LOW GWP REPLACEMENTS FOR R-404A IN A COMMERCIAL FREEZER

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VERY LOW GWP REPLACEMENTS FOR R-404A – PERFORMANCE TESTS IN A COMMERCIAL FREEZER

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Abstract

R-404A has been the global industry standard HFC refrigerant for commercial refrigeration in both small and large systems. However, due to its high global warming potential (AR4 100 year GWP = 3922), lower GWP alternatives to R-404A are urgently needed. In particular, the recently enacted European F-Gas regulation requires the use of lower GWP alternatives. Regulations on high GWP limits for HFCs are also being proposed in other regions.

To address this need, two hydrofluoroolefin (HFO) refrigerant mixtures with <150 and <240 GWP named Opteon™ XL20 (R-454C) and XL40 (R-454A) have been developed, respectively. Both are a mixture of HFO-1234yf and HFC-32. HFO-1234yf is in the formulation to dramatically reduce the GWP and HFC-32 has been added to increase the cooling capacity and provide performance close to R-404A. XL20 has been developed for smaller, hermetically sealed systems which face a ban of fluids with a GWP >150 for commercial refrigeration in 2022. XL40 offers better performance with a slightly higher GWP, representing the ideal solution for smaller, non-hermetically sealed systems. Though they are mildly flammable, the small charge sizes found in self-contained systems are intended to accommodate refrigerants with some degree of flammability.

This paper will present results from experimental testing of XL20 and XL40 in a self-contained freezer originally designed to use R-404A. Standard performance parameters will be measured and compared to the R-404A baseline, including energy consumption, pressures, temperatures and mass flow rate.

Introduction

Finding low GWP alternatives in commercial refrigeration continues to be a need because the leading HFC refrigerant in use is R-404A with a 100 year GWP of 3922 (IPCC4), among the highest of the HFC refrigerants. Though non-flammable A1 alternatives have been developed such as Opteon™ XP40 (R-449A) and Opteon™ XP44 (R-452A), there is need for lower GWP options to meet recently enacted regulations under European F-Gas 517/2014.

Two new refrigerants have been developed with performance similar to R-404A, named Opteon™ XL20 and Opteon™ XL40. Both have received a safety classification of A2L and provisional name of R-454C and R-454A, respectively. While Opteon™ XL20 (R-454C) is a mixture containing 21.5 weight% R-32 and 78.5 weight% HFO-1234yf, Opteon™ XL40 (R-454A) is composed of 35 weight% R-32 and 65 weight% HFO-1234yf; the higher content of R-

32 leads to an improved performance of Opteon™ XL40 but also to a slight increase in GWP. While its GWP amounts to 238 (IPCC5), Opteon™ XL20 has a lower GWP of 146 (IPCC5), falling under the important threshold of 150 in F-Gas and Ecodesign. Since they are mildly flammable, their use will likely be limited to small and medium-sized charge direct systems. Drop-in performance of both has been evaluated in a reach-in freezer originally designed for R-404A. Thermal stability and materials compatibility have also been assessed.

Thermodynamic Properties And Performance

A comparison of thermophysical properties of XL20 and XL40 compared to R-404A are shown in Table 1. The boiling points are very similar with the critical point about 7-10 K higher than R-404A. Vapor pressures and liquid densities are slightly lower, as well as the vapor densities which will reduce mass flow rates.

Table 1: Thermophysical Properties

	R-404A	**Opteon™ XL20 (R-454C)**	**Opteon™ XL40 (R-454A)**
Boiling Point °C	-47	-46	-48
Critical Point °C	72	82	79
Vapor Pressure at 25°C in kPa	1254	1169	1342
Liquid Density at 25°C in kg/m3	1044	984	977
Vapor Density at 25°C in kg/m3	65.3	44.3	47.7

To evaluate the thermodynamic cooling performance, cycle modeling was performed for XL20 versus R-404A under low temperature refrigeration conditions: Evaporator temperature = -35 °C, Condenser temperature = 40 °C, Subcool amount = 2 K, Superheat = 15 K and compressor isentropic efficiency = 70 %. Results shown in Table 2.

Table 2: Thermodynamic Cycle Performance

	P_{suct} bar. g	P_{disch} bar. g	T_{disch} °C	$T_{glide, Evap}$ °C	CAP kW	CAP Rel to R-404A	COP	COP Rel to R-404A
R-404A	0.64	17.2	84	0.4	82.3	100 %	1.252	100 %
Opteon™ XL20 (R-454C)	0.25	14.5	95	4.4	73.3	89 %	1.362	109 %
Opteon™ XL40 (R-454A)	0.54	17.2	108	4.3	91.0	111 %	1.372	110 %

Opteon™ XL20 (R-454C) exhibits slightly lower pressures and capacity than R-404A because it is a lower pressure refrigerant. However, the thermodynamic cycle efficiency is 9 % higher than R-404A. Opteon™ XL20 also has a moderate temperature glide. However other refrigerants such as, R-407C, which have been used successfully for many years, have a higher temperature glide of 5 K. Compressor discharge temperatures are also about 11 K higher than R-404A, but well below temperatures which may require liquid or vapor injection, usually greater than about 135°C. Opteon™ XL40 on the other hand offers a clear performance advantage. It exhibits higher capacity (+11 %) and better efficiency (+10 %) than R-404A. The glide is in the same order of magnitude as for Opteon™ XL20. The discharge temperature is higher (+ 24 K) due to the higher amount of R-32, but still below the critical values of many compressor technologies.

Drop-In Commercial Freezer Testing

In order to measure system performance of XL20 in a system, a reach-in freezer was selected, fully instrumented and placed in a constant temperature room. The freezer is a 1.5 m^3 double-door unit was designed for R-404A with a refrigerant charge size of 1.05 kg. It has a reciprocating compressor which uses 1.15 kg polyol ester (POE) 32 centistokes lubricant. The system is controlled with a thermal expansion valve (TXV). A picture of the unit is shown in Figure 1.

Figure 1: R-404A Reach-in freezer used in experimental testing

The freezer was placed in a constant temperature room and fully instrumented with temperatures (T), pressures (P), mass flow rate (M) and energy measurement (W) as shown in Figure 2**.**

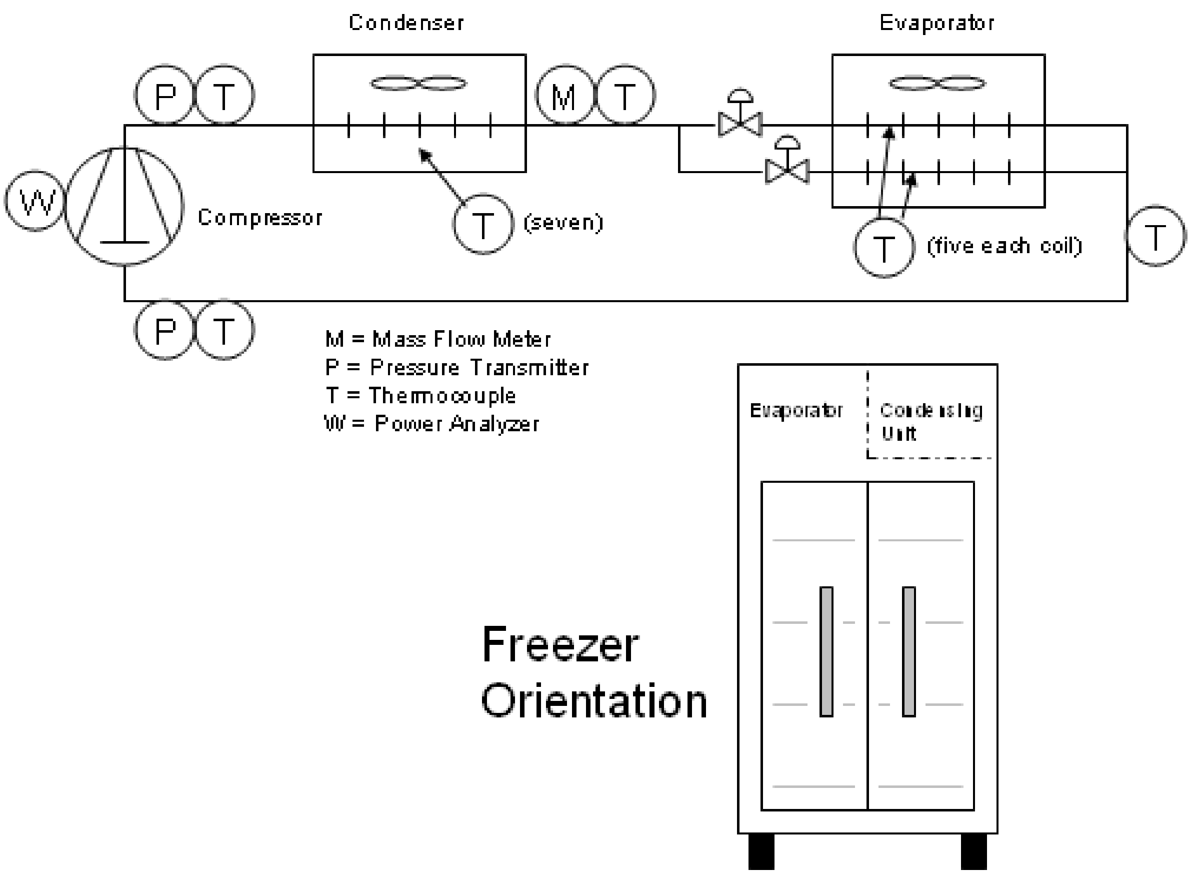

Figure 2: Schematic showing instrumentation of reach-in freezer

Opteon™ XL20 (R-454C): Tests were conducted at two ambient conditions 32 °C and 21 °C. An R-404A baseline was tested first. At each condition, the evaporator exit superheat was controlled by adjusting the TXV to 3-4 K. The freezer internal average compartment temperature (average of four thermocouple readings) was controlled to -17°C. After testing, R404A was replaced with XL20. A charge optimization was conducted to optimize energy consumption. A low charge was initially introduce in the systems, superheat set and energy consumption measured. Additional charge was added until the energy consumption was minimized. The refrigerant charge for XL20 was 1.00 kg, about 5 % lower than R-404A. A new charge of the same POE lubricant was added to the system to prevent cross-contamination from the baseline test. No other changes were made to the system except to adjust the evaporator superheat with the TXV to match R-404A superheat conditions, taking the temperature glide of XL20 into account. For XL20, the TXV was closed approximately 1 1/2 turns due to the lower mass flow rate. Results are shown in Table 3.

Table 3: Reach-in Freezer Test Results Opteon™ XL20 – SI Units

	EC (kWhr/day)	EC Rel to R404A	M (kg/hr)	P_{suct} (bar.a)	P_{disch} (bar.a)	CR	T_{disch} (°C)
Ambient T = 32°C							
R404A	34.3	100%	43	2.2	20.7	9.4	96
XL20	34.8	101%	35	1.7	17.9	10.4	103
Ambient T = 21°C							
R404A	23.7	100%	48	2.0	15.9	7.9	77
XL20	24.4	103%	33	1.7	13.5	8.2	82

Operating pressures and mass flow rate were lower for XL20, as expected from the thermodynamic analysis. XL20 compression ratio was also similar to R-404A. XL20 exhibits about 1-3% higher energy consumption than R-404A. This was not expected based on the higher COP observed in the thermodynamic analysis. However, thermodynamic analysis does not take into account system effects such as compressor efficiencies, heat transfer properties, pressure drop and other factors. There is opportunity for optimization in a new system designed for use with XL20 specific properties. Results also indicate efficiency is improved at higher ambient conditions. Although compressor discharge temperatures of XL20 were slightly higher than R-404A, they were still within a range that should not require liquid injection. Liquid injection is usually needed at discharge temperatures greater than about 130°C.

Opteon™ XL40 (R-454A): Tests were conducted at three ambient conditions 32°C, 24°C and 21°C. An R-404A baseline was tested at the three ambient conditions first. At each condition, the evaporator exit superheat was controlled by adjusting the TXV to 3-4 K. The evaporator superheat was calculated from the suction pressure and the temperature reading at the exit of the evaporator. The freezer internal average compartment temperature was controlled to -17°C. The compressor was allowed to cycle to maintain the cabinet set point temperature. Temperatures and pressures are reported as averages only while the compressor was running. After testing, R404A was replaced with XL40. In each test, the system was flushed to remove lubricant and a new charge of the same type of POE lubricant was added to the system. No other changes were made to the system except to adjust the evaporator superheat with the TXV to match R-404A superheat conditions (closed one turn). Steady state results are shown in Table 4.

Table 4: Reach-in Freezer Test Results Opteon™ XL40 – SI Units

	EC (kWhr/day)	**EC Rel to R404A**	**M (kg/hr)**	**P_{suct} (bar.a)**	**P_{disch} (bar.a)**	**CR**	**T_{disch} (°C)**
Ambient t = 32°C							
R404A	33,46	100%	44	2.1	20.3	10	90
XL40	30,81	92%	34	1.9	21.3	11	105
Ambient t = 24°C							
R404A	25,11	100%	46	2.0	16.5	8	75
XL40	23,91	95%	35	1.8	17.3	9	91
Ambient t = 21°C							
R404A	23,39	100%	48	2.0	15.6	8	70
XL40	22,62	97%	36	1.8	16.0	9	85

Experimental results in the reach-in freezer show XL40 exhibits similar performance compared to R-404A with improved energy efficiency at higher ambient conditions. XL40 consumed 8 % less energy at 32°C ambient temperature; at lower ambient conditions, XL40 still demonstrated 3-5 % improved efficiency. The mass flow rate was slightly lower and the discharge temperature was slightly higher. However, the discharge temperatures were still low enough to not require liquid injection.

Thermal Stability

XL20 was evaluated for thermal stability in sealed glass tubes using ASHRAE Standard 97 with POE 32 centistoke as a lubricant. As it is composed of the same components, these findings also hold true for Opteon™ XL40. The glass tubes were loaded with carbon steel, copper and aluminum coupons. Refrigerant and lubricant were then added to the tubes and frozen before a vacuum was pulled to remove air. In some tubes, air (2000 ppm) contamination was added to refrigerant and moisture contamination (500 ppm) was added to the oil. The tubes were sealed and aged in a heated oven at selected temperatures 175 ^{o}C for 14 days. Tubes and coupons were visually inspected and analyzed after exposure for fluoride ion using ion chromatography. High concentrations of fluoride ion would indicate fluid decomposition. MDL (Minimum Detection Limit) indicates fluoride ion level was below the procedure detection limit of (MDL = 0.3 ppm). As shown in Table 5, XL20 was determined to be thermally stable as negligible amounts of fluoride ion were generated and metal coupons and fluids showed no visible changes.

Table 5: Thermal Stability Results

Aging Temp (ºC)	**Air (ppm)**	**Water (ppm)**	**Fluoride ion F- (ppm)**	**Coupon and Fluid Visual Inspection**
XL20	None	None	0.31	No Change
XL20	None	500	0.51	No Change
XL20	2000	None	MDL	No Change
XL20	2000	500	MDL	No Change

Plastics And Elastomers Compatibility

The compatibility of Opteon™ XL20 - again exemplarily also for Opteon™ XL40 - was evaluated with a range of typical plastics and elastomers typically used in the refrigeration industry. Samples of different plastics and elastomers were prepared and their initial weights and dimensions measured. Tubes were then placed in sealed glass tubes which were filled with either pure refrigerant or a 50/50 mixture of refrigerant and POE lubricant. The tubes were filled and placed in a 100 °C oven for two weeks. After heating, the plastics were removed and measured for changes in physical properties (weight, length, and hardness change) twenty four hours after removal from the tubes. The following rating system was used to characterize the compatibility of the different samples tested:

Rating

0 </= 10% weight gain or loss, and </= 10% linear swell and </= 10 hardness change

1 >10% weight gain or loss, or >10% linear swell or >10 hardness change

2 >10% weight gain or loss, and >10% linear swell and >10 hardness change

Results for plastics evaluations are shown in Table 6. Performance is very similar for both R-404A and XL20, indicating there are many suitable plastics and elastomers for use with XL20. Overall, the plastics showed less reactivity than the elastomers which is typical of refrigerant compatibility testing. It should be recognized that these data reflect compatibility in sealed tube tests, and that refrigerant compatibility in real systems can be influenced by the actual operating conditions, the nature of the polymers used, compounding formulations of the polymers, and the curing or vulcanization processes used to create the polymer. Specific grades, additives, etc. can also vary and potentially affect results for different polymers and other materials.

Table 6: Plastics and Elastomers Compatibility for XL20 and R-404A

Material Tested	R-404A Rating	% Wt Change	% Length Change	Delta Hardness	XL20 Rating	% Wt Change	% Length Change	Delta Hardness
neoprene 1	0	3%	1%	1	0	2%	2%	3
epichlorohydrin	0	9%	3%	-9	0	9%	3%	-6
butyl rubber	1	13%	4%	-8	1	13%	5%	-10
EPDM	0	7%	2%	-8	0	7%	3%	-9
fluorosilicone	1	6%	3%	-14	0	6%	3%	-8
HNBR	1	16%	5%	-6	1	16%	4%	-7
NBR	1	12%	4%	-10	1	11%	5%	-9
fluorocarbon FKM	1	18%	10%	-12	1	19%	9%	-11
neoprene 2	0	9%	4%	-6	0	9%	4%	-4
Viton A	1	17%	8%	-12	1	18%	9%	-10
Viton GF	0	10%	5%	-10	1	9%	4%	-13
polyester	0	9%	3%	-3	0	9%	2%	-5
nylon resin	0	-1%	1%	-1	0	0%	-1%	0
polyamide-imide	0	0%	0%	0	0	0%	0%	-1
polyphenylene sulfide	0	0%	0%	-2	0	0%	0%	0
PEEK	0	0%	0%	-1	0	0%	0%	0
nylon 6.6 polymer plastic	0	-1%	0%	0	0	0%	0%	0
PTFE	0	2%	1%	-1	0	2%	2%	-3

Conclusions

Two new HFO-based refrigerants Opteon™ XL20 (R-454C) and XL40 (R-454A) have been developed as potential low-GWP replacements for R-404A in commercial refrigeration. XL20 has a GWP of about 146 which is 96 % lower than R-404A. Both are mildly flammable (2L) and therefore may have some limitations for use in larger refrigerant charge systems such as supermarket racks. However, they are suitable for single condensing unit systems and stand-alone coolers and freezers. Drop-in performances of both have been evaluated in a reach-in freezer originally designed for R-404A. The only changes made to the system were a TXV adjustments. Overall, energy consumption of Opteon™ XL20 is comparable to R-404A while it shrinks with Opteon™ XL40. Efficiency is improved at higher ambient conditions. Plastics and elastomers compatibilities are also similar to R-404A. Use of Opteon™ XL20 and XL40 can dramatically reduce the environmental impact of refrigeration systems by allowing transition away from R-404A with a refrigerant with similar performance and properties.