HFC-134a) in Chillers**, Du Pont Chemicals Customer Service Center, brochure, October 1992.

Du Pont is producing HFC-134a for use in new and existing chillers. Differences in miscibility of CFC-12 and HFC-134a in mineral oil are discussed along with the implications on oil return to the compressor. Du Pont suggests the use of polyolester lubricant, which is miscible with HFC-134a. For retrofitted systems, the mineral oil concentration should be less than one or two percent to prevent the formation of a second lubricant phase. Three retrofit case studies are presented with capacities between 700 and 3000 tons. In one case, the compressor lubrication system and evaporator were flushed with CFC-11; in another the compressor and lubrication system were flushed with CFC-11; and in the third case the compressor and lubrication system were flushed with polyolester lubricant. No serious problems are reported with these flushing procedures.

14. **Forane® 404A Tech Digest**, Elf Atochem North America, Inc. Fluorochemicals, advertising brochure.

A near azeotropic blend of HFC-125, HFC-143a, and HFC-134a (44-52-4) is marketed as a replacement for R-502. The blend requires a change to polyolester lubricant with less than 5% residual mineral oil.

15. **Retrofitting Large Refrigeration Systems with KLEA® 134a**, Corr, S., Gregson, R. D., and Tompsett, G. (ICI Chemicals and Polymers Ltd., Runcorn, UK) with Savage, A. L. and Schukraft, J. A. (ICI Americas, Inc.).

The use of HFC-134a as a replacement for CFC-12 in existing food processing equipment is discussed. Effects on system performance, chemistry, and lubrication are addressed and presented with descriptions of sealed-tube and accelerated compressor life tests. Although CFC-12 is identified as an important near-term flushing solvent, the retrofit procedure recommended in this paper is to operate the system with successive lubricant replacements with

polyolester. Mineral oil concentration should be reduced to less than one percent before replacing the CFC-12 with HFC-134a. A retrofit case history is presented for a food processing plant.

16. **Retrofitting Large Refrigeration Systems with R-134a**, Corr, S. (ICI Chemicals & Polymers Ltd., Runcorn, UK), Dekleva, T. W. (ICI Fluorochemicals), Savage, A. L. (formerly ICI Fluorochemicals), ASHRAE Journal, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, February 1993.

Retrofits of CFC-12 refrigeration systems to HFC-134a are possible as a result of the development of synthetic lubricants such as polyolester. At one time, attempts were made to run the systems with HFC-134a and the system's original mineral oil. This led to several problems. The immiscibility of the mineral oil in HFC-134a causes the viscosity of the lubricant to remain high. At low temperatures and particularly in the evaporator, the viscosity is too high for the refrigerant to circulate the mineral oil. Even in the presence of considerable amounts of polyolester lubricant, mineral oil tends to concentrate in the evaporator. The polyolester in a refrigeration system needs to be 96% - 99% free of mineral oil in order to cause the residual mineral oil to circulate properly.

17. **Experimental Evaluation of an R-32/R-134a Blend as a Near Drop-In Substitute for R-22**, Sanvordenker, K. S. (Tecumseh Products), ASHRAE Transactions, V. 99 Pt. 2, 1993.

This paper describes calorimetry tests of an HFC-32/HFC-134a blend as a potential replacement for HCFC-22. The effects of miscibility and solubility of the refrigerant blend with polyolester lubricants are discussed. Low solubility of the refrigerant in the lubricant can lead to high startup pressures. This presents another reason for assuring full mineral oil removal in an HFC-134a retrofit; the existing compressor may lack adequate torque to start if a high level of mineral oil remains in the system.

18. **Retrofitting Mobile Air-Conditioning Systems with HFC-134a—An Update**, Dekleva, T. W. (ICI Americas, Inc.) et. al., Proceedings of the International CFC and Halon Alternatives Conference (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, September 1992, pp. 697-706.

This article addresses the development of HFC-134a retrofit procedures for mobile air-conditioning equipment. Time requirements and implications of flushing procedures are discussed. Perchloroethylene and trichloroethylene are discussed as candidate flushing solvents.

19. **Navy Investigations of HFC-134a as a Replacement for CFC-12 in Shipboard Applications**, Nickles, A. D., Brunner, G. P., and Hamilton, D. L., Jr., Naval Engineers Journal, May 1992, pp. 98-103.

The US Navy used 2 million pounds of CFC-12 in 1990. This paper presents the results of the Navy's HFC-134a investigations and outlines both future testing and designs for HFC-134a air conditioning plants. Specific retrofit tests are discussed which involved polyalkylene glycol and polyolester lubricants. Mineral oil removal procedures varied from retrofit to retrofit, but included both the "triple flush" method and the use of CFC-11 as a flushing fluid in conjunction with disassembly of the system.

20. **R-22 Alternative Refrigerants Evaluation Program (AREP) Program Status Report**, AREP Technical Committee, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 16, 1994.

The Alternate Refrigerants Evaluation Program (AREP) provides performance data for R-22 and R-502 equipment which has been retrofitted to non-ozone depleting refrigerants. Testing was conducted on 26 refrigerants by more than 30 manufacturers in Japan, Canada, the US, and Europe.

Retrofit Guidelines

21. **Retrofitting Centrifugal Chillers from R-12 to Forane[®] 134a**, Elf Atochem North America, Inc., undated.

The "triple flush" process for mineral oil is recommended for use in CFC-12 centrifugal chillers. Baseline system data is recorded first; then the system is tested for leaks and serviced as necessary. The lubricant is replaced several times with polyolester until the mineral oil level is less than 5 percent. The system is run for 24 to 48 hours between each lubricant change. The CFC-12 charge is recovered next, the filter/driers are changed, and the system is evacuated and charged with HFC-134a. After the charge and control settings are properly trimmed, the system is labeled with the new refrigerant and lubricant.

This procedure works almost amazingly well. A 400 horsepower centrifugal chiller which cools the press areas of a 400,000 square foot printing plant was retrofitted to HFC-134a by Ruyle Mechanical in a total of 18 hours. The system operates more efficiently than it did before the retrofit, but now it uses 1300 pounds of HFC-134a.

22. **Retrofit Guidelines for SUVA[®] 134a (SUVA[®] Cold MP) in Stationary Equipment**, DuPont Chemicals Customer Service Center, January 1993.

The "triple flush" process for mineral oil is recommended for use in stationary CFC-12 equipment. Baseline system data is recorded first. The lubricant is replaced several times with polyolester until the mineral oil level is less than 5 percent; this may require temporarily removing the CFC-12 charge for each change. The system is run for 24 to 48 hours between each lubricant change. The CFC-12 charge is recovered next, the filter/driers are changed, and the system is evacuated, tested for leaks, and charged with HFC-134a. After the charge and control settings are properly trimmed, the system is labeled with the new refrigerant and lubricant.

23. **Refrigerant Changeover Guidelines CFC-12 to HFC-134a**, Form 93-04-R1, Copeland Corporation, April 1993.

Copeland does not advocate retrofitting systems from CFC refrigerants to HCFCs or HFCs on properly operating equipment that does not leak. It is noted that the UL listing of the system may be invalidated as a result of a retrofit. As these are a system manufacturer's retrofit guidelines, they go into considerable detail and discuss issues specific to Copeland equipment.

Prior to any service on the system, leak testing and repairs are done. System operating conditions are then recorded while CFC-12 is still being used. Three changes of the system lubricant with Mobil EAL[™] Arctic 22 (polyolester) are performed; the system is run for at least 24 hours between each change. The CFC-12 is recovered, and the system is evacuated and charged with HFC-134a. The system is operated, and adjustments are made to the refrigerant charge,

superheat setting, and other controls. Components are labeled to indicate the new refrigerant and lubricant. The used oil is properly disposed of, and the recovered refrigerant is recycled or reclaimed.

24. **Retrofitting Automotive Air-Conditioners from R-12 to Forane® 134a**, Elf Atochem North America, Inc., undated.

The Elf Atochem procedure for mobile air-conditioning retrofits begins with testing the system for leaks. The CFC-12 charge is recovered, and the system is evacuated. Mineral oil is removed by flushing the system with CFC-12 using a recovery device. If a thermal expansion valve is present, it can be opened by applying heat. The flushing refrigerant is recovered and the system is evacuated. New polyolester is added to the system, and the CFC-12 fittings are replaced with HFC-134a fittings. The system is evacuated again, charged with HFC-134a, and checked once more for leaks. The system is then labeled as having been retrofitted with synthetic oil and HFC-134a.

25. **Handling Used Refrigerant Oils**, United States Environmental Protection Agency, Air and Radiation, July 1993.

Used oils from compressors in refrigeration or air-conditioning equipment generally contain more than 5,000 ppm total halogen content. Technicians working with these oils must follow standards for off-specification used oils. Two standards govern the management of used oils destined for recycling; which standard is in use varies from state to state. The most recent, 40 CFR 279, applies in Iowa, Alaska, Wyoming, and Hawaii as of July 1993. The remaining states follow the standards in 40 CFR 266. In general, CFC-contaminated oil should be sold to a used oil marketer. These can be located through the yellow pages, service stations, and the EPA RCRA Hotline (800-424-9346). The other alternative is to recycle the oil in a used-oil fired space heater, an option which the EPA appears to discourage.

Cleaning Solvents

26. **Solvent Alternatives Guide (SAGE version 2.1, computer program)**, US EPA Control Technology Center, Center for Aerosol Technology, Research Triangle Institute, Research Triangle Park, North Carolina, October 1994.

SAGE is a computer program for providing alternatives to chlorinated solvents. A "decision tree" format is used; alternatives are suggested after a series of questions has been answered. This program's focus is primarily restricted to the cleaning of easily accessible parts during manufacturing and prior to assembly. The chemical alternatives that SAGE can propose are water, aqueous solutions of varying pH, ethyl lactate, semi-aqueous solutions, aqueous chemistry additives such as builders and surfactants, alcohols, acetone, n-methyl pyrrolidone, terpenes, dibasic esters, glycol esters, and petroleum distillates. The process alternatives in the database are low and high pressure spraying, power washing, immersion cleaning, ultrasonic and megasonic cleaning, brushing, wiping, abrasives, steam, carbon dioxide snow and pellets, plasma cleaning, laser ablation, UV/ozone cleaning, supercritical carbon dioxide, xenon flash lamp, fiberglass mold cleaning, printed circuit board cleaning, paint stripping, and no-clean options.

27. **SNAP Lists of Alternatives to Ozone-Depleting Compounds**, Saltonstall, K. (United States Environmental Protection Agency Office of Air and Radiation),

memorandum accompanying the SNAP proposal as published in 58 FR 28094, Federal Register, Vol. 58, No. 90, Wednesday, May 12, 1993.

The EPA's Significant New Alternatives Policy (SNAP) program is a regulatory mechanism for screening alternatives to ozone depleting compounds including refrigerants, halons, aerosols, solvents, foam blowing agents, and other miscellaneous uses. 58 FR 28094 outlines the SNAP program's structure and data requirements for making submissions for review by the EPA. It also includes the proposed SNAP listing decisions of acceptable and unacceptable alternatives for ozone depleting compounds by application.

28. **New Life for Old Solvents**, Shelley, S., Chemical Engineering, Vol. 100 No. 6, June 1993, pp. 63-65.

Emissions of trichloroethylene, perchloroethylene, and methylene chloride have been restricted since 1970 as a result of the Clean Air Act. This resulted in many solvent users adopting 1,1,1-trichloroethane as a primary solvent. As a result of the Montreal Protocol, however, a worldwide phaseout for CFC-113 and 1,1,1-trichloroethane is to be complete January 1, 1996. The Clean Air Act Amendments of 1990 authorizes the EPA to determine which alternatives for ozone depleting substances can be used in the United States. On May 12, 1993, the EPA issued its list of proposed acceptable and proposed unacceptable alternatives. Once the rules are promulgated in 1994, it will be unlawful to replace ozone depleting substances with any substitute which has not been approved through the Significant New Alternatives Policy (SNAP) program.

While chlorinated solvents such as trichloroethylene, perchloroethylene, and methylene chloride are expected to be SNAP approved, they are regulated under the Clean Air Act Amendments as a hazardous air pollutant. More rules which address the use of these solvents are expected soon. These materials also have toxicity problems. They are not currently believed to contribute to stratospheric ozone depletion.

Other alternatives to 1,1,1-trichloroethane may include hydrocarbons, aqueous, and semi-aqueous solvents. Concerns about the flammability of hydrocarbons and the treatment of wastewater make these substitutes a difficult choice for many applications.

29. **Zero Discharge Semi-Aqueous Cleaning Systems**, Harman, J. (Envirosolv, Inc.), Wescon Conference Record, Vol. 36, 1992.

The proposed Clean Water Act contains discharge allowances for many substances that are low enough to be effectively zero. New environmental regulations such as RCRA, the Clean Water Act, and the Pollution Prevention Act are increasingly directed toward eliminating the use of chemicals wherever possible. When selecting alternatives to ozone depleting substances for cleaning, the regulatory focus of zero emissions and pollution prevention must be examined early; otherwise, it may soon be necessary to change processes again.

Refrigeration System Contaminants

30. **Moisture and Other Contaminant Control in Refrigerant Systems**, TC 3.3, Contaminant Control in Refrigerating Systems, 1994 Refrigeration Handbook, American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), pp. 6.1 - 6.13.

This chapter provides a solid introduction to the contaminants which appear in refrigeration systems and addresses moisture, acids, dyes, oil deterioration products, metallic contaminants, dirt, sludge, wax, tars, residual solvents, antifreeze agents, and noncondensable gases. A general description of motor burnouts also appears followed by a 50 paragraph procedure for cleaning the system after a hermetic motor burnout.

31. **Sealed-Tube Stability Tests on Refrigeration Materials**, Parmelee, H. M. (E. I. DuPont de Nemours and Company), paper 1024, Transactions, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Vol. 71 part 1, January 1965, pp. 154-161 and 167-168.

The stability of CFC and HCFC refrigerants with residual cleaning and degreasing agents, system components, and lubricants is investigated. The paper emphasizes that a refrigeration system should be kept chemically simple; every material added to the system increases the possibility of reactions which could reduce the life expectancy of the system.

Terpene Products for Cleaning

32. **D-Limonene, Terpenes Compete in Non-CFC Arena**, Santos, W., Chemical Marketing Reporter, Vol. 243 No. 8, February 22, 1993, p. 24.

Storchem, Inc., of Ontario, Canada, has introduced a line of non-ozone depleting terpene based solvent products which are non-toxic, biodegradable, and have a moderately high flash point. D-limonene is another option to chlorinated solvents, but its sales have not been as strong as many had expected. The price of d-limonene delivered to major US ports from Brazil as of November 1992 was approximately 50 cents per pound.

33. **ART-338 Refrigerant Flush Sales Information**, Advanced Research Technologies, Inc., 9/24/92.

A cleaning fluid for refrigeration systems is available from Advanced Research Technologies, Inc. The fluid contains no halogens and no chlorine compounds, is compatible with lubricants, does not dissolve synthetic rubber, and has a 104° F [40° C] flash point. The 329° F [165° C] boiling point results in a very low vapor pressure. The contents of this material have been withheld as a trade secret under 29 CFR 1910.1200, but its UN 2319 designation indicates terpene hydrocarbons. The density, molecular weight, vapor pressure, and boiling point suggest a preponderance of β -pinene. The sales information relies on the low vapor pressure of this substance when assessing health risks.

34. **Unpublished Information**, Advanced Research Technologies, Inc., 1993.

Sealed tube stability tests were performed with combinations of ART-338, CFC-12, HFC-134a, mineral oil, polyalkylene glycol lubricant, aluminum, copper, and steel at 347° F [175° C] over 14 days. The writer concludes that ART-338 does not increase chemical activity in automotive air conditioning systems. In another set of tests, swashplate seizure tests with ART-338 added to polyalkylene glycol lubricant showed no apparent loss of lubricity. No reference is made to testing of ART-338 with plastics, elastomers, or gasket materials.

35. **A/C Flushing Kit Instruction Manual**, Bright Solutions, Inc., Undated.

Bright Solutions, Inc., has developed a pump for circulating BSL-338 CLEAR-FLUSH™ through a mobile air conditioning system's lines, evaporator, and condenser. After flushing the system, the solvent is removed by purging with at least 600 cubic feet of dry shop air at 90-120 PSI.

Fluoroiodocarbons

36. **A New Class of Nonflammable, Environmentally Safe Solvents**, Nimitz, J. (Environmental Technology & Education Center), Lankford, L. (J. J. Research Labs), Fourth Annual International Workshop on Solvent Substitution, Phoenix, AZ, December 7-10, 1993.

A new group of nonaqueous, nonflammable solvents is presented. These solvents have zero ozone-depletion potential (ODP), near-zero global warming potentials (GWPs), excellent cleaning ability, and very low acute toxicity. These solvents consist of azeotropic blends of fluoroiodocarbons (FICs) with conventional solvents such as hydrocarbons, esters, and ketones. Fluoroiodocarbons are excellent fire extinguishants (comparable to halons) and are environmentally benign because they break down in sunlight within days, forming harmless products. They are also "anti-VOCs", destroying components of smog and improving urban air quality. The properties of these solvents and current status of laboratory testing is discussed. It appears likely that several of these solvents will be suitable as "drop-in" replacements for CFC-113, methyl chloroform, trichloroethylene, and perchloroethylene and may eliminate the need to replace existing vapor degreasers. [Author abstract.]