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

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Executive Summary

Integral Sciences Incorporated is engaged in Part 2 of ARTI Contract No. 660-52502 assessing methods for removing residual mineral oil during retrofits of refrigeration systems. Part 2 focuses on a low side oil separator technique for removing mineral oil from systems being retrofitted to use HFC-134a. The method appears less expensive than the current practice of three lubricant changes with polyolester and may effect an accelerated transition to HFC's.

Testing and method verification has been performed using a refrigeration system located at ISI's facility. Two HFC-134a field retrofits employing this method will be implemented during the first quarter of 1995. A third and final field retrofit will also be performed to evaluate the advanced method in an R-502 conversion.

Introduction

The phaseout of CFC-12 under the terms of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer is effecting an immediate shift away from this fluid in refrigeration systems towards HFC-134a, a substitute refrigerant with zero ozone depletion potential.

HFC-134a is not miscible with the mineral oil used to provide lubrication in current CFC-12 systems. Two problems result from this immiscibility. At temperatures occurring in the evaporator, very little HFC-134a is dissolved in the mineral oil, resulting in a high viscosity lubricant that does not circulate. Instead, the mineral oil trapped in the evaporator interferes with refrigerant flow and heat transfer. Because of this, oil return is impeded and can eventually leave the compressor without sufficient lubricant.

Processes developed for removing mineral oil during a retrofit have been developed by refrigeration equipment manufacturers and refrigerant producers. The prevailing "triple flush" procedure safely and effectively removes mineral oil from the system, but this procedure has high costs associated with lubricant, waste disposal, and technician labor. This study was conducted to identify a procedure which requires less time and materials without compromising the reliability offered by the methods currently in use.

Background

Mineral oil removal is by far the most expensive requirement of HFC-134a retrofits for refrigeration systems, and the "triple flush" procedure is especially time inefficient and costly. In some cases four flushes are required. The result is that contractors are uncomfortable with HFC-134a retrofits from a procedural and cost standpoint, especially in supermarket applications. Many contractors are simply choosing to retrofit using HCFC refrigerants and blends which can tolerate high levels of residual mineral oil. Other contractors are advising equipment owners not to retrofit systems at all.

In April 1994, Integral Sciences Incorporated proposed four techniques for lowering the time and cost requirements of mineral oil removal when retrofitting systems from CFC-12 to HFC-134a. The work was done using DOE and ARTI funds under Part I of this contract. Three of the four methods called for the addition of foreign substances to the refrigeration system which require subsequent removal. The fourth approach was the use of a low side oil separator to prevent mineral oil from contaminating the new polyolester lubricant. At ARTI's request, Part 2 work addresses this fourth alternative exclusively.

Although the work statement for ARTI Contract No. 660-52502 also asks for methods for servicing motor burnouts, Part I research found that existing practices for handling burnouts are both mature and effective. Additionally, as the low side oil separation method provides for mineral oil removal but not for cleaning per se, no burnout contaminant removal has been attempted under Part 2.

Test Equipment and System Preparation

Integral Sciences Incorporated has installed at its facility a 3 ton [12 kW] refrigeration system similar to a supermarket display case. The system is driven by a 3 horsepower [2.2 kW] bolted hermetic reciprocating compressor. A 3 ton [12 kW] air-cooled condenser is also mounted to the chassis. This condenser contains a total of 200 feet [60 m] of tubing in 3 identical parallel circuits of 70 feet [20 m] each. A liquid line filter/drier, receiver, and sight glass follow the condenser.

150 feet [46 m] of 5/8 inch [1.6 cm] outer diameter soft copper refrigeration tubing run from the system's high side into a 4000 cubic foot [110 m^3] room which houses the evaporator. Several low spots are deliberately placed in this tubing. A thermostatic expansion valve sized for 3 tons [12 kW] 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 [180 m] in length. Air is forced over the evaporator fins by two fans.

Another 150 feet [46 m] of tubing run from the evaporator to the compressor's suction port. The outer diameter of this tubing is 9/8 inches [2.9 cm]. Several bends occur in this tubing, and two very pronounced low points are equipped with access valves and sight glasses to visually evaluate oil removal at these locations. An intentional dead spot occurs at the evaporator inlet just after the expansion valve. The evaporator temperature was maintained at 40° F [4° C] for all laboratory tests.

Before each test was conducted, the system was prepared by isolating the compressor and reverse flushing the high and low sides with reclaimed CFC-12 for 4 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 and any oil separators) consistently measured between 12 and 14 ounces [350 and 400 grams] of mineral oil.

An Atago N-3000 hand refractometer, frequently the choice of AC&R field 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 50 percent. As these tests were done by laboratory personnel, results from refractometers used in the field should be interpreted cautiously. ISI also measured the mineral oil content of the polyolester by liquid chromatography; the results in this report are derived from this method as it is known to be more accurate. A more comprehensive review of each method will be discussed as part of the final report of this contract.

Method Description: "Triple Flush"

The "triple flush" method for mineral oil removal is achieved by diluting the mineral oil in large amounts of polyolester lubricant. Repeated replacement of the compressor lubricant after periods of system operation result in progressively lower mineral oil levels. Unfortunately, this process does not isolate all of the mineral oil in one location where it can be effectively removed in one pass.

The "triple flush" method provides a straightforward, universally applicable, but costly and wasteful mechanism for removing mineral oil from a refrigeration system. 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; a hoist may be required. 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 provide guidelines indicating 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 concentration 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.

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 high side oil separator is temporarily installed in the compressor discharge line. This prevents all but a very 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 high side oil 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 5/8 inches [1.6 cm] OD.

The low side oil separator is actually a high side separator 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 low side 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 low side separator was 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 high side oil 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 high side oil separator rated to 99.994% efficiency to the compressor discharge line. The high side separator should be charged with POE to the separator manufacturer's recommendations.

4. Install an appropriately sized "high 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 should be run a minimum of 24 hours.

6. Pump down and recover the CFC-12 from the system.

7. Remove the high and low side oil 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 should 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 if appropriate. 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.

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 low side oil separator is installed after the accumulator. If this is not possible, it should be 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 serious 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 low side oil 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 low side oil 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 high side oil 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 its oil would be lost to the system with this rating. Fortunately, a second separator was installed that was rated to 99.994% efficient and subsequently was tested to this rating. A detailed discussion of the specifications and characteristics of the oil separators used for testing will be provided in the final report.

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 an additional two days' mixing and a fifth visit would be needed to measure and document it. As Table 1 shows, material and labor charges for this retrofit are estimated at $743. Waste disposal does not appear as a cost, but will be included as part of the final report of this contract. Table 2 documents the waste generated from this procedure.

The baseline test employing the "triple flush" procedure required the <u>least</u> 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 is thought that larger system retrofits will accentuate the cost disparity of the triple flush procedure and the advanced method. 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 is thought that the amount of time for the oil-drain step will increase as system size is increased, and that the amount of POE used for the "triple flush" retrofit will also measurably increase. The field retrofits performed as part of this contract should bring more clarity to this proposition.

Table 1: Material and Labor Costs for Laboratory Procedures

Item	"Triple Flush"	Flush Test I	Flush Test II	Flush Test III
Final mineral oil level	2.6%	3.8%	5.7%	1.6%
Polyolester	$ 68	$ 32	$ 28	$ 43
Travel labor	$250	$150	$150	$150
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
Waste disposal				
Total cost	$743	$707	$636	$665

Cost Assumptions:

$35.00 / gallon [$9.25 / liter] for polyolester lubricant
$50.00 / visit for travel labor
$40.00 / hour on-site labor

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 Flush Test 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, Flush Test II shows the result of this compromise to the method. Flush Test III remedies this using a second lubricant change.

Flush Test 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; this required a hoist. Polyolester lubricant (Mobil Arctic 22) was then added to the compressor and high side 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 very 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 1. The high and low side 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 three separate site visits. 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. Although the lubricant was tested during this site visit, a third and final site visit was utilized to retest the lubricant and evaluate system performance. No unusual observations were reported. Although laborious, this third site visit should remain a standard practice for this procedure to allow sufficient time for the remaining system lubricant to mix uniformly with the compressor lubricant. The mineral oil level at the compressor, however, did not change appreciably after the second visit in any of the laboratory tests; this is one indication of the low side separator's efficiency in removing mineral oil.

Flush Test 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 2. 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.

Table 2: Summary of Laboratory Flush Tests

	% Mineral Oil	Retrofit Cost	Waste Generated	Site Visits Required
Flush Test I	3.8	$707.00	2420 g	3
Flush Test II	5.7	$636.00	2350 g	3
Flush Test III	1.6	$665.00	4040 g	3
Triple Flush	2.6	$743.00	6050 g	5

See Table 1 for a detailed cost breakdown and pricing assumptions.

Flush Test II

While the proper compressor oil drain procedure is that outlined in Flush Test I, inaccessibility, time constraints, or other problems sometimes make the recommended procedure impractical. For this reason, a second test was conducted to determine the 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. Flush Test II shows the result of this compromise to the method. Flush Test III resolves this by simply employing a second lubricant drain if the analysis reveals excessive mineral oil levels.

Except for the change to the compressor oil drain procedure, this test was conducted incorporating the identical test methodology described in Flush Test 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 vist.

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

Flush Test III

Flush Test 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 Flush Test 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 sixth site visit would have been required to achieve this result by the triple flush method on ISI's laboratory system.

Field Retrofits

Integral Sciences Incorporated will evaluate the advanced method on field equipment during the first quarter of 1995. Supermarket retrofits will be performed on three separate systems, one of which will be an R-502 conversion. A contractor will assist ISI with these tests and provide feedback related to any practical advantages or difficulties encountered.

The field tests are not expected to present any unusual difficulties, and a final report will follow shortly after the conclusion of the field retrofits documenting the proposed mineral oil removal method, testing procedures, conditions, and results in a manner which will enable future investigators to reproduce these experiments. A list of equipment, materials, waste disposal, time, and capital requirements will also be included.