Latest Developments in Low Global Warming Refrigerants for Heat Pump Applications

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New refrigeration system working fluids with the positive attributes of both high thermal performance and low environmental impact are currently in development. These materials maintain the high level of system efficiency we are accustomed to with fluorocarbon refrigerants but with significantly lower global warming impact than current refrigerants. The evaluation of potential replacements for common heat pump refrigerants such as R-410A, R-407C, and R-22 will be discussed for several heat pumps applications. Chemical and physical properties for the new molecules, as well as experimental results for the heat pump applications using these developmental refrigerants are compared and contrasted.

Introduction

Two new low GWP refrigerant molecules (HFO-1234yf, HFO-1234ze) have been identified. These molecules are Hydro-Fluoro-Olefins (HFO) that have an extremely low global warming potential (GWP) of only 4 to 6 (as compared to 1430 for R-134a). We are in the process of developing and evaluating refrigerant blends that balance the attributes of higher capacity and low global warming potential while maintaining the efficiency of present systems without significant increases in system cost. This study will discuss properties and applications of potential refrigerant options to replace R-410A, R-407C, and R-22 in stationary heat pump systems.

Working Fluids

Depicted in Table 1 are potential low global warming molecules as well as a reference higher global warming molecule, R-134a. Also shown in Table 1 are Permissible Exposure Limits (PEL) and flammability limits (LFL and UFL). It should be noted that fluids that do perform well in applications where R-134a is used doesn't imply that these same refrigerants will also perform well in other applications such as heat pumps where refrigerants with higher volumetric capacity, higher pressure, and other distinct properties are used. It is for this reason that refrigerant blends that are better suited for heat pump and other applications are currently in development.

Table 1 - Working Fluid Properties

Refrigerant	GWP	PEL (ppm)	LFL / UFL (Vol%, 23°C)
R-134a	1430	1000	-
HFO-1234ze	6	1000	-
HFO-1234yf	4	500	6.2-12.3
R-32	675	1000	14.4-29.3
R-600a	~20	800	1.8-8.5
R-290	~20	1000	2.1-10.0

Table 2 – Honeywell's Refrigerant Options

Current Product	N-Series (Reduced GWP) (A1 Classification)	L-Series (Lowest GWP) (A2L Classification)
R-404A GWP=3922	HFO Blend – GWP ~1300 (retrofit) N-40 HFO Blend – GWP ~1000 (new equipment) N-20	HFO Blend – GWP ~200-300 L-40
R-407C/ HCFC-22 GWP= 1774/1810	HFO Blend – GWP ~1000 N-20	HFO Blend – GWP <150 L-20 HFO Blend – GWP <400 L-20+
HFC-134a GWP=1430	HFO Blend – GWP ~600 N-13	HFO-1234yf – GWP=4 L-YF HFO-1234ze– GWP =6 L-ZE
R-410A GWP=2088		HFO Blend – GWP <500 L-41

Several low-GWP blends with operating characteristics close to R-404A, R-22, and R-410A are under investigation. Although blends can be formulated with a GWP below 150, trade-offs in performance are necessary to accomplish this. Blends with GWP greater than 150 can provide a better performance match with existing refrigerants, and still offer a GWP reduction of 75% to 95%

R410A Applications

A representative air-to-air reversible heat pump designed for R410A was tested. This ducted unit was tested in Honeywell's Buffalo, New York application laboratory.

The ducted unit is a 3-ton (10.5 kW cooling capacity) 13 SEER (3.8 cooling seasonal performance factor, SPF) with a heating capacity of 10.1 kW and an HSPF of 8.5 (rated heating SPF of ~2.5), equipped with a scroll compressor. This system has tube-and-fin heat exchangers, reversing valves and thermostatic expansion valves for each operating mode. Due to the different pressures and densities of the refrigerants tested, some of the tests required the use of Electronic Expansion Valves (EEV) to reproduce the same degrees of superheat observed with the original refrigerants.

Test Setup

Tests shown in table 3 were performed using standard [AHRI, 2008] operating 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 designed according to industry standards [ASHRAE, 1992]. All primary measurement sensors were calibrated to ±0.25ºC for temperatures and ±0.25 psi for pressure. Experimental uncertainties for capacity and efficiency were on average ±5%. Capacity values represent the air-side measurements, which were carefully calibrated using the reference fluid (R-410A). The developmental blend, L-41 was tested in this heat pump in both cooling and heating modes along with the baseline refrigerant R-410A.

Table 3 – Operating Conditions

Operating Conditions (Cooling Mode)				
Test Condition	Indoor Ambient		Outdoor Ambient	
	DB(°C)	WB(°C)	DB(°C)	WB(°C)
AHRI Std. A	26.7	19	35	24
AHRI Std. B	26.7	19	27.8	18
AHRI Std. C	26.7	14	27.8	-
AHRI Std. MOC	26.7	19	46.1	24

Operating Conditions (Heating Mode)				
Test Condition	Indoor Ambient		Outdoor Ambient	
	DB(°C)	WB(°C)	DB(°C)	WB(°C)
AHRI Std. H1	21.1	15.6	8.3	6.1
AHRI Std. H2	21.1	15.6	1.7	0.6
AHRI Std. H3	21.1	15.6	-8.3	-9.4

Note – MOC --> maximum operating condition

Cooling Mode Results

Table 4 shows performance results in cooling mode. L-41a shows efficiency comparable to R410A with capacities of 97% for a quasi drop-in

Table 4 – Cooling Mode Results – R-410A vs. L-41

R410A Options (L-41, A2L, GWP<500)							
Ref.		Cooling		Heating Std. Rating (AHRI H1)		Heating Low Temp. (AHRI H3)	
	Glide Ev (ºF)	Cap. @ 95ºF Amb (AHRI A)	Eff. @ 82ºF Amb (AHRI B)	Heating (47ºF/70ºF) Capacity	Heating (47ºF/70ºF) Eff	Heating (17ºF/70ºF) Capacity	Heating (17ºF/70ºF) Eff
R410A	0.1	100%	100%	100%	100%	100%	100%
L-41a	4.0	97%	102%	97%	104%	93%	101%
L-41a*	4.0	107%	100%	104%	98%	102%	97%
L-41b	2.4	98%	102%	99%	105%	96%	103%

**Used larger compressor*

test and 107% when a larger compressor is used. The second alternative (L-41b) matches capacity and efficiency of R410A (differences lie within the experimental uncertainty). Due to the lower mass flow rates than R410A , there may be potential improvements of the heat exchangers. Discharge temperatures are just slightly higher than that of R-410A but remain at acceptable levels.

Heating Mode Results

Table 4 also shows performance results in heating mode. The trends seen in the cooling mode test results are also seen with heating results. When evaluated at the standard temperature test, L-41a shows efficiency and capacity comparable to R410A Mass flow rates are approximately 30% lower than R410A. Discharge temperatures remain at an acceptable level though marginally higher than that of R-410A.

Learnings

Overall, both L-41a and L-41b show potential to replace R-410A. Any slight performance differences between the two refrigerants can be reduced or eliminated with minor system changes. One of these options is using a slightly larger compressor, which was tested and provided satisfactory results. This performance can be achieved without concern of high discharge temperature and with a GWP of less than 500; it offers a considerable reduction from R-410A (more than 75%).

R407C Applications

A ducted reversible heat pump with a 3-ton (10.5 kW) cooling capacity, an efficiency rating of 13 SEER (3.8 seasonal COP), a heating capacity of 10.1 kW and an HSPF of 8.5 was used for this evaluation. This system was originally designed for R-22 but was converted to R-407C, which serves as the baseline refrigerant. R-407C was selected since R-22 has already been phased out for new equipment in many countries and R-407C is used in many types equipment that formerly utilized R-22.

In addition to R-407C, three alternative refrigerants were evaluated. L-20 and N-20 that were identified on Table 1 along with another option, L-20+. N-20 is a non-flammable refrigerant blend with a GWP under 1000 while L-20 has mild flammability with an expected flammability classification of "2L" but has a GWP under 150. L-20+ is another "2L" option that has a GWP under 400 (>80% reduction from R-407C) with performance characteristics nearly identical to that of R-407C.

Cooling Mode Results

Table 5 shows the results of this heat pump operating in cooling mode. All three alternatives operate with cooling efficiencies at or slightly above that of R-407C with acceptably low discharge temperatures. L-20+ also matches the cooling capacity of R-407C. L-20 would need a slightly larger compressor displacement to make up for the 10% lower capacity while N-20 comes closer to meeting the capacity of R-407C.

Table 5 – Cooling Mode Results – R-407C vs. L-20, L-20+, and N-20

Cooling Mode								
Refrigerant	AHRI-Std	Capacity	EER	Mass flow	Tcd	Tev	Tdisch	Pd/Ps
		% of R407C	% of R407C	% of R407C	% of R407C	% of R407C	°C	% of R407C
R-407C	A	100%	100%	100%	100%	100%	76	100%
	B	100%	100%	100%	100%	100%	66	100%
L-20	A	90%	105%	84%	100%	103%	70	99%
	B	88%	101%	84%	100%	103%	62	98%
L-20+	A	101%	101%	77%	101%	99%	82	101%
	B	100%	100%	77%	102%	99%	71	100%
N-20	A	93%	104%	106%	98%	104%	65	94%
	B	94%	104%	105%	98%	103%	57	94%

Table 6 – Heating Mode Results – R-407C vs. L-20, L-20+, and N-20

Heating Mode								
Refrigerant	AHRI-Std	Capacity	EER	Mass flow	Tcd	Tev	Tdisch	Pd/Ps
		% of R407C	% of R407C	% of R407C	% of R407C	% of R407C	°C	% of R407C
R-407C	H1	100%	100%	100%	100%	100%	75	100%
L-20	H1	87%	104%	84%	104%	97%	66	93%
L-20+	H1	102%	101%	77%	100%	103%	85	102%
N-20	H1	97%	99%	106%	95%	102%	68	105%

Heating Mode Results

Heating mode results are depicted in Table 6 with basically very similar results as those seen in cooling mode. L-20+ again shows nearly identical heating capacity and efficiency performance to R-407C with the other candidates matching efficiency but with somewhat lower capacity.

Discussion

Three low global warming refrigerant candidates were evaluated with promising results. L-20 with a GWP less than 150 (>90% reduction from R-407C) achieved comparable efficiency and with minor system changes would likely achieve the same capacity as the baseline refrigerant. Another refrigerant option, L-20+ matches both the capacity and efficiency of R-407C with a greater than 80% reduction in GWP. N-20, a non-flammable option with a GWP reduction of more than 45%, achieves comparable efficiency and only sees a slight reduction in capacity.

It should be noted that the heat pump used for the R-407C evaluations is noticeably larger in size (primarily the outdoor heat exchanger) than the previous unit used for the R-410A so it is difficult to compare the two series of tests. R-407C and its alternatives discussed here are likely to perform worse in the smaller R-410A unit even if measures were taken to make it function with R-407C using the correct compressor and other minor components.

GWP Impact on Life Cycle Climate Performance (LCCP)

An evaluation was conducted on the contribution of the direct impact of refrigerant GWP on overall system contribution to global warming. LGWP refrigerants with GWPs of 500 and 150 were compared to R-410A.

Calculations were performed using a conservative 5% annual leak rate estimate, 15 year life and 15% end-of-life charge loss. A Southern EU climate was used with the CO_2 equivalent of electrical energy consumption being 0.59 kg CO_2/kWh. This value

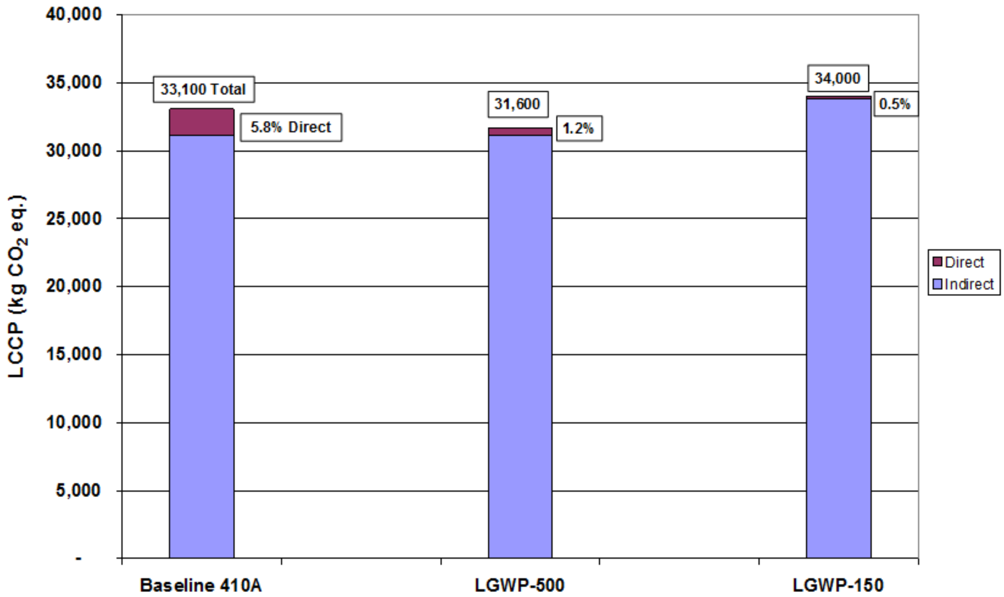

Figure 1 – LCCP Analysis

was calculated using a population weighted average of four countries (Spain, Italy, Portugal and Greece). The units are reversible (heat/cool) with no efficiency loss relative to R-410A for LGWP-500. There is an assumption of an 8% lower COP for LGWP-150 and it would be an R-407C-like refrigerant. In addition, the heat exchanger size was the same as it is for R-410A and its alternative. This last assumption was made since the analysis should assume that the equipment costs are comparable.

Results show minimal gain in direct impact when reducing GWP below 500 (figure 1). Any decrease in efficiency would more than offset any reduction in direct impact

This analysis is based on paper presented at Earth Technology Forum [Spatz, 2004] and heat pump results obtained in the present study.

Conclusions

Recently developed low global warming molecules may have potential applications in systems that currently employ medium pressure refrigerants such as commercial refrigeration and AC systems. Unlike CO_2, comparable performance to existing refrigerants can be achieved in applications investigated to date without significant hardware modification.

Preliminary evaluations of higher pressure blends show promise; however there are trade-offs in performance, flammability, and GWP that need to be made.

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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