RECENT DEVELOPMENTS IN LOW GWP REFRIGERANTS FOR AIR CONDITIONING APPLICATIONS

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Abstract Due to the growing global concerns around the use of refrigerants with relatively high global warming potential, new working fluids with the positive attributes of both high thermal performance and low environmental impact are currently in development. These refrigerants exhibit promising performance when compared with refrigerants currently used in AC systems such as R-410A and R-407C. They also show significantly lower flammability characteristics than the much more flammable hydrocarbons. Replacements for common HFC refrigerants such as R-407C and R-410A are discussed for residential air conditioning applications. Thermal properties as well as experimental results in representative air conditioning systems are presented, showing the benefits of using these new working fluids.

Keywords: Refrigerants, Global Warming, Hydro-fluoro-olefins

1 Introduction

Increasing concerns about the warming of the earth has spurred on development of working fluids that have significantly lower impact on climate change. Many fluids are being evaluated in the broad range of refrigeration and air conditioning applications. This paper will discuss options for low global warming refrigerants in the major air conditioning applications.

2 Working Fluids

Depicted in Table 1 are options we have identified to replace existing higher GWP refrigerants. There are two series of products being developed, the "N" series consists of reduced GWP refrigerants that offer considerable reduction in GWP relative to the refrigerant it replaces and are non-flammable. These options have the potential to be used in existing systems. Another series ("L" series) consist of the lowest GWP offerings but are mildly flammable. Typically these would be used in new equipment designed and installed to address any flammability issue. Among these options are both single component refrigerants and blended refrigerants. The single component refrigerants HFO 1234yf and/or HFO 1234ze(E) shows promise that it can be utilized in systems that have employed R-134a. Another molecule under development, N-12 is a candidate to replace R-123 in low pressure centrifugal chillers. To better suit the operating characteristics of refrigerants such as R-404A, R-22, and R-410A, blended refrigerants are being developed. HFO/HFC refrigerant blends can provide a better performance match with existing refrigerants, and still offer a GWP reduction of 75% to 95%. In addition, they can offer performance comparable and in some cases superior to that of the higher GWP refrigerant it replaces so both the direct global warming impact and the indirect impact is lower.

Table 1 – Honeywell's Refrigerants Options



Current Product	Reduced GWP Option (A1) — N Series	Lowest GWP Option (A2L) — L Series
R-404A GWP=3922	HFO Blend – GWP~1300 (retrofit) **N-40** HFO Blend – GWP~1000 (new equip) **N-20**	HFO Blend GWP~200-300 **L-40**
HCFC-22 GWP=1810	HFO Blend – GWP ~1000 **N-20**	HFO Blend GWP <350 **L-20**
R-410A GWP=2088		HFO-Blend GWP <500 **L-41**
HFC-134a GWP=1430	HFO Blend – GWP ~600 **N-13**	HFO-1234yf GWP = 4 **L-YF** HFO-1234ze GWP = 6 **L-ZE**
R-123 GWP= 77	HFO–GWP =7 **N-12**	

3. Unitary Heat Pump R-410A Applications

Residential and light commercial air conditioning, sometimes termed unitary a/c, is a high volume use of refrigerants worldwide and is growing readily in Article 5 countries. It was therefore a high priority in our low GWP refrigerant development activity. In order to understand the performance of candidates to replace R-410A a typical system that is used in North America was evaluated in our development laboratories in Buffalo, NY.

The R-410A system was a ducted split reversible heat pump unit with a nominal cooling capacity of 10.5 kW (3 tons) and Seasonal COP of 3.80 (13 SEER). The heating capacity was 10.1 kW with an HSPF of 8.5. The test conditions were in accordance with AHRI Standard 210/240.

3.1 Performance Results of Ducted Split Heat Pump

This heat pump was tested at the standard conditions.

All tests were performed inside environmental chambers equipped with instrumentation to measure both air-side and refrigerant-side parameters. Refrigerant flow was measured using a coriolis flow meter while air flow and capacity was measured using an air-enthalpy tunnel. All primary measurement sensors were calibrated to ±0.25ºC for temperatures and ±0.25 psi for pressure. Experimental uncertainties for capacity and efficiency were within ±5% with reproducibility in the ±2% range. Capacity values represent the air-side measurements, which were carefully calibrated using the reference fluid (R-410A). L-41 was tested in this system along with R-32 and R-410A again as the baseline. Table 2 shows the summary of the results of the split heat pump tests at the representative conditions, with Tables 3 and 4 showing more details from the cooling and heating tests.

The L-41 results show equivalent or slightly superior efficiency in both cooling and heating relative to the baseline refrigerant with the capacity just slightly lower. To get back this slight capacity deficit, a compressor with slightly increased compressor displacement was installed and tested with L-41 at the same conditions previously tested. This compressor was the next size standard compressor of the same type used in the original heat pump. Capacity and efficiency results are shown and indicate that performance now match or exceed that of R-410A while maintaining the efficiency of the baseline refrigerant. Although the capacity and efficiency of R-32 does match that of R-410A, the discharge temperature of this refrigerant is higher than that of the baseline refrigerant, or L-41, as depicted in Tables 3 and 4. High discharge temperatures at extreme ambient temperatures can be a concern. Another consideration is the condition of the condenser as all these tests were run with a new condenser. Typical fouling of the condenser will exacerbate the situation leading to potential system reliability concerns.

Table 2: Test Results Summary – R-410A HP

R410A Options (A2L)								
Refrigerant	Characteristics		Cooling		Standard Heating (8ºC Ambient)		Low Temp Heating (-8ºC Ambient)	
	GWP (AR4)	Glide Ev (ºC)	Cap. @35ºC Amb (Test A)	Eff. @ 28ºC Amb (Test B)	Capacity	Efficiency	Capacity	Efficiency
R410A	2088	0.1	100%	100%	100%	100%	100%	100%
R32	675	0	108%	101%	105%	100%	102%	98%
L-41	<500	2	98%	102%	96%	103%	96%	102%
L-41*	<500	2	108%	101%	103%	100%	100%	98%

* Used larger compressor

Table 3: Detailed Cooling Results – R-410A HP

Cooling Mode										
Refrigerant	AHRI-Std	Delta Tcd	Delta Tev	Tdisch	Superheat evap_out	Pd	Ps	Pd/Ps	Isentropic Efficiency	Volumetric Efficiency
		°C	°C	°C	°C	kPa	kPa	% of R410A	% of R410A	% of R410A
R410A	A	0	0	77	5.3	2788	1056	100%	100%	100%
	B	0	0	67	5.7	2382	1035	100%	100%	100%
	MOC (115)	0	0	94	4.8	3533	1104	100%	100%	100%
R32	A	0.6	-0.7	98	6.1	2890	1070	102%	102%	95%
	B	0.3	-0.9	83	5.7	2447	1045	102%	102%	95%
	MOC (115)	0.8	-0.9	120	4.8	3683	1116	103%	103%	93%
L-41	A	1.8	1.3	89	3.1	2544	946	102%	102%	94%
	B	1.3	1.2	76	3.3	2145	926	101%	101%	95%
	MOC (115)	1.9	0.6	112	3.3	3239	969	104%	104%	93%
L-41 w/larger compr.	A	3.2	0.5	93	4.1	2633	919	109%	109%	95%
	B	2.6	0.5	79	3.8	2215	902	107%	107%	95%
	MOC (115)	3.4	-0.1	115	4.5	3350	943	111%	111%	95%

Table 4: Detailed Heating Results – R-410A HP

Heating Mode										
Refrigerant	AHRI-Std	Delta Tcd	Delta Tev	Tdisch	Superheat evap_out	Pd	Ps	Pd/Ps	Isentropic Efficiency	Volumetric Efficiency
		°C	°C	°C	°C	kPa	kPa	% of R410A	% of R410A	% of R410A
R410A	H1 (47/70)	0.0	0.0	79	7.6	2492	774	100%	100%	100%
	H2(35/70 avg)	0.0	0.0	76	7.1	2233	634	100%	100%	100%
	H3 (17/70)	0.0	0.0	90	7.5	2144	464	100%	100%	100%
R32	H1 (47/70)	0.8	0.0	100	7.4	2596	802	101%	100%	96%
	H2(35/70 avg)	-0.2	0.2	97	7.4	2283	644	101%	102%	98%
	H3 (17/70)	-0.3	0.1	120	7.1	2176	479	98%	101%	93%
L-41	H1 (47/70)	3.6	0.5	94	4.6	2373	667	111%	99%	96%
	H2(35/70 avg)	2.4	2.7	93	5.3	2113	540	111%	101%	96%
	H3 (17/70)	3.7	1.1	109	4.1	2051	402	110%	101%	94%
L-41 w/larger compr.	H1 (47/70)	2.6	1.0	91	4.7	2320	677	107%	102%	96%
	H2(35/70 avg)									
	H3 (17/70)	1.6	0.7	103	4.5	1947	396	106%	106%	96%

3.2 Discussion of R-410A Alternatives Evaluation

Overall, L-41 shows potential to replace R-410A as its performance is close to that of R-410A. Any slight differences seen can be reduced or eliminated with minor system changes. This performance can be achieved without concern of high discharge temperature, and with a GWP of less than 500; this is a considerable reduction in GWP as compared to R-410A (more than 75%).

4. Positive Displacement Chiller Applications

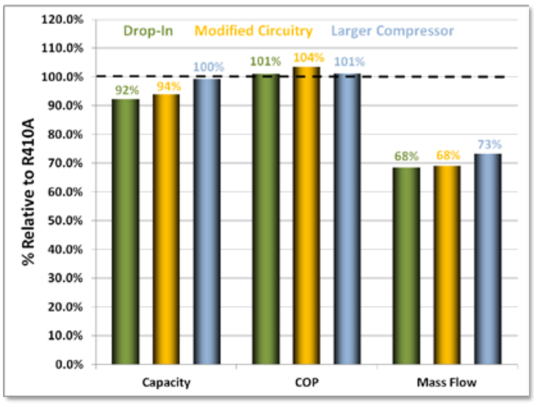
A performance analysis was carried out for an air cooled 20 ton (70 kW) chiller using a lumped parameter modeling approach for the heat exchangers. The water inlet and outlet temperatures were assumed to be 12^{o}C and 7^{o}C respectively. The analysis was performed at an ambient air temperature of 35^{o}C. The evaporator superheat and condenser subcooling were set at 5.5^{o}C. An assumption was made that the volumetric and isentropic efficiencies were the same for all refrigerants. Results for R-410A and its alternative are shown in Figure 1.

Since drop-in performance of L-41 into the R-410A system showed a significant drop in mass flow rate and pressure drops, the number of circuits in the evaporator was decreased by 23% and in the condenser by 13% to increase the mass velocity for L-41. This led to increase in capacity and COP of the system due to improvements in heat transfer.

The capacity was fully recovered when the compressor displacement was increased by 8% (270 cc to 290cc) and the number of circuits was decreased by 18% in the evaporator and by 11% in the condenser.

Recent tests that were part of AHRI's LGWP AREP program show that the capacity of L-41 dropped into a R-410A chiller achieved somewhat better results with a capacity ratio of ~96% relative to R-410A with efficiency exceeding R-410A's by ~3%. No modifications were made to the circuitry or compressor displacement.

Figure 1: Positive Displacement Chiller Analysis:



5 Centrifugal Chiller Applications

A compressor design analysis was conducted for both medium pressure and low pressure refrigerants using specific speed and diameter approach as discussed in Biederman *et al* (2004), in order to size single-stage compressors for alternative low global warming refrigerants. Using the same specific speed (0.76) and specific diameter (3.4), the resulting compressor speed N and diameter D is given by:

$$N = 0.76\frac{H^{0.75}}{\sqrt{Q}} \qquad \text{(1a)}$$

$$D = 3.4\frac{\sqrt{Q}}{H^{0.25}} \qquad \text{(1b)}$$

Where H = Isentropic enthalpy rise or "Head" in J/kg and Q = Volumetric flow rate in m^3/s.

Cycle analyses and compressor sizing were conducted for two sets of refrigerants, medium pressure refrigerants that are potential replacements for HFC-134a and low pressure refrigerants that are more suited for chillers that ran CFC-11 or HCFC-123. For both applications, a refrigerant capacity of 500 tons (1760 kW) was selected assuming evaporation and condensation temperatures of 5 and 35°C, respectively. The cycle analyses yielded the values for isentropic enthalpy rise and volumetric flow rate needed to determine the speed and compressor impeller diameters using equations 1a and 1b.

5.1 Medium Pressure Chiller Applications:

Table 6 shows the results for medium pressure refrigerants:

Table 6 Medium Pressure Refrigerants

		Fixed Capacity				Fixed Diameter	
Parameter	Units	R-12	R-134a	R1234ze(E)	N-13	R1234ze(E)	N-13
mdot	kg/s	14.31	11.33	12.34	12.04	8.84	10.17
density	kg/m^3	20.54	16.86	13.74	15.56	13.74	15.56
Vdot	m^3/s	0.70	0.67	0.90	0.77	0.64	0.65
N (Impeller Speed)	rpm	11983	14691	11919	13131	14079	14291
D (Impeller Dia.)	m	0.255	0.235	0.278	0.256	0.235	0.235
u2 (tip speed)	m/s	160	181	174	176	174	176
Pr (Pressure Ratio)	-	2.34	2.54	2.57	2.55	2.57	2.55
COP	-	8.01	7.90	7.91	7.85	7.91	7.85
COP Rel to R134a		101.3%	100.0%	100.1%	99.3%	100.1%	99.3%
Cap. Rel to R134a		100.0%	100.0%	100.0%	100.0%	73.4%	85.3%

These results show that all three alternative refrigerants could be applied to a centrifugal compressor designed for R-134a with only minor changes. If the same speed and diameter were used, the specific speed and diameter will for the most part stay in the optimum range for these parameters. The operating envelop would have to be evaluated to ensure reliable operation over the expected conditions a particular chiller would see. Efficiency would be very close to the baseline refrigerant.

5.2 Low Pressure Chiller Applications:

Table 7 shows the results of this analysis for low pressure refrigerants.

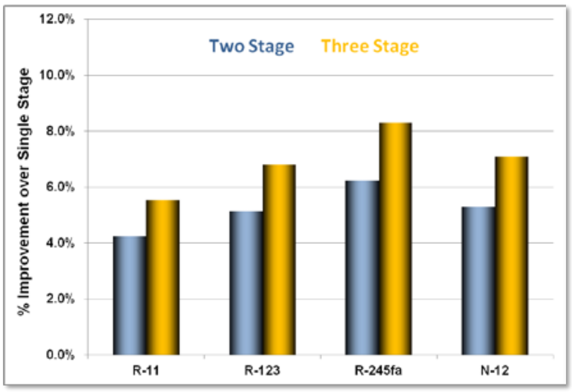
Table 7: Low Pressure Refrigerants

		Fixed Capacity				Fixed Diameter
Parameter	Units	R-11	R-123	R-245fa	N-12	N-12
mdot	kg/s	10.75	11.64	10.66	10.48	15.23
density	kg/m^3	2.98	2.73	3.94	3.38	3.38
Vdot	m^3/s	3.61	4.27	2.71	3.10	4.50
N (Impeller Speed)	rpm	6241	5474	6450	6966	5780
D (Impeller Dia.)	m	0.550	0.607	0.468	0.503	0.607
u2 (tip speed)	m/s	179	174	183	183	183
Pr (Pressure Ratio)	-	3.00	3.20	3.20	3.07	3.07
COP	-	8.49	8.36	8.21	8.33	8.33
COP Rel to R123		101.6%	100.0%	98.1%	99.6%	99.6%
Cap. Rel to R123	-	100.0%	100.0%	100.0%	100.0%	141%

The results for N-12 show that this refrigerant could be used in these applications without significant modifications. Larger capacity with comparable, if not superior, energy efficiency could be obtained using this refrigerant. Not part of this analysis is the evaluation of operating pressures, and due to somewhat higher pressure than HCFC-123, pressure code vessels would be required if this refrigerant were used (similar to HFC-245fa).

The above analysis was extended to include multi-stage impacts for the low pressure refrigerants. As shown in Figure 2, the efficiency has a significant increase when going to either 2 or 3 stages.

Figure 2: Low Pressure Chiller Multi-stage Analysis



5 Conclusions

Recently developed low global warming molecules may have potential applications in systems that currently employ medium pressure refrigerants, such as commercial refrigeration and stationary A/C systems. Unlike CO2, comparable performance to existing refrigerants can be achieved in applications investigated to date without significant hardware modification.

The use of these molecules to formulate higher pressure blends are now being evaluated and preliminary results show promise, however there are trade-offs in performance, flammability, and GWP that need to be made. With that said the use of the L-41 blend in R-410A systems (both unitary and chillers) offer performance comparable to that of the baseline refrigerant.

For both medium and low pressure chiller applications, 1234ze(E) and the N-12 molecule offer very good performance along with their very low GWP.

This initial work is encouraging but further work is needed to more fully explore these applications. This would include additional performance evaluations as well as conducting flammability risk assessments where appropriate.

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