1996

Serviceability Issues Associated with R407C Refrigerant

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WITH

R407C REFRIGERANT

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Abstract

Many investigators in the past have indicated that R407C is a drop-in HCFC-22 replacement. Engineering testing have shown that R407C is not practically a simple drop-in refrigerant. System performance at ARI conditions of 80F Tdb/67F Twb indoor and 95F Tdb outdoor temperatures, has dropped by 3% to 4% in capacity and up to 5% in efficiency. Additional testing was conducted to simulate slow leak (isothermal leak) from the system up to 50% of the nominal charge at the suction, discharge and liquid lines, and after TXV. When the leak simulation was completed the system was recharged with the nominal composition of R407C. Laboratory test results showed that the composition of R407C changed especially during the first two leak simulations and were dependent on the location of the leak.

Performance degradation of the system during the standard operation as well as during the leak simulation suggest that R407C is not a practically drop-in HCFC-22 replacement.

1. Introduction

The depletion of the Earth's stratospheric ozone layer is a global problem which has to be solved during the next several years. According to the Montreal Protocol and the Copenhagen Amendment, the phase-out of ozone depleting substances is as follows:

CFCs	HCFCs
in 1995 - 100%	in 1996 - freeze
	in 2004 - 35%
	in 2010 - 65%
	in 2020 - 99.5%
	in 2030 - 100%

The latest satellite measurement of the ozone layer over Antarctica revealed a hole as big as the United States which appears each Spring and grows even bigger every year. This situation puts pressure on scientists and engineers to find new fluids which would replace CFC and HCFC refrigerants. So far, chemical companies have manufactured few single refrigerants and mixtures which due to their Global Warming Potential (GWP) and Atmospheric Life Time (ALT), are rather short term replacements for CFCs and HCFCs. Hydrofluorocarbons (HFCs) have to fulfill very strict conditions, and must be both non-toxic and non-flammable. In addition, these refrigerants must exhibit low electrical conductivity, material and oil compatibility, good thermodynamic and transport properties. They must be chemically stable with GWP of less then 0.5 and ALT of less then 15 years. Finally, new refrigerants have to be cost effective and easy to manufacture. When the impact of CFCs and HCFCs compounds on the atmosphere was discovered, scientists, chemical companies, and the HVAC&R industry spent a great deal of money, time, and energy to approve new alternate refrigerants. Alternatives have been sought among partially halogenated hydrocarbons, among different classes of organic compounds, and among mixtures. The existence of hundreds of refrigerants is predicted. Of those only some 30 - 40 have been reported as possible alternatives to CFCs and HCFCs. In the past, the most widely used refrigerants were CFC-11, CFC-12, HCFC-22, and R-502. However, since these refrigerants are no longer environmentally acceptable, we must continue to look for better alternatives.

2. Compressor Calorimeter Test

The drop-in compressor calorimeter test was provided by the compressor manufacturer. The purpose of this test was to understand how the mixture performs with the compressor and to quickly estimate the system performance. Also, the compressor calorimeter test results would allow to check the heat balance during the system tests. The testing of zeotropic mixtures provides particular challenges. Special consideration must be given to the terms "evaporating temperature" and "condensing temperature" since blends with temperature glide may have significant temperature differences across the heat exchanger. Another concern while testing zeotropic blends was that the refrigeration composition flowing through the compressor might be different than the bulk refrigerant composition in the system. This is due to different vapor pressures within the components and the possibility that one or more of the components could reside in the accumulator in the liquid phase or with the oil in the compressor crankcase.

3. Drop - in test

The purpose of this test was to quickly estimate the performance of the system charged with R407C and to focus the attention on how the new refrigerant impacts performance and serviceability. This test was classified as a drop-in test even though the lubricant and the TXV were changed.

3.1 Test facility

The experimental evaluation of R407C system was conducted on a commercially available 3 ton HCFC-22 Split System Heat Pump (SSHP). The tested unit was instrumented with refrigerant-side and air-side temperature and pressure sensors, watt transducers and watt hour meter. Temperatures were measured with thermocouples. Pressure readings were made with pressure transducers. Indoor and outdoor conditions were maintained within 0.5F dry-bulb, and within 1% relative humidity of the set conditions. All instrumentation were calibrated before conducting the test. The test was performed according to the ARI Standard 210/240 (1989) following the loop air-enthalpy method. The enthalpies were determined by measuring the wet and dry bulb temperatures along with the pressure of the air entering and leaving the indoor unit.

The 3 ton SSHP was placed in the psychrometric room simulating outdoor conditions (outdoor unit), while the indoor unit was located in another psychrometric room simulating indoor conditions.

3.2 Tested equipment

A 3 ton HCFC-22 split heat pump

- Capacity:	3 ton
- Efficiency:	12 SEER

was tested with the following changes:

- Compressor:	POE oil
- Expansion device:	TXVs (ID and OD) were adjusted
- Refrigerant:	R407C

- No other changes were made to the system

3.3 Test results

- performance

The compressor, TXV, oil and refrigerant were changed. The system was flushed three (3) times to insure less than 5% of mineral oil (MO) remained in the system. Therefore, the test represent pure drop - in replacement of HCFC-22 which is realized in the field. The drop-in performance test results obtained during the steady-state cooling and heating conditions with the working fluids HCFC-22 and R407C are presented in Fig.1 and Fig.2.

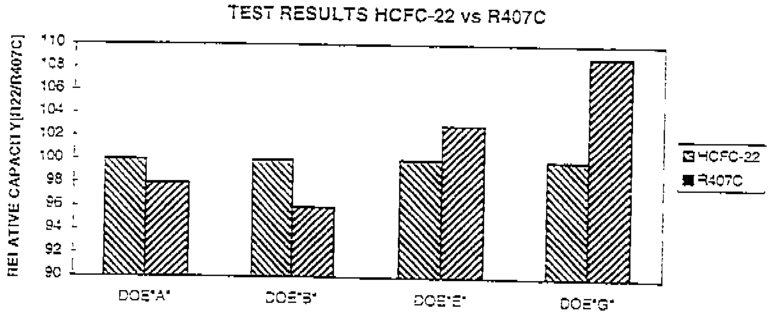

Fig.1

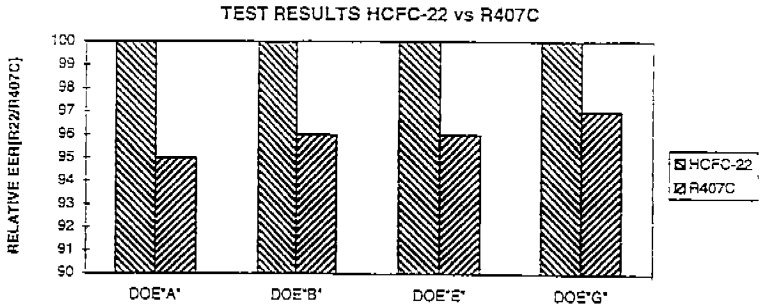

Fig.2

The comparison of R407C test with HCFC-22 baseline test showed that the capacity and EER measured with the blend R407C were 3% to 4% lower for the cooling mode. For the heating mode, the capacity was 4% to 9.0% higher and EER was 3% to 4.0% lower than that of HCFC-22.

The efficiency degradation was due to the higher pressure ratio of R407C. On the other hand, the lower capacity was due to higher vapor specific volume of the R407C mixture so the compressor with the fixed displacement pumped less refrigerant through the system.

Related to the performance is a temperature glide and the heat exchanger geometry which could be related to the degradation in performance of the system. The temperature glide could be beneficial if the heat exchanger is configured as counter flow.

- leakage

The objectives of the leakage test was to simulate serviceability of the unit and to determine the effect of repeated loss of the system charge and recharge on the system performance. This issue is vital in case of field units which are topped off with charge several times by field technician. The system performance as well as circulating and leaked mixture composition, are crucial. It was desired to determine the percent system performance degradation, as well as the final circulation composition. The final (circulating and leaked) mixture composition is a concern not only due to performance, but flammability issue as well. (Due to lack of proper equipment - gas chromatograph - for the composition analysis we concentrated on the system performance degradation).

The leakage test was simulated by removing a known amount of charge from the system and recharging the same amount of pure mixture (R407C). The leakage was conducted in four (4) different places:
- after TXV
- suction line at 6" from the compressor
- discharge line at 6" from the compressor
- liquid line at the exit from the condenser

To simulate a leak the following procedure was used:
- from each location; 10% of the system nameplate charge was removed
- system was charged to nameplate amount
- cooling and heating ARI tests were conducted
- the removal and recharge for 20%, 30%, 40%, and 50% of the system nameplate charge were repeated.

4. Results analysis

Shown on the following charts are the test results from the leakage tests. During these tests, there was a considerable fluctuation in latent heat, subcooling, and superheating measurement. Therefore, for a comparison of the system performance in each test the results were normalized, which gives a good representation of the overall system performance. The test results are presented in Fig. 3 through Fig. 10.

4.1 Capacity and Efficiency

The results obtained during the steady state cooling and heating modes are shown in Fig. 3, 4, 5, and 6.

The cooling and heating capacity dropped by 3% to 4% when the leak was simulated after TXV. This was due to the 2 phase flow and the loss of R32 which is the highest pressure component in the mixture.

4.2 Subcooling and Superheating

The maximum subcooling change was measured when leak occurred in the liquid line during the cooling mode as indicated in Fig.8.

In terms of superheating the greatest decrease was observed during the leak from the suction line in the heating mode. It was due to the loss of R32 and R125 from the system.

5. Discussion

The general observed trend was a drop in both capacity and efficiency and also in suction and discharge pressures. It was due to a loss of R32 which is the highest pressure component in the mixture. Flammability issue may have to be considered for vapor leaks due to the higher percentage of R32 in the leaking vapor. Pressures drop causes a drop in the power consumption by the compressor.

The system performance was slightly effected by shifting the composition in the system. Capacity for cooling and heating modes dropped approximately 3% to 4%, and efficiency dropped by 5% in the worse case.

6. Conclusion

A typical Split System Heat Pump (SSHP) was tested with alternative refrigerant. Without any changes (drop-in test) the R407C mixture showed decreases in efficiency and capacity. The mixture has a major problem - fractionation, due to the temperature glide. The basic issue is how to deal with the difference in the composition between the liquid and vapor phase. Due to the fractionation issue and the performance degradation the R407C mixture cannot be classified as a drop - in replacement for HCFC-22. The most important part of the test was how a mixture with the temperature glide behave in the field, and how to deal in the field with this kind of mixture.

When a leak occurs the technician charge the system based on the superheat/subcooling, because he can measure temperatures and pressures. Depends on the location of the leak the system during the recharge process can be over- or under-charge.

Overcharging the system decreases the system efficiency and in addition when the mixture leaked from the two phase flow area the remained mixture contains more R125 and R134a. More R125 in the system increase in addition the power consumption of the system.

Undercharging the system (leak occurs at the suction line) decrease the capacity of the system as well the suction and discharge pressures. This is due to the loss of R32 which is the highest pressure component of the mixture.

Summarize the test results we concluded:

1. Superheat and subcooling variation:

a) The subcooling and superheat varied depending on the leak location

b) Cooling superheat variation:
- the leak from the liquid line decreased the superheat due to a less R32 and R125 in the system
- the leak after the TXV increased the superheat due to a lower percentage of R32 in the system

c) Cooling subcooling variation:
- the leak from the liquid line decreased the subcooling due to a less of R32 and R125 in the system
- the leak from the suction line increased the subcooling due to the higher amount of R134a in the system

d) Heating superheat variation:
- loss of R32 and R125 from the system during the leak after the TXV decreased the superheat

e) Heating subcooling variation:
- the leak from the liquid line decreased the subcooling due to the lower R32 concentration in the system
- the leak from the discharge line increased the subcooling due to the higher R134a concentration in the system.

2. Performance variation

a) When 50% of charge was leaked and recharged to the nameplate amount, the capacity dropped 3% - 4% and efficiency 5%

b) Capacity and efficiency degradation :
- capacity and efficiency depend on the location of the leak
- the highest degradation in both capacity and efficiency from the suction line and after the TXV is due to the two phase flow when leaked vapor was richer in R32

c) Higher amount of HFC-125 in the system decreased the efficiency

d) The composition change has a significant impact on the subcooling and superheating during both cooling and heating modes.

Besides the performance degradation an zeotropic mixture creates another problems related to the temperature glide and fractionation associated with the temperature glide. These problems were identified and are as follows:

1. Service issues:
a) The composition of refrigerant remaining in the system that is leaking cannot easily determine
b) The system must be charged with the liquid phase
c) The composition of refrigerant in charging cylinder cannot cannot easily determine
d) If a system leak occurs, the system should be reclaimed and recharged with the nameplate amount
e) Due to superheat and subcooling variations, a technician can easily overcharge the system if he charges to superheat
f) The HCFC-22 system has to be flushed before charging with R407C and POE oil
g) POE oil is very hygroscopic and the system cannot be opened longer than 10-15 min.
h) Mixture of water and POE oil form acid that react with motor winding insulation
I) POE oil act as detergent, removing paraffin used as a drawing lubricant that subsequently can plug capillary tubes
k) New leak detection equipment is required
l) Recovery machine is required

2. Design issues
a) Temperature glide effect - coils redesign is required to take the advantage of the glide
b) Additional surface area will be needed to meet minimum energy efficiency requirements
c) Optimizing inner groove geometry of enhanced tubes to properties of new refrigerant could be required
d) The compressor bearing lubrication systems can be redesigned
e) Higher discharge temperature and lower heat transfer characteristics require redesigned OD and ID coils
f) The use of the zeotropic mixture may result in an ice formation in the low temperature

3. Manufacturing issues:
a) Mixture composition in the storage tank and the charging station can vary
b) In case that in a storage tank left 20% of R407C , all remained mixture should be reclaimed?
c) Gas chromatography can be required on the production line
d) New leak detection equipment is required
e) Lower moisture level (bellow 60 ppm) is required
f) POE oil could potentially react with expending lubricants, rust inhibitors, solvents, and other chemicals
g) Production process changes are necessary to prevent moisture contamination

4. Safety issues:
a) Due to the temperature glide the mixture fractionate
b) Leaking gas can be flammable (rich in R32)
c) Mixture of water and POE oil forms acid, therefore eyes and hand protection is required during the service

ACKNOWLEDGMENTS
The authors would like to acknowledge the support of York International - Unitary Product Group in Norman and the cooperation of Rick Marrale - Vice President of Engineering, we are greatly appreciated.

R407C - COOLING CAPACITY VARIATION AS A FUNCTION OF % REFRIGERANT REMOVAL AND ADDITION

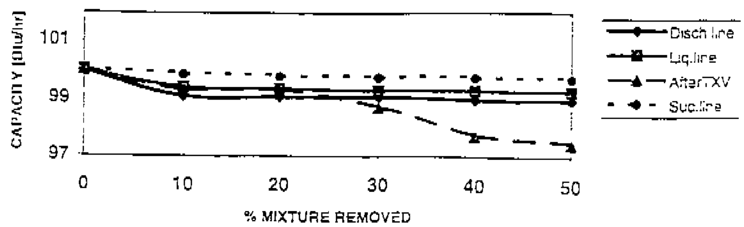

Fig.3

R407C - COOLING EER VARIATION AS A FUNCTION OF % REFRIGERANT REMOVAL AND ADDITION

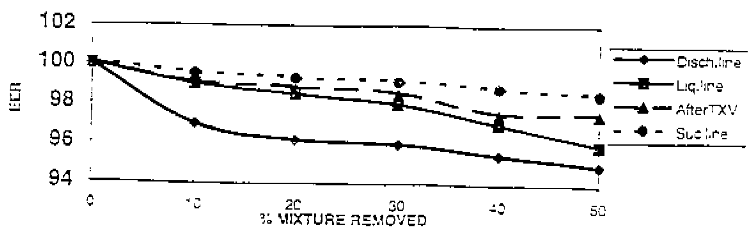

Fig.4

R407C - HEATING CAPACITY VARIATION AS A FUNCTION OF % REFRIGERANT REMOVAL AND ADDITION

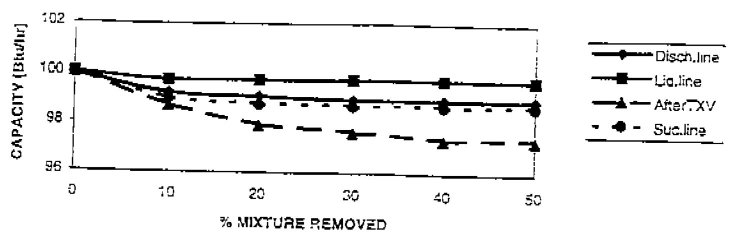

Fig.5

R407C - HEATING COP VARIATION AS A FUNCTION OF % REFRIGERANT REMOVAL AND ADDITION

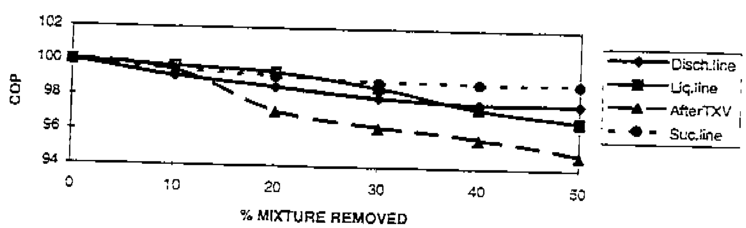

Fig.6

R407C - COOLING SUPERHEAT VARIATION AS A FUNCTION OF % REMOVAL AND ADDITION

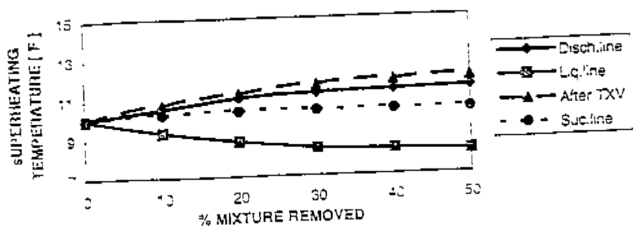

Fig.7

R407C - COOLING SUBCOOLING VARIATION AS A FUNCTION OF % MIXTURE REMOVAL AND ADDITION

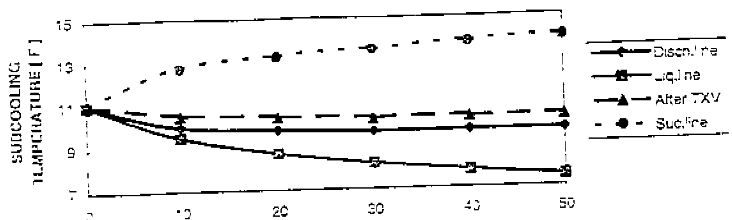

Fig.8

R407C - HEATING SUPERHEAT VARIATION AS A FUNCTION OF % REFRIGERANT REMOVAL AND ADDITION

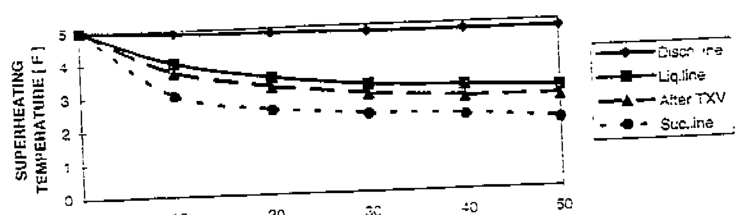

Fig.9

R407C - HEATING SUBCOOLING VARIATION AS A FUNCTION OF % REFRIGERANT REMOVAL AND ADDITION

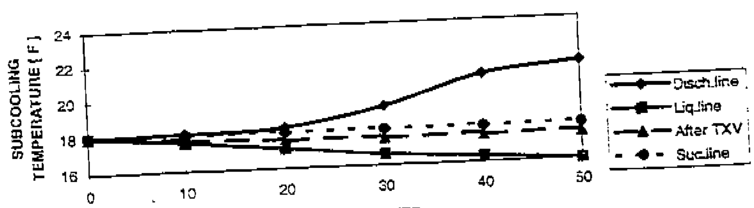

Fig.10