

Testing of HFO Refrigerant With Less Than 150 GWP in a Commercial Freezer

*Barbara Minor
Sonali Shah
Luke Simoni
The Chemours Company*

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Topics



- Background
- Properties
- Refrigerant Testing
 - Drop-In Commercial Freezer Testing
- Compatibility Testing
- Conclusions



Background



- R-404A
 - Leading HFC refrigerant for commercial refrigeration
 - AR4 100 year GWP = 3922
- Several regulations requiring <150 GWP refrigerants:
 - EU F-Gas – hermetically sealed systems by Jan, 2022
 - EPA SNAP de-list of 404A in new condensing units Jan, 2018 standalone MT systems by Jan, 2019 and LT by Jan, 2020
 - California proposed non-residential refrigeration by Jan, 2020
- <150 GWP options are needed for standalone and condensing unit systems



XL20 – R-454C



- Refrigerant with GWP 148 (IPCC AR4), 146 (IPCC AR5), 96% lower than 404A
- 21.5/78.5 wt% R-32/HFO-1234yf
- Designed for standalone commercial refrigeration systems and condensing units
- Also suitable as R-22 alternative for a/c
- ASHRAE Class A2L low toxicity, mildly flammable



XL20 vs HCs



- Hydrocarbons have <150 GWP, but charge sizes are very limited due to high flammability
- XL20 has improved flammability properties allowing large charge size:

Refrig	LFL (% in air)	LFL (kg/m ³)	BV (cm/s)	HOC (MJ/kg)	MIE
Propane	2.1	0.038	39	50.3	0.25
Isobutane	1.8	0.043	45	49.5	0.8
XL20	7.9	0.293	1.6	10.5	300-1000

XL20 allows ~1800 g (per EN378) vs HCs at 150 g



Thermodynamic Modeling



Evaporator temperature: -35 °C
Condenser temperature: 40 °C
Subcool amount: 0 K
Suction temperature: -15 °C
Compressor isentropic efficiency: 70 %

	P_{suct} kPa	P_{disch} kPa	T_{disch} °C	T_{glide} °C	CAP Rel to 404A	COP Rel to 404A
404A	167	1833	90	0.4	100%	100%
XL20	124	1563	102	5.9	87%	107%

XL20 has slightly lower capacity, but higher efficiency than 404A



Drop-In Commercial Freezer Testing



- Tested 404A baseline, then XL20
- Commercial freezer installed in constant temperature room
- 52 ft³ (1.5 m³) double-door unit
- Designed for use with R-404A
- Reciprocating compressor with 1.15 kg polyol ester (POE) 32 centistokes lubricant
- System is controlled with a thermal expansion valve (TXV)

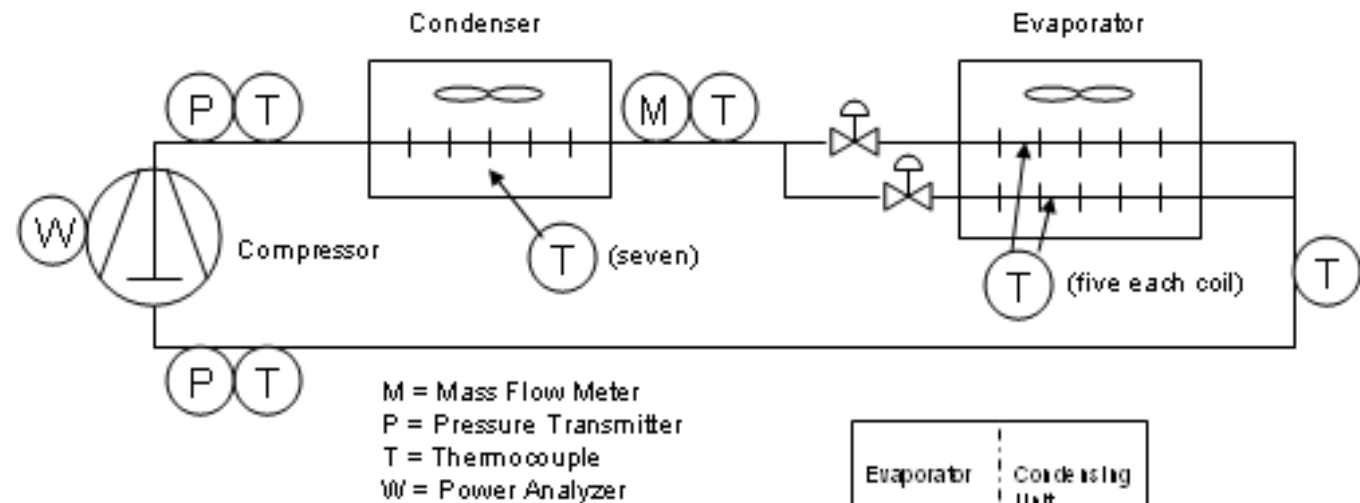




Drop-In Commercial Freezer Testing

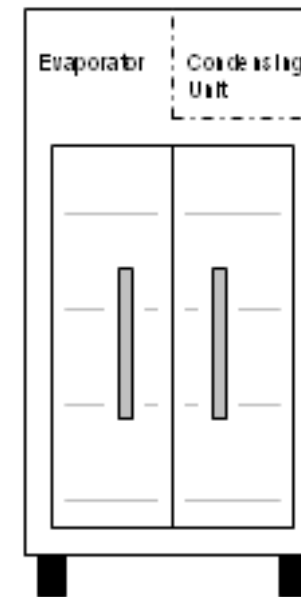


Test Set Up



- Charge optimizations were performed with both refrigerants to minimize energy consumption
- Refrigerant charge for XL20 was about 5% lower than R-404A
 - » R-404A: 1.05 kg
 - » XL20: 1.00 kg

Freezer Orientation





Drop-In Commercial Freezer Testing



- Tests were conducted at two ambient conditions:
32°C and 21°C +/- 0.3K
- Freezer internal average compartment temperature: -17°C
- The same POE lubricant was used for both refrigerants; a new charge was added between tests to prevent cross contamination
- For XL20 testing, TXV was closed approximately 1 ½ turns due to the lower mass flow rate



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



Drop-In Commercial Freezer Testing



	EC Rel to R404A	Mass Flow (kg/hr)	P _{suct} (kPa)	P _{disch} (kPa)	Comp Ratio	T _{disch} (°C)
Ambient T = 32°C						
R-404A	100%	43	220	2068	9.4	96
XL20	101%	35	172	1785	10.4	103
Ambient T = 21°C						
R-404A	100%	48	200	1585	7.9	77
XL20	103%	33	165	1351	8.2	82

- XL20 exhibits 1-3% higher energy consumption than R-404A
 - » Considering compressor efficiencies, heat transfer properties, pressure drop, etc.
- Opportunity for optimization in new systems due to favorable thermo properties
- Compressor discharge temperatures within the range that does require liquid injection



Thermal Stability



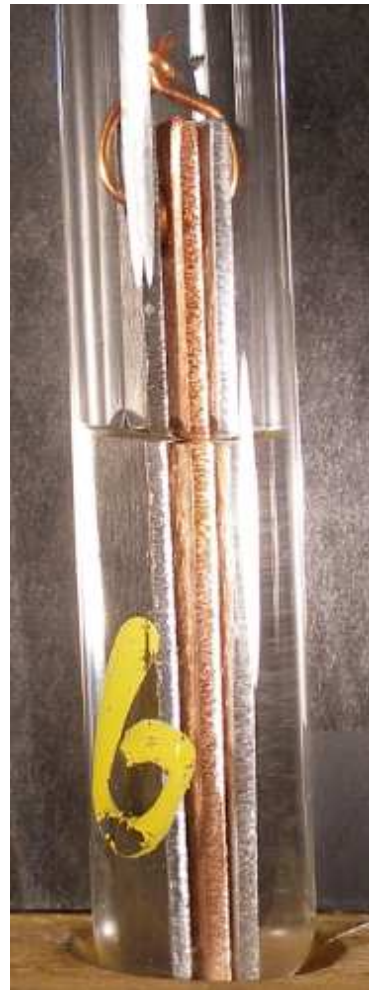
- Thermal stability was evaluated using ASHRAE Standard 97 with POE 32 centistoke lubricant
- Tubes were loaded with carbon steel, copper, aluminum coupons, then filled with refrigerant and lubricant
- Some tubes contained refrigerant with air contamination (2000 ppm) and oil with moisture contamination (500 ppm)
- Tubes were sealed and aged at 175°C for 14 days



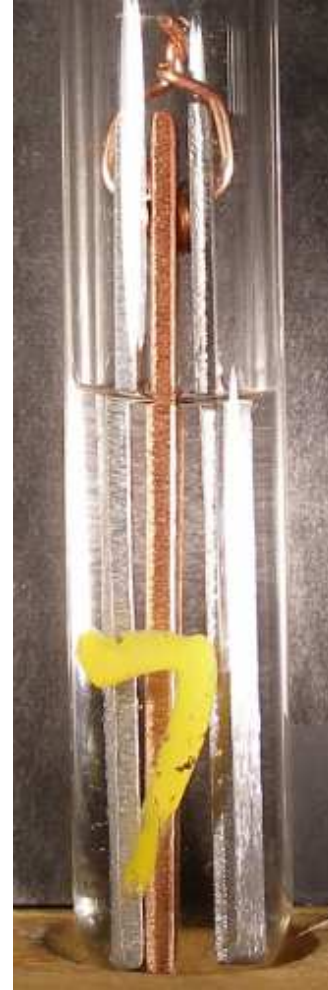
Thermal Stability Results



No Air/Water



500 ppm Water



2000 ppm Air



500 ppm Water/
2000 ppm Air



Thermal Stability Results



XL20 is thermally stable

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

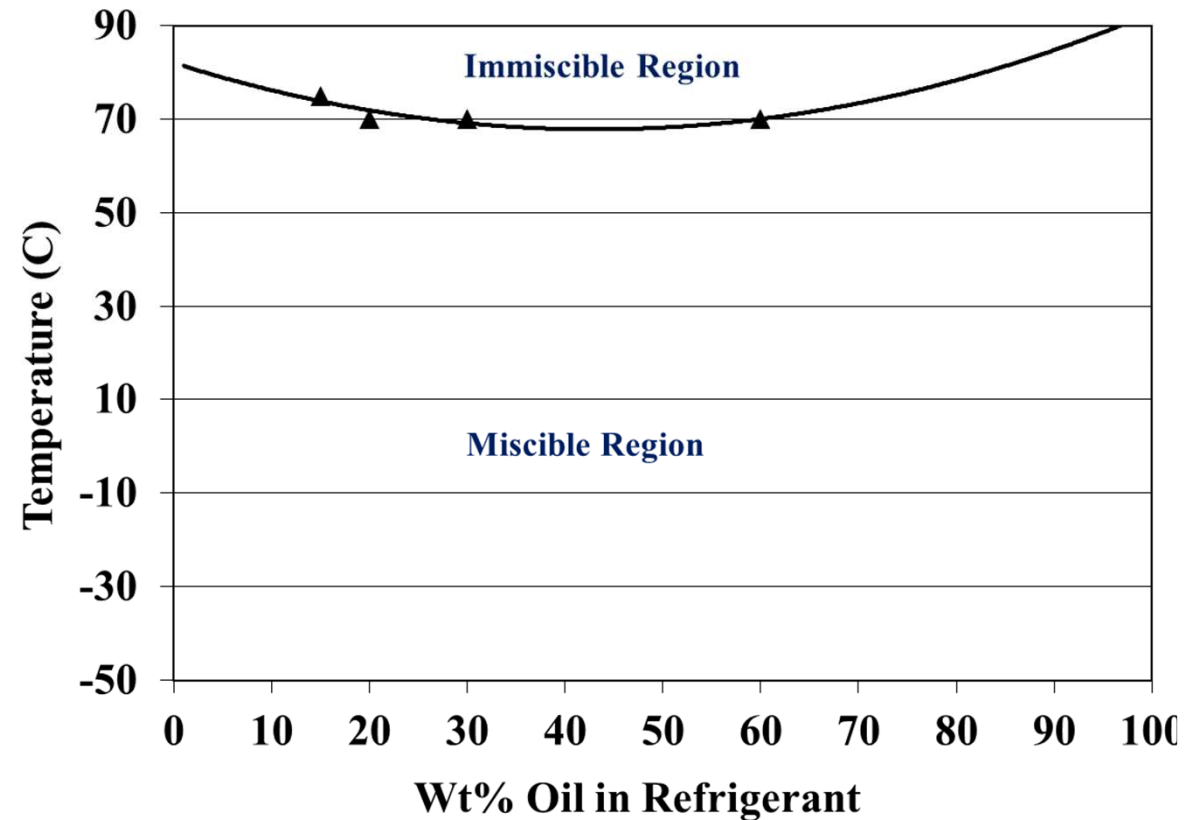
MDL (minimum detection limit) → fluoride ion was below procedure detection limit (MDL = 0.3 ppm)



Lubricant Miscibility



- Miscibility was tested with POE 32 lubricant
- Refrigerant and oil mixtures were prepared in sealed glass tubes
- Tubes were heated to 75°C and then cooled to -50°C and observed in 5K increments



XL20 miscible over operating range of refrigeration systems



Plastics and Elastomers Compatibility



- Compatibility of XL20 was evaluated with a range of plastics and elastomers and compared to R-404A
- Samples were placed in sealed tubes with 50/50 mixture of refrigerant and POE 32 lubricant
- Tubes were filled and placed in a 100 °C oven for two weeks
- Weight, length, and hardness changes were evaluated

Rating

- 0** $\leq 10\%$ weight gain or loss, and $\leq 10\%$ 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



Plastics and Elastomers Compatibility



Material Tested	R-404A/POE Rating	% Wt Change	% Length Change	Delta Hardness	R-454C/POE 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

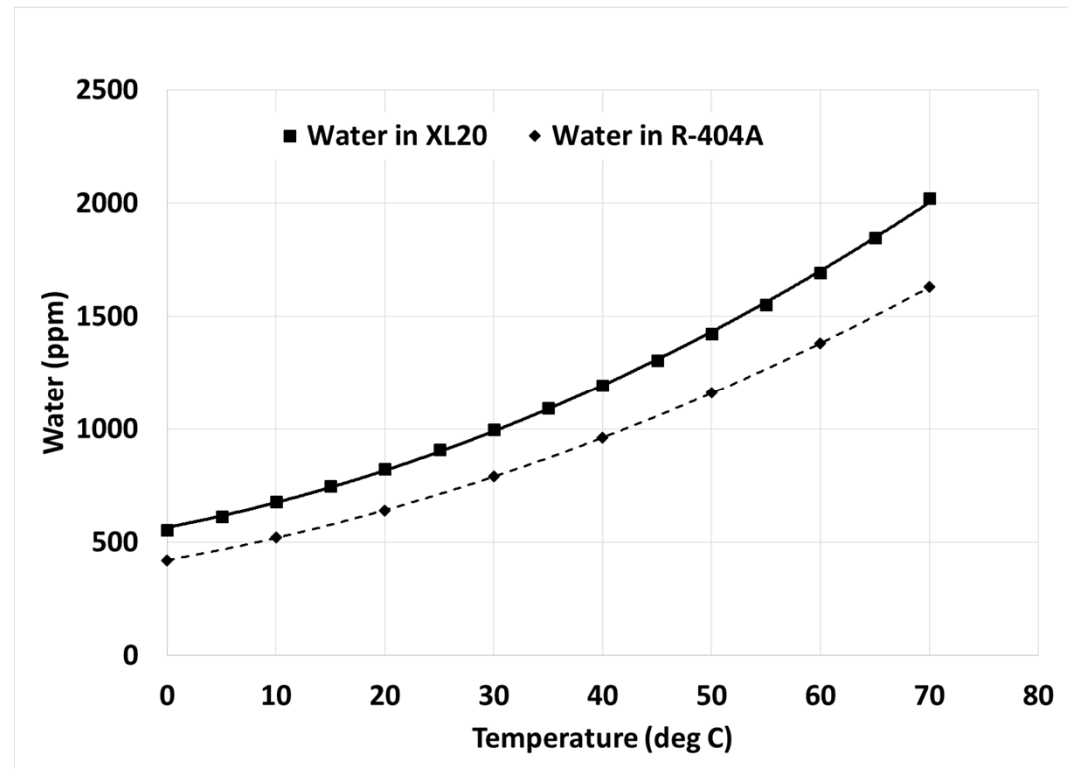
XL20 exhibits compatibility very similar to R-404A



Water Solubility



- Vapor-liquid-liquid equilibrium (VLLE) of XL20 was measured with water
- The VLLE data was used to create an equation of state and determine saturated concentration of water in liquid refrigerant over a range of conditions

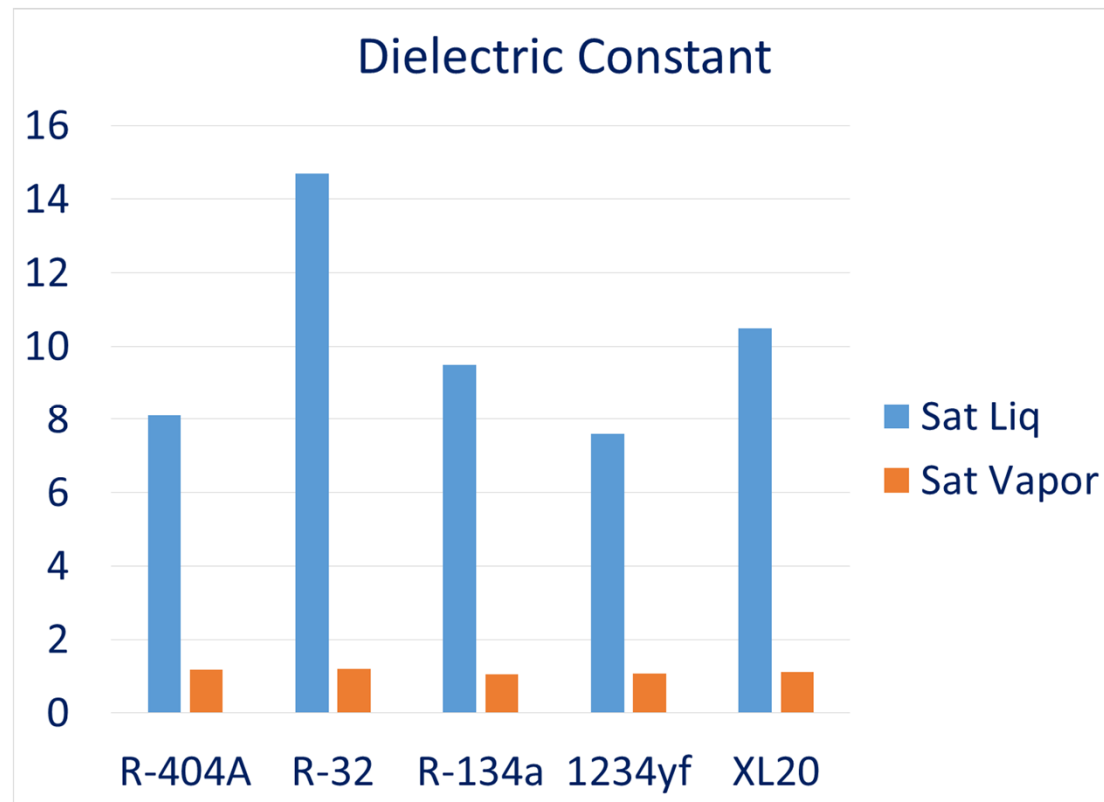


XL20 water solubility is comparable to R-404A



Dielectric Properties

- Dielectric constant of XL20 was calculated using experimental values for HFC-32 and HFO-1234yf
- Kirkwood theory for polar components was used in calculations



XL20 dielectric constant is similar to other refrigerants



Conclusions



- Regulatory requirements are increasing need for refrigerants with < 150 GWP
- XL20 (R-454C) is a low GWP HFO-based refrigerant with 96% lower GWP than 404A
- XL20 has improved flammability properties versus hydrocarbon options, allowing larger charge size
- XL20 is suitable for use in new R-404A systems
 - Comparable energy consumption in drop-in test
 - Similar stability, compatibility, water solubility and dielectric properties
 - Uses same POE lubricant

XL20 is a suitable <150 GWP alternative for R-404A in standalone refrigeration and condensing units

Thank You!

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