ENERGY SAVING REFRIGERANT BLENDS COMPRISING R125, R134a, R600 OR R600a

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ABSTRACT

The replacement of CFCs and HCFCs under revisions of the Montreal Protocol to limit damage to, and ultimately allow recovery of, the ozone layer is now well underway. This replacement process has been due to studies of hydrofluorocarbon based blends resulting in products such as R407C, R404A and R507A to replace R22 and R502. Although these blends have enabled a relatively swift transition away from ozone depleting substances, it is questionable if the energy efficiency or global warming potentials of these products are satisfactory or if better non-flammable HFC alternatives exist.

This paper presents the results of laboratory and practical studies of three HFC blends based on R125, R134a and R600 or R600a which have been shown to demonstrate superior energy efficiency and in one case 23% lower global warming potential than the above mentioned HFC alternatives.

1. INTRODUCTION

The replacement of CFCs and HCFCs under revisions of the Montreal Protocol to limit damage to, and ultimately allow recovery of, the ozone layer is now well underway. This replacement process has been due to studies of hydrofluorocarbon based blends resulting in products such as R407C, R404A and R507A to replace R22 and R502. Although these blends have enabled a relatively swift transition away from ozone depleting substances, it is questionable if the energy efficiency or global warming potentials of these products are satisfactory or if better non-flammable HFC alternatives exist.

Later revisions of the Montreal Protocol have now dictated the future phase-out of HCFCs and this program is now underway with regional variations e.g. in the EU production will be completely phased out by 2010, USA a 90% phase out by 2015. Also end use controls are being introduced e.g. production of new equipment has already been banned in the EU and in the USA R22 will be banned for use in new equipment from January 1 2010.

This has resulted in the refrigeration properties of chlorine free HFCs, being investigated. These can retain many of the advantages of CFCs and HCFCs. Non-flammability can be achieved by keeping the hydrogen to fluorine ratio low. Many of them have a very low toxicity similar to the CFCs. Stability within the equipment can be high, but they have the advantage that after release to the atmosphere, they are more rapidly degraded.

Non-accumulation within the atmosphere is important, since although HFCs do not affect the ozone layer, they are strong greenhouse warming gases. The greenhouse warming properties of the HFCs are seen as a significant problem, particularly in Europe, where certain countries have already placed severe taxes on HFCs based on their GWP and others are proposing use bans.

Pure HFC based products have the problem of not being suitable for use with the traditional lubricants; e.g. mineral oils or alkylbenzene oils, due to poor oil transport properties. This has resulted in the development of alternative oils, e.g. polyolester oils; however, these have the disadvantages of being both higher cost and sensitive to moisture. An alternative solution is to add some hydrocarbon to the refrigerant to aid oil transport, but not sufficient to cause flammability. An example of this type of refrigerant is R417A, which Roberts (1998) showed has good oil transport properties for the traditional lubricants.

Currently, there are several HFC blends available to meet the requirements of R22. For use in air conditioning units R407C, R410A and R417A are used. The first two have the disadvantage of not being suitable with mineral or alkylbenzene oils and the R410A requires significant redesign due to the large differences in physical properties. The R417A can be used with mineral based lubricants and has a slightly lower cooling capacity than R22 but has demonstrated significant increase in energy efficiency.

The present zero ODP substitutes for R502, and R22 in low temperature applications, are R404A and R507A. The problem with these products is that they have the highest global warming potentials (GWPs) of the commonly used HFC refrigerants. At low temperatures, R22 generates very high compressor discharge temperatures and, in addition, is an ozone depleter and so will be phased out.

The concept of global warming potential (GWP) has been developed to compare the ability of a greenhouse gas to trap heat in the atmosphere relative to carbon dioxide and are, hence, given as dimensionless numbers. The global warming potentials for gases quoted are given in IPCC (1996) for the 100 year time horizons. There is a later report, IPCC (2001), but the earlier one was that used in the Kyoto protocol and is hence used here.

R507 has a GWP of 3300 and R404A is only slightly less at 3260. These high GWPs are due to the main component, R143a (CF_3CH_3), which has a GWP of 3800. In contrast, the GWPs of R125 and R134a are 2800 and 1300 respectively. A blend based on the latter two compounds will thus have a lower GWP than R404A or R507.

This paper examines the performance of two refrigerant blends comprising R125, R134a and either R600 or R600a. The compositions of the blends are given in table 1 and the performances of each blend in laboratory calorimeter systems have been published previously by Roberts (1998) and Chambers and Roberts (2003). This paper aims to give a summary of the performance of these blends as determined in the field or in ‘off the shelf’ units. Although every effort was made to measure all relevant parameters and make comparisons on a like for like basis much of the work was performed by third parties in ‘real world’ situations with the result that the data reported is more of a qualitative nature i.e. the data gives a firm indication but the absolute values may be different.

2. THE BLENDS

The two blends under consideration in these studies are intended for different applications. The first blend is R417A which has been available since 1997 and is suitable for use as a general R22 replacement in high, medium and low temperature applications. The second blend (R422A) has been developed for use in low temperature applications which would have previously used R502.

Table 1 Refrigerant blend compositions and selected properties compared to R22 and R502

	R22	R502	R417A	R422A
Composition	$CHClF_2$	R115 / R22 (51.2% / 48.8%)	R125 / R134a / R600 (46.1%/50.0%/3.4%)	R125 / R134a/R600a (85.1%/11.5%/3.4%)
Normal boiling point / ºC	-40.8	-45	-41.8	-48.7
Max. temperature glide at normal boiling point / K	0	0	5.1	2.5
Saturated Liquid Vapour pressure @ -20ºC	2.45 bar	2.87 bar	2.43 bar	3.24 bar
Saturated Liquid Vapour pressure @ 40ºC	15.34 bar	16.64 bar	14.36 bar	18.58 bar
Temperature at critical point	96.1ºC	80.2ºC	89.9ºC	71.8ºC
Ozone Depletion Potential	0.05	0.23	0	0
Global Warming Potential	1700	5600	1938	2530

As can be seen from table 1 above, R417A is a ternary zeotropic blend which has the ASHRAE Standard 34 (2001) safety classification A1 (i.e. lowest toxicity and lowest flammability classification). The physical properties of

R417A are very similar to that of R22 allowing, for the majority of cases, R417A to be used in equipment designed for R22 without any equipment or engineering changes. R417A does contain a small quantity of hydrocarbon which provides compatibility for use with mineral based lubricants but, as shown by the safety classification, remains non-flammable even under the worst case leak scenarios defined in the ASHRAE standard. As previously mentioned the performance of R417A has been proven in calorimeter studies but the real test for any refrigerant blend is in 'real world' situations and this paper summarises conversions from R22 in a range of applications from heat pump to low temperature supermarket systems. Although the GWP of R417A is higher than that of R22 it has been found that in the majority of cases lower energy consumption is achieved after conversion which gives a lower total equivalent warming impact (TEWI).

The R422A is also a ternary zeotropic blend and as with R417A when replacing R22, R422A can be used in systems originally designed for R502 without the need for equipment or engineering changes and can also be used with mineral based oils. As R422A is zero ODP it can also be considered as a replacement for the HCFC based R502 replacements such as R402A and R408A and an example of this is included. The current phase-out legislation based on the Montreal Protocol only addresses the ozone depletion issue but the Kyoto Protocol is bringing attention to global warming. Although no phase-out legislation exists based on GWP, some countries (Austria and Denmark) have proposed bans on HFCs due to their high GWP values. Many more countries, the EU in particular, are focussing on controlling emissions in terms of carbon dioxide equivalents (i.e. the same units as GWP) and so any reduction in the GWP value of the refrigerant will increase the possible reductions in emissions that can be achieved. As R422A has a significantly lower GWP than the currently used low temperature refrigerants, i.e. R404A and R507A, then it can also be considered as a possible successor for these products. This paper gives results from conversions of low temperature systems converted from R408A, R404A and R22.

3. FIELD STUDIES

A summary of the studies reported in this paper is given in table 2.

Table 2. Summary of field studies.

Converted From	Converted To	Application	Evaporator Temperature	Compressor Power (R22)
R22	R417A	Airedale close control ducted air conditioner	5 ºC	8.35 kW
R22	R417A	Liebert close control air conditioner	10.8 ºC	6.99 kW
R22	R417A	Weatherite rooftop reverse cycle air conditioner	-6ºC/-2ºC Heat / Cool	17.9kW/19.7kW Heat / Cool
R22	R417A	Supermarket low temperature rack	-35 ºC	53.2 kW
R408A	R422A	Supermarket low temperature rack	-35 ºC	Not reported
R404A	R422A	Reach-in commercial freezer	-30 ºC	1.6 kW
R404A	R422A	Frozen food storage room	-35 ºC	14.4 kW
R22	R422A	Supermarket medium & low temperature racks	-36 ºC to 1ºC	375 kW total

The conversions were done in Europe and the USA and all parties were requested to follow the general conversion procedure given below.

Prior to conversion the system was checked and any obvious problems were rectified. The system was fitted with the full data logging equipment and monitored for two weeks prior to conversion. Where possible the suction, discharge, liquid line and evaporator exit temperatures and pressures were recorded as well as the ambient and cooling medium temperatures. As well as temperature and pressure measurements the compressor power consumption was also recorded to determine if any energy savings would be made following conversion.

At the time of conversion no changes were made to the equipment other than those considered good refrigeration practice e.g. change filter dryer, checking and if necessary adjusting the superheat. No changes were knowingly made to the system that may have artificially improved the performance of the replacement refrigerant. Once the data for both the original and the replacement refrigerants were collected it was analysed to find periods of similar operating conditions in order to compare the two fluids.

4. RESULTS AND DISCUSSION

4.1 Conversion of an Airedale Close Control Ducted Air Conditioner from R22 to R417A

Tesco supermarkets of the UK initiated a program of trials to investigate possible R22 replacements. This particular unit was situated in a computer suite at one of the Tesco office buildings. The unit converted was an eleven year old Airedale Model EDFGFC20T incorporating 3 Maneurop reciprocating compressors. The conversion was made without any modification and typical operating data is shown in table 3. The refrigerant charge was optimised and in this case was found to be 10% less than the R22 removed (6.9 kg of R417A compared with 7.7 kg R22). The temperature and pressure data was gathered using an Eltec 1033U data logger fitted with calibrated pressure transducers and k-type surface mounted thermocouples. The energy consumption of the unit was monitored using a Trifid T210P logging monitor.

It was noted that the systems typically operated with two of the three compressors running 24 hours per day both before and after conversion.

Table 3. Typical operating parameters of R22 and R417A in an Airedale close control Ducted Air Conditioner

Parameter	R22	R417A
Evaporating Pressure / bar	5.84	5.01
Evaporating Temperature / ºC	4.5	4.1*
Discharge Pressure / bar	20.32	19.63
Condensing Temperature / ºC	51.5	56
Discharge Temperature / ºC	76	66
Suction Superheat / K	12	11
Liquid line subcooling / K	5	11.5
Evaporator Air off temperature / ºC	20.5	18
System power / kW	8.35	7.24
Typical run time / hours/day	24	24
Amps per phase	12.5 / 13.8 / 13.6	11.6 / 12.8 / 12.5

*Mean evaporator temperature

In general the operating conditions were very similar between the two refrigerants. The notable differences after conversion were the higher condensing temperature, increased liquid subcooling and the decrease of the system power by 13%. The two beneficial differences occurred despite the higher condensing temperature with R417A. Determination of the actual cooling capacity was not possible in the field as there were too many uncontrollable variables however the fact that the third compressor did not run when converted to R417A indicates sufficient capacity was available.

4.2 Conversion of a Liebert Close Control Air Conditioner from R22 to R417A

This Liebert FE 240G-G10 close control air conditioner was used for computer room temperature control. Again the Eltec 1033U and Trifid dataloggers were used to collect the operating data.

As with the previous example the operating conditions with R417A are very similar to those with R22. The condensing temperatures are again slightly higher with R417A but despite this the power consumption of the unit is 4% lower with R417A than with R22. The difference in air temperature on and off the evaporator is virtually identical for both fluids indicating no problems with lower capacity was experienced. No humidity data was logged but over the 16 day logging period it is likely that the average conditions were comparable for both fluids.

Table 4. Typical operating parameters of R22 and R417A in a Liebert FE 240G-G10 Air Conditioner

Parameter	R22	R417A
Suction pressure	72 Psig	66 Psig
Suction temperature	6ºC	7ºC
Discharge pressure	16.88 to 18.12 Psig	16.53 to 17.22 bar
Condensing temperature	44 to 47ºC	48 to 50ºC
Discharge temperature	76ºC	47ºC
Superheat	9 K	3K
Sub cooling	10K	11K
Air supply	23 to 23.8ºC	23 to 24.0ºC
Air Return	20.4 to 21.5ºC	20.4 to 21.5ºC
Average Power consumption over 8 days	6.99kW/h	6.69kW/h
Amps per phase	11.73	11.23
Mean Ambient (daytime)	22.5ºC	23.0ºC

4.3 Conversion of a Weatherite Rooftop Reverse Cycle Air Conditioner from R22 to R417A

The unit was a packaged reverse cycle air conditioner model RHPE 125/2/90 using two Maneurop scroll compressors. The unit was monitored for one week on R22 and then converted to R417A and monitored for a further week. The manufacturer, Weatherite, was involved with the trial, performed the conversion and approved the results of the monitoring period.

Table 5. Typical operating parameters of R22 and R417A in a Weatherite Rooftop heat pump.

	R22	R417A	R22	R417A
Average data	Heating	Heating	Cooling	Cooling
LP	3.99 bar	3.39 bar	4.68 bar	3.89 bar
HP	13.57 bar	11.91 bar	16.74 bar	15.06 bar
Liquid Line	29.5ºC	28.7ºC	36.0ºC	36.8ºC
Suction Line	7.5ºC	-1.1ºC	14.1ºC	2.7ºC
Suction Superheat	9.0ºC	6.0ºC	10.6ºC	5.2ºC
Sub Cooling	7.5ºC	2.4ºC	9.0ºC	2.8ºC
Air On Indoor coil.	20.5ºC	20.4ºC	19.8ºC	17.7ºC
Air Off Indoor coil.	25.3ºC	25.1ºC	16.3ºC	14.6ºC
Capacity	34.8 kW	34.1 kW	25.4 kW	22.5 kW
Compressor Discharge	81.2ºC	54.1ºC	87.9ºC	58.2ºC
Compressor Power Input	11.45 kW	10.5 kW	12.9 kW	11.25 kW
Amps per phase	21.1	19.3	21.8	17.8

As with the previous examples the operating parameters of both refrigerants were very similar. The Superheat with R417A was less with R417A but still within acceptable limits. The capacity measurements made by the manufacturer show an almost identical heating capacity and an 8% lower compressor power with R417A. In cooling mode the capacity was 12% lower but the compressor power was 13% lower which could still give a net energy benefit.

4.4 Conversion of a Supermarket Low Temperature Rack from R22 to R417A

The system converted was a Hussman low temperature rack systems comprising 4 Copeland reciprocating compressors (2x D4DT2200 and 2x D4DT2500) with a air cooled roof top condenser feeding 7 low temperature cabinets or cold rooms.

The operating conditions as with the other examples were generally very similar. The most notable differences were the significantly lower compressor discharge temperature with R417A and the lower compressor power consumption. The monitoring period coincided with the very high temperatures experienced in the UK during the summer of 2003 and therefore it was not surprising that the unit run time was continuous. Despite the unusually high temperatures no capacity related issues were reported.

Table 6. Typical operating parameters of R22 and R417A in a Hussman low temperature rack system.

	R22	R417A
Evaporating pressure	5 Psig	5.9 Psig
Evaporating temperature	-35.5ºC	-32.3ºC (mean)
Average Discharge pressure	173 Psig	171 Psig
Condensing temperature	33.0ºC	38ºC
Average Discharge temperature	99.1ºC	78.5ºC
Peak Discharge temperature	107.5ºC	82.7ºC
Avg. Liquid Line temperature	31.2ºC	31.6ºC
δT air on/off condenser	5K	5K
Power Consumption (instantaneous)	53.2 kW	50.9 kW
Power Consumption (per day)	1277 kW	1222 kW
Amps per phase	73.4/78.3/68.9	68.1/73.3/67.0
Run Time	24 hours / day	24 hours / day
Highest Ambient	31.0ºC	34.4ºC

4.5 Conversion of a Supermarket Low Temperature Rack from R408A to R422A

The conversion was performed and the reported data was provided by Space Cooling of the UK.

Table 7. Typical operating parameters of R408A and R422A in a low temperature rack system.

Parameter (Average over 7 day period)	R408A	R422A
Suction Pressure / bar	1.0	0.4
Saturated Liquid Suction Temperature / ºC	-29	-37
Suction Temperature / ºC	17.5	17.3
Discharge Pressure / bar	15.1	13.8
Condensing Temperature / ºC	35.0	30.8
Discharge Temperature / ºC	101.7	70.0
Peak Condenser Pressure / Temperature	18.1 bar / 44.7 ºC	17.0 bar / 38.7 ºC
Peak Discharge Temperature / ºC	115	102
Ambient Temperature (24 hr average) / ºC	19.2	18.6

As can be seen from table 7, the unit whilst running with R408A may not have been fully optimised. The evaporating temperature was ~5 degrees higher than may have been expected to be normal for this type of application. Although the period of monitoring with R408A did see higher peak ambient temperatures, the 24 hour average temperatures were comparable. Because of these differences it is difficult to make a comparison but it can be seen that the compressor discharge temperature with R422A is significantly lower than that with R408A. The energy consumption was not monitored during this period but the engineers who performed the trial have subsequently reported verbally lower energy consumption.

4.6 Conversion of a Low Temperature Cold Room from R404A to R422A

The unit monitored was in Caerphilly, UK, and was used by Peter Food Services as a storage room for the frozen savoury foods they manufacture. The unit was cooled by a Uniblock Zanotti package utilising a Dorin K4000cc 3 cylinder compressor. The unit was charged with R404A and a polyol ester oil of unknown viscosity and manufacturer. Typical operating parameters are given in table 9 but the suction pressures were below the range of the transducer (i.e. below 0 bar gauge) and so not reported.

As can be seen the monitoring was performed during the winter at a period of relatively low ambient temperature. The capacity was not determined but there was no noticeable difference in the operation of the cold room indicating the capacities were similar. The most notable difference between the data for R404A and R422A is the 9% decrease in power consumption after the conversion.

Table 8. Typical operating parameters of R404A and R422A in a low temperature cold room.

Parameter	R404A	R422A
Ambient / ºC	7.1	8.3
Discharge Pressure / bar	10.37	10.08
Condensing Temperature / ºC	18.0	17.1
Discharge Temperature / ºC	75.0	71.5
Compressor Power / kW	14.4	13.1
Refrigerant Charge / kg	10.5	11.3
Liquid line temperature / ºC	18.5	16.0

4.7 Conversion of a Low Temperature Reach-in Freezer from R404A to R422A

An 'off the shelf' True Manufacturing 2 m^3 reach-in freezer supplied with R404A and a 1.6 kW Copeland semi-hermetic compressor with a capillary expansion device. The performance of the freezer was determined with both R404A and then R422A. As an indication of the relative capacity of the two refrigerants the time taken to pull down from 16ºC to -30ºC was measured and shown in figure 1. The charge quantity of R422A was 9% higher than R404A.

The pull down profile indicates a slightly greater cooling capacity for R422A compared to R404A especially at the lower temperatures which meant that R422A achieved the set point temperature significantly quicker than with R404A. The unit was allowed to run for a total of 420 minutes in continuous mode and the power consumption of the unit determined. After 420 minutes operating with R404A the freezer attained a temperature of -31ºC and had consumed 1734.05 Wh. After 420 minutes with R422A the freezer attained a temperature of -32ºC and had consumed 5% less energy (1648.42 Wh). The lower temperature attained was further evidence that R422A has greater capacity than R404A. Lower energy consumption combined with the lower GWP of R422A compared to R404A would make a significant reduction in carbon dioxide equivalent emissions.

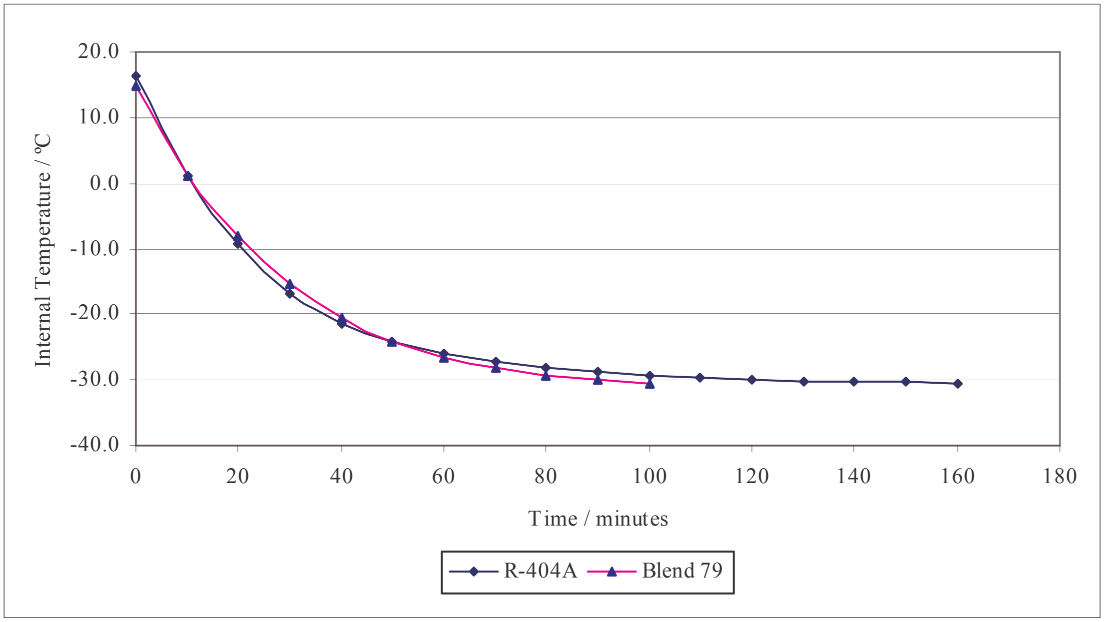

Figure 1. Pull down time comparison in a True Manufacturing freezer comparing R404A and R422A.

4.8 Conversion Of Supermarket Medium & Low Temperature Racks From R22 To R422A

A major US supermarket operator has decided to investigate the possible options to replace R22 in their refrigeration systems. A typical store was chosen consisting of 2 low temperature racks and 2 medium temperature racks with a total of 16 Carlyle 06 reciprocating compressors, 6 of which were compound. Due to the differences in properties of R22 and R422A it was necessary to change the power elements of the expansion valves to an R404A element and one of the racks required an oil change (Suniso 3GS) due to a compressor failure the week before the conversion. It was found during the conversion that 4 of the expansion valves were in fact incorrectly sized and so were replaced with the appropriate valves. Representatives from the compressor manufacturer and component manufacturers were present during the conversion and in line with their advice the o-rings in the system were replaced. The conversion of the entire store was completed within 12 hours.

The system was monitored before and after conversion but at the time of writing the data was not available but will be presented during the conference. The system has been reported as operating very satisfactorily.

5. CONCLUSION

In combination with the results reported by Roberts (1998) and Chambers and Roberts (2003) the results presented in this paper demonstrate that the blends R417A and R422A are suitable for use as replacements for the ozone depleting refrigerants R22, R402B, R408A and R502. In the case of R422A it has also been demonstrated that a superior performance can be achieved with a very significant reduction in carbon dioxide equivalent emissions compared to R404A and R507A when leakage is also considered.

R417A has been demonstrated as suitable for the full temperature range of applications from air conditioning (cooling and heating) to low temperature supermarket rack systems with no problems experienced through lack of capacity but in every case energy savings were experienced.

R422A has been demonstrated to be suitable for use as a replacement for the HCFC based R502 replacements without the need for system or oil changes and to replace R22 with minimal changes to the expansion valves. R422A has also been demonstrated to be suitable for use in R404A systems without changes and has also achieved energy savings.

The cases reported in this paper have been chosen to try to represent a range of different applications but are entirely representative of the case studies which the authors have had the opportunity to review i.e. in all cases studied no capacity issues have been identified and in the vast majority, where measured, energy savings have been achieved.

With the environmental focus moving from ozone depletion to global warming the importance of energy efficient lower GWP refrigerants will grow rapidly and the importance of R417A and R422A is likely to also grow.

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