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PERFORMANCE OF NOVEL LOW GWP REFRIGERANTS for AC and HEATING

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ABSTRACT: Laboratory testing to evaluate the performance of some new candidate refrigerants has been conducted and the results reported here. The low GWP fluid HFO-1234yf (2,3,3,3-tetrafluopropene) and two blends based on that new molecule were tested as a "drop-in" in a high performance R-410A AC/Heat Pump system. Follow up testing was done at modified conditions. While the low GWP HFO-1234yf did not give the desired performance in the test system, one candidate blend, DR-5, did show promising performance. Test conditions were modified to further evaluate the cooling and heating performance of the fluid DR-5. It was shown to perform at levels very close to that of R-410A in the test system. Conclusions and recommendations are presented.

NOMENCLATURE:

COP	Coefficient of Performance: a measure of system efficiency equal to the ratio of cooling (or heating) achieved to the total power consumed.
DR-n	designation for one of several Developmental Refrigerants or refrigerant compositions that include HFO molecules in the composition
GWP	Global Warming Potential
HFO-	Hydrofluoroolefin: a molecule containing a carbon-carbon double bond in its backbone structure, and containing one or more fluorine atoms bonded to carbon atoms.

1. INTRODUCTION

Concerns about the earth's climate and potential for damage due to human activity have prompted research to evaluate new materials that offer better energy efficiency and reduced potential for environmental impacts. In the fields of air conditioning and refrigeration, the new molecule, HFO-1234yf was identified and is being evaluated for use as a replacement for R-134a [1]. This molecule exhibits high stability inside of operating compressors and heat exchangers, but by virtue of the olefin structure, it can decompose in a matter of days if it is released into the atmosphere, due to the actions of sunlight and oxygen [2]. Indeed, this molecule has been selected by SAE International for use in automobile air conditioning systems as new car platforms are developed and commercialized in the European Union [3], in order to comply with the EU F-gas Directive. While HFO-1234yf does offer cooling performance similar to that of R-134a, it lacks the capacity of higher pressure refrigerants such as R-410A which is widely used in stationary air conditioning and heat pump systems, and in some low temperature commercial refrigeration.

Novel refrigerant fluids with higher capacity have been developed for use in air conditioning and heat pumping, which have superior environmental properties, and can reduce the carbon foot print that results from indoor climate control. Work is being performed in laboratories to measure and validate the chemical and physical properties of these new fluids, which are based on HFO (hydrofluoroolefin) chemistry. In addition, measurements have been made in AC and heat pump systems to verify and validate actual cooling, heating, and energy consumption performance of these new candidate fluids. In this paper, results from some of this measurement work will be reported and discussed. Base line comparisons are made with respect to the incumbent AC fluid, R-410A.

This work is part of an effort to develop alternative refrigerants for cooling and heating systems for residential and light commercial systems that currently use refrigerant R-410A, which has a direct Global Warming Potential of 2088 on a one hundred year time horizon, according to the IPCC Fourth Assessment Report on global warming gases. R-410A does exhibit high volumetric capacity for use in cooling and heating systems, and good energy efficiency, and extensive work has been done to design and optimize mechanical systems to use this fluid. The global installed base of equipment that currently uses R-410A is hundreds of millions of units. The novel fluids described in this work have been tested in equipment designed for use with R-410A, and the results of that testing are reported. One of the fluids, DR-5, shows high potential to be used directly in R-410A systems, with even less energy use than in the baseline system.

The selection of working fluids for use in cooling and heating systems has always required certain trade offs, and this is still the case. Some of the trade offs considered with respect to these fluids include the short atmospheric lifetime and result low direct GWP value, versus a low degree of flammability, which will fall into the ISO and ASHRAE "2L" safety category. These molecules are difficult to cause to burn, and if ignited create a weak and unstable flame that is easily extinguished. The heat liberated during the slow combustion is quite low, as compared to more common flammable molecules like hydrocarbons. The consequences of this flammability include impacts on safety regulations and building codes. Work is underway at several agencies, including ASHRAE, AHRI, and Underwriters Laboratories to define safe operating requirements for using class 2L flammable refrigerants.,

Impacts of these trade offs, including energy efficiency, capacity, safety, and heat transfer performance as well as direct environmental considerations and how they might impact possible regulations regarding air conditioning and commercial refrigeration all need to be evaluated.

2. REFRIGERANTS TESTED

The refrigerants used in this work are listed in Table 1. Listed in the table are results of modeling work to predict and compare the theoretical cycle performance of these refrigerants. As the driver for this work is to find the refrigerant with the least overall impacts on the environment, especially formation of carbon dioxide and equivalents, the first candidate evaluated was pure HFO-1234yf, as it has a direct GWP value of only 4. While the predicted capacity is low, compared to R-410A, the predicted COP is quite good, making it an intriguing molecule for testing. DR-1 is a non flammable composition. While its direct GWP is higher, there was interest in a non flammable candidate. DR-5 is a fluid that in other tests has shown to give performance close to that of R-410A, but it has about 75 % lower direct GWP. R-134a was not used in this test, but it is shown on the table for as a reference point, showing that HFO-1234yf and DR-1 have performance properties the more similarly resemble that molecule, not R-410A.

Modeling can give good predictions if sufficient thermophysical and transport information are available and accurate. However, for a new molecule that has not yet been exhaustively studied and measured. It is desirable to run actual equipment tests, under actual use conditions. By so doing, factors such as pressure drop, heat transfer, and temperature glide related effects.

Modeling of Cycle Performance at AC Conditions, vs. R-410A
T Evap = 7° C, T Condenser = 47 C Subcool = 12 K
Return Gas superheat = 3 K Compressor Efficiency = 70 %

Refrigerant Candidate	GWP	Glide K	Dischg Press kPa	Dischg Temp °C	Critical Temp °C	Cap % Δ Vs R-410A	COP % Δ Vs R-410A	Flammable Rating
R-410A	2088	0.1	2823	81	71	0	0	1
R-134a	1430	0	1222	64	102	-55	8.4	1
HFO-1234yf	4	0	1209	55	95	-57	5.6	2L*
DR-1	<700	0	1280	59	98	-54	7.1	1
DR-5	< 500	1	2748	89	81	0	0.8	2L*

Table 1. Refrigerants used in this study. Performance data from cycle models. Comparisons to R-410A and per cent difference. * indicates flammability anticipated rating.

3. TEST DESCRIPTION

Refrigerant testing was performed in a high performance inverter type AC/Heat pump unit designed to use R-410A. Nominal cooling capacity was 7.2 kW. Testing was done in a psychrometric environmental chamber. Test conditions for cooling were:

Outdoor:	35/24 °C
Indoor:	27/19 °C

First, baseline operating conditions were measured at normal operating conditions with R-410A, and the COP was measured to be 3.1 by measuring the input power and the net cooling capacity achieved. The candidate refrigerants were tested in sequence as 'drop in", with only charge optimization for each fluid. The compressor speed was the same in each case.

A second run was made for DR-5, because in its first run power use was less than the baseline, and total cooling was also less than the baseline, but the COP was about higher than R-410A. A second run was made with DR-5, this time with the compressor speed set about 7 % faster in order to create net cooling capacity equal to the 410A base line so that COP could be compared.

A similar sequence of testing was performed in the heat pump mode with the same set of refrigerants, again as drop in tests. As in cooling, a second run was made with DR-5, now with the compressor speed increased about 5 % so that its capacity matched R-410A. Heating test conditions were:

Outdoor	7/6 °C
Indoor	20/15 °C

Results of these tests are shown in Figures 1 through Figure 4, at the end of this section and discussed in the Results section.

4. RESULTS

Detailed performance results showing power consumption, cooling or heating capacity measured, and COP values are shown in bar graph form in Figures 1 through 4 at the end of the body of this paper. The more significant COP and Capacity comparisons are also summarized in Table 2 and Table 3 below for cooling and heating, respectively.

Cooling: Refrigerant	410A	134a	1234yf	DR-1	Drop In DR-5	Capacity Match DR-5
Capacity	100.0%	56.6%	57.5%	58.3%	96.3%	99.7%
COP	100.0%	137.1%	143.5%	134.5%	102.9%	98.4%

Table 2. Relative COP and Capacity results, Cooling

In table 2 the capacity and COP results are normalized with respect to the respective values for R-410A. It is not too surprising to see that R-134a, HFO-1234yf, and DR-1 all gave capacity in the range of 56 % to 58 % of R-410A. HFO-1234yf is, after all, a replacement for R-134a, and DR-1 is in the same category. One would not normally try to run an R-410A AC unit with R-134a. While it might be possible to design a residential AC unit that runs on R-134a or a similar low GWP gas, there will be several design issues that need to be resolved or mitigated. The lower volumetric capacity of the refrigerant might be mitigated by using a larger compressor and pumping a greater mass flow rate of refrigerant. However, the larger motor would consume more power in the process. Further, the higher flow rate of refrigerant will result in significantly larger pressure drop throughout the system, possibly requiring larger piping and larger heat exchangers. This system would require a larger mass of refrigerant due to the larger volume. The heat exchangers and the compressor housing will need to be commensurately larger, and therefore more difficult to install, due to the larger size and weight. Even though the COP is higher, the combined losses have been shown to out weigh the COP advantage in terms of the total environmental impact over the life of the AC system.[6].

On the other hand, the DR-5 in the drop in test showed a COP gain of 2.9 % over R-410A, but with a loss in capacity of 3.7 %. The compressor speed was increased to give capacity approximately matching R-410A, but in this case the COP dropped to about 1.6 % less than R-410A. These results indicate that DR-5 is very close to being a performance match for R-410A. Since its GWP is about one fourth of that of R-410A, DR-5 becomes an attractive alternative to consider for replacing 410A in order to gain the GWP advantage. It may possible to fine tune the AC system design and realize more performance improvements. Such an evaluation is work that is yet to be done. Even with no system or design optimization environmental advantages can likely be achieved by use of DR-5.

Heating: Refrigerant	410A	134a	1234yf	DR-1	Drop In DR-5	Capacity Match DR-5
Capacity	100.00%	50.90%	46.60%	50.90%	91.60%	100.90%
COP	100.00%	142.00%	136.80%	138.90%	105.20%	104.20%

Table 3. Relative COP and Capacity results – Heating

The results from the heat pump test track similarly to those from the AC test. The R-134a, HFO-1234yf, and the DR-1 blend give the expected low value for capacity in this system. The DR-5 in the drop in test showed a capacity deficit of 8.4 %, but with a COP advantage of 5.2 %. When the compressor speed was increased by about 5 % to bring the heating capacity up to match 410A, the COP dropped to about 1.6 % below the R-410A value. These are initial results, and it may be possible with minor system tweaking to match or exceed the performance of R-410A. Even at this level of performance the reduced GWP may sufficient to provide an environmental advantage over R-410A, as reported in reference [6].

5. DISCUSSION

This work is part of a larger effort to identify near term and medium term, and hopefully long term solutions that can mitigate the environmental and climate change consequences that can result from the use of air conditioning, heating, and refrigeration. While we recognize that there is no single perfect refrigerant that will work efficiently in every cooling and heat pump application, we believe it is possible, and necessary, for us to identify the most appropriate refrigerant fluids for especially the high volume end uses, like residential and light commercial air conditioning, that account for substantial amounts of refrigerant use.

In this study, it was shown that of the candidates evaluated, the DR-5 is the fluid that most nearly can serve as a replacement for R-410A and thereby provide substantial reduction in the direct GWP potential of the installed refrigerant bank. A replacement refrigerant that can work as a “drop in” in existing equipment and in equipment designs will facilitate a faster transition away from the high GWP refrigerants like R-410A.

In a research project similar to this one[6] it was shown that the DR-5 fluid offers Life Cycle Climate Performance that is superior to pure HFO-1234yf or other lower GWP refrigerant blends. The results of the study reported here are very similar to the other project, and the two support each other and affirm that refrigerants with intermediate direct GWP values, like DR-5, can give greater environmental and climate benefits than refrigerants with very low GWP values, like pure HFO-1234yf, when used in residential scale air conditioning and heat pumping applications. These results can be very valuable for regulators and policy makers who are tasked with developing regulations that are intended to preserve our environment.

6. CONCLUSIONS

The work described in this paper has shown that the reduced GWP candidate DR-5 can work well even as a "drop in" refrigerant in existing equipment that was designed and optimized for use with R-410A. Because R-410A has a very high direct GWP value of 2088, according to the fourth assessment report of the International Panel on Climate Change, it is likely to face regulatory or legislative controls to limit its use. Even in the absence of regulation, there is a need to reduce the impacts on our environment that from society's use of refrigeration and air conditioning.

Ultimately, most environmental damage that results from refrigerant gases comes from two sources. These are leakage of the refrigerant from the system, which often happens at the end of the life of the equipment as it is taken out of service, and carbon dioxide that is emitted from fossil fuel power plants that generate the electricity used by AC and heat pump equipment. To address the former, there is a need to develop measures to protect the refrigerant gas, from "cradle to grave" and prevent it from escaping into the atmosphere. However, if the refrigerant does escape, it should be a gas that decomposes in a relatively short time to yield benign final decomposition products. We believe that the gases we are working on and describe in this study fall into the category of causing minimum environmental impact should they inadvertently escape into the atmosphere, and by using less electricity due to high energy efficiency.

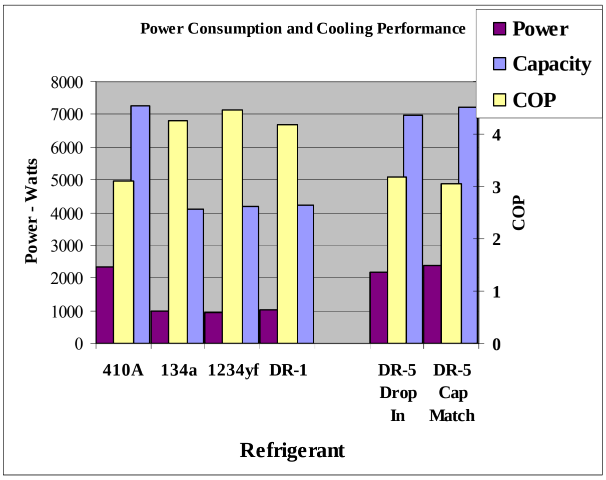

Figure 1. Power Consumption, Cooling capacity, and COP for Air Conditioning tests.

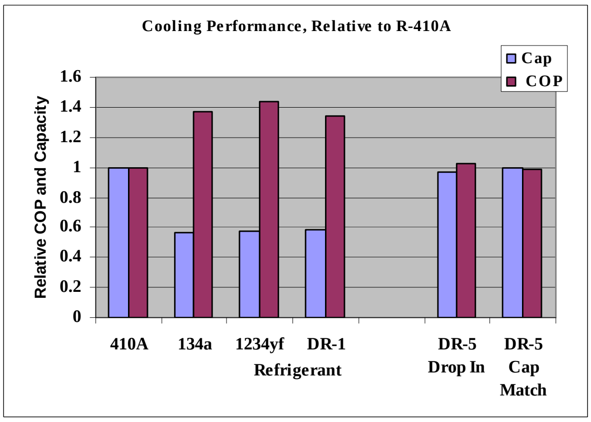

Figure 2. Cooling performance shown normalized to R-410A =1

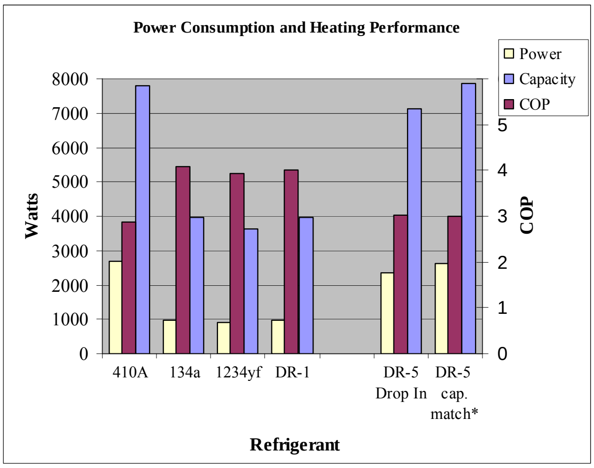

Figure 3. Power consumption, heating capacity, and COP for heat pump tests. *compressor speed increased to give match DR-5 with R-410A.

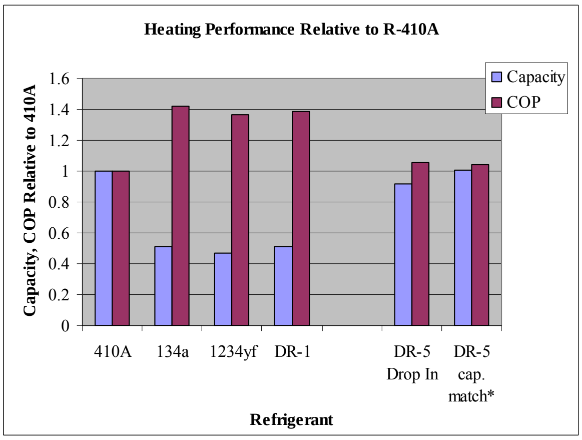

Figure 4. Heat Pump Performance, normalized relative to R-410A heating. * Compressor speed was increased to match DR-5 capacity with R-410A.

7. DISCLAIMER

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