

# ANALYSIS OF LGWP ALTERNATIVES FOR SMALL REFRIGERATION (PLUGIN) APPLICATIONS

YANA MOTTA, S.<sup>(\*)</sup>, SPATZ, M., VERA BECERRA, E.

<sup>(\*)</sup>Honeywell International, 20 Peabody Street, Buffalo, NY 14210,  
Samuel.YanaMotta@honeywell.com

## ABSTRACT

Novel refrigeration working fluids with attributes of superior thermal performance and low environmental impact are in development stages approaching commercialization. These fluids known as HFO-1234yf and HFO-1234ze exhibit very low global warming potential, good refrigeration performance, improved flammability characteristics compared to hydrocarbon materials, and are in conformance with the EU F-Gas Regulation (EC 842/2006). Use of these fluids in small refrigeration machines, which currently use R-134a, offers the potential to improve energy performance. This article presents and analyzes results of experimental evaluations for typical vending systems.

**Keywords:** Refrigerants, Global Warming, Hydro-fluoro-olefins, Vending Machines.

## 1. INTRODUCTION

Due to a growing global concern about the increasing impact of mankind on the warming of our atmosphere, the refrigerants that have been used as working fluids for small (plug-in) refrigeration applications have come under scrutiny. Regulators around the world are now focusing on the direct global warming impact of these fluids. An example of this is the European directive that will phase out the use of R-134a in automobile air conditioning systems starting in 2011 and a complete phase out scheduled for 2017. More recently the United States along with Canada and Mexico proposed adding a phase down in the use of HFCs to the Montreal Protocol calling for a 10 percent reduction by developed nations beginning in 2013, culminating in an 85 percent phase down by 2033.

As a result of the need to find suitable substitutes for higher global warming refrigerants, two new low global warming refrigerant molecules have been identified, HFO-1234yf & HFO-1234ze. These molecules are Hydro-Fluoro-Olefins (HFO) and Honeywell has discovered that these molecules have an extremely low global warming potential (GWP) of only 4 to 6 (as compared to 1430 for R-134a). This article will discuss properties and applications of these potential refrigerant options in small refrigeration systems.

## 2 WORKING FLUIDS

### 2.1 Pure Refrigerants Properties

Depicted in Table 1 are properties of both HFO-1234yf and HFO-1234ze, together with some refrigerants also proposed as replacements for R-134a. Also shown in Table 1 are Permissible Exposure Limits (PEL) and flammability limits (LFL and UFL). Both HFO fluids have very low toxicity. HFO-1234yf is already classified as “A” by ASHRAE [3] with similar expectancy for HFO-1234ze. It is also important to note that HFO-1234ze does not exhibit flame limits under standard test conditions of ASTM E-681 [3] or EU A11. HFO-1234ze does, however, exhibit flame limits at elevated temperatures (above 30°C). All test data obtained in this research was analyzed using properties from Refprop NIST (Lemmon et al., 2002 [4]) which we modified to add our newly developed refrigerants.

Table 1. Refrigerant Properties

Refrigerant	GWP	Boiling Temp. (°C)	Critical Temp. (°C)	PEL (ppm)	LFL / UFL (Vol%, 23°C)
R-134a	1430	-26	101	1000	-
HFO-1234ze	6	-19	110	800	-
HFO-1234yf	4	-30	94	500	6.2-12.3
R-600a	~5	-12	135	800	1.8-8.5
R-744	1	-78.4	31	4000	

## 2.2 Refrigerant/oil properties

Measurements were made of the properties (solubility, density and viscosity) of the refrigerant and lubricant pair using ISO 10 POE oil with HFO-1234yf and HFO-1234ze. These pairs were found to be fully miscible for the operating range (-25 to 70°C). Testing methodology is well explained in Seeton and Hrnjak [1].

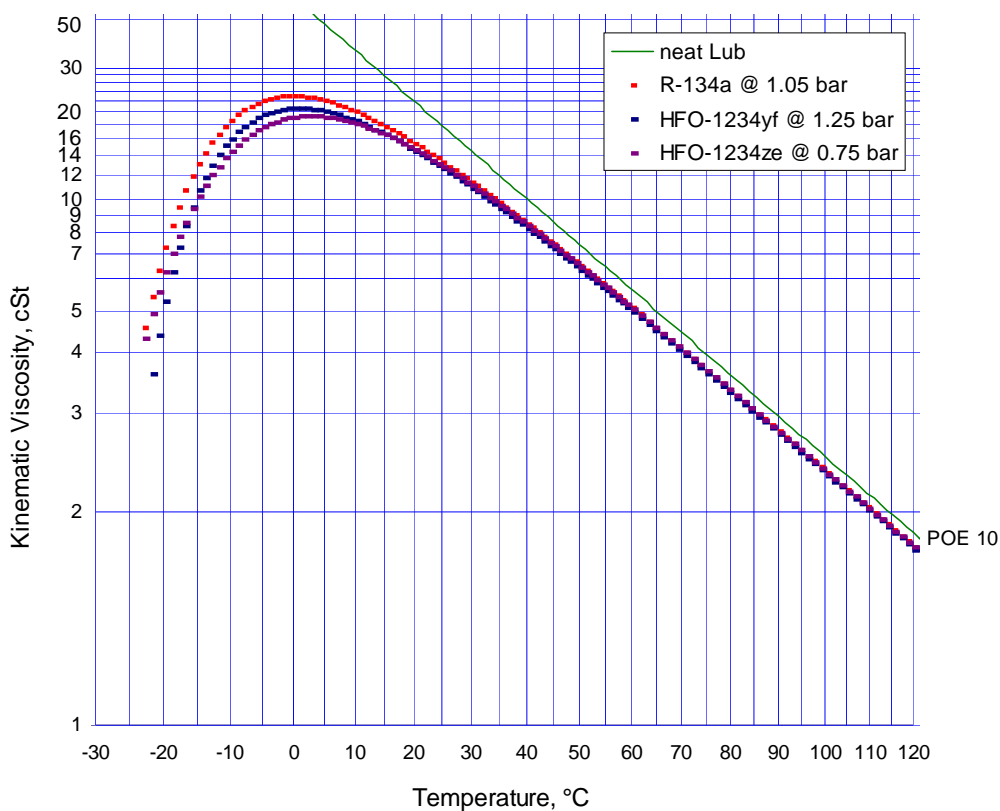


Figure 1. Refrigerant oil viscosity comparison at typical operating conditions.

The results showed that HFO-1234yf and this lubricant have solubility similar to R-134a whereas HFO-1234ze is slightly more soluble than R-134a. Using this solubility information, we evaluated compressor sump viscosities at typical evaporating temperatures. As shown in figure 1, viscosities of HFO-1234yf/oil and HFO-1234ze/oil are similar to R-134a/oil. Therefore, we can conclude that lubricating properties are not likely to be impacted by use of HFO-1234yf or HFO-1234ze.

## 3. EQUIPMENT WITH SYSTEM INTEGRATED IN THE CABINET

This evaluation deals with a traditional vending machine where the refrigeration system is integrated with the cabinet. Pull down and cycling tests were performed using a 360-bottle/glass-door vending machine equipped with a 0.56 kW (3/4 HP) reciprocating hermetic compressor, fin-tube heat exchangers and a capillary tube installed in the LL-SL heat exchanger configuration. These initial tests were essentially “drop-in” ones where the refrigerant charge size of HFO-1234yf was the same as R-134a.

All tests strictly followed ASHRAE Standard 32.1 procedures and operating conditions (32.2°C @ 65% RH). The vending cabinet was loaded with a total of 360 bottles (591 ml each). 56 bottles were filled with a glycol/water (20/80) mixture and their temperature measured to verify product conditions (2.2°C ±0.5°C). All tests were performed in environmental chambers providing proper conditions.

### 3.1 Pull-Down Evaluations

Figure 2 shows results for the pull-down tests for R-134a and HFO-1234yf. Average temperatures measured for 56 bottles show R-134a and HFO-1234yf as being very similar with HFO-1234yf (22.8h) having a slightly shorter pull-down time than R-134a (23.2h). The integrated value gives an energy consumption of 10.81 kW-h for R-134a and 10.71 kW-h for HFO-1234yf. Overall one can say that HFO-1234yf is a near drop-in for R134a in this system.

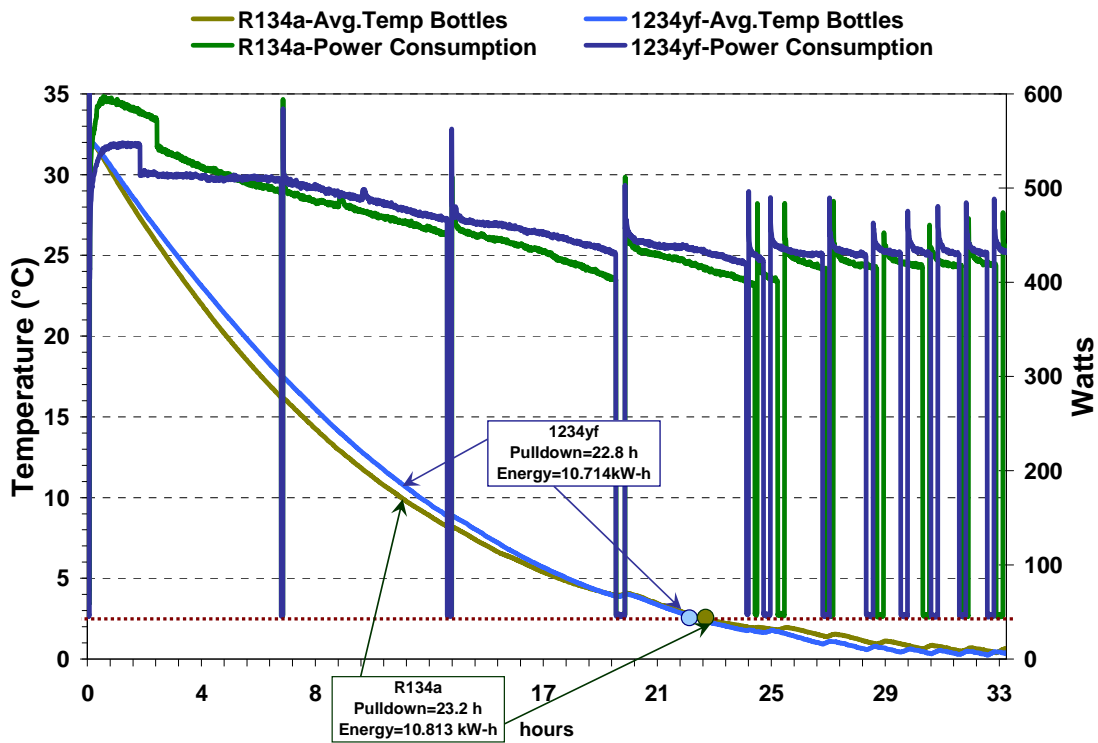


Figure 2. Pull-down results

### 3.2 Cycling Evaluations

Standard cycling evaluations were performed for a 24h period as required by ASHRAE standard 32.1. Similarly to the pull-down tests, no significant difference was found between R-134a and HFO-1234yf. In fact, the slightly higher energy consumption of HFO-1234yf (+1.5%) is in the range of experimental uncertainty of these measurements.

Table 2. Summary of cycling evaluations

Refrigerant	Cycling 24h (Kw-h)	ON Operation (%)	Bottles Temp (°C)
R-134a	7.14	68.4%	1.4°C
HFO-1234yf	7.25	67.5%	1.3°C

The above results show that HFO-1234yf performance is comparable to R-134a using current vending systems designs. Better efficiencies are possible with minor design/sizing changes of the capillary tube in the Suction-Line/Liquid-Line (SL-LL) configuration.

## 4. CASSETTE SYSTEMS

### 4.1 System Description

An experimental study for R-134a, HFO-1234yf and HFO-1234ze was performed using a representative vending machine. The original R-134a system consisted of tube-and-fin heat exchangers, a reciprocating compressor and thermostatic expansion valve. Tests with HFO-1234yf required the use of a needle valve as expansion device to reproduce the same degrees of superheat observed with R-134a. Tests with HFO-1234ze required a needle valve as expansion device and a compressor with 75% larger displacement. The compressor used for HFO-1234ze was a commercially available larger capacity R-134a compressor.

### 4.2 Operating Conditions and Test Setup

Tests were performed using operating conditions developed to evaluate efficiency and capacity. The efficiency test requires an external ambient temperature of 90°F (32.2°C) and 65% relative humidity while the interior space was maintained at 2°C. The capacity test uses the same interior temperature (35.6°F or 2°C) but with an external ambient temperature of 105°F (40.5°C) and 75% relative humidity.

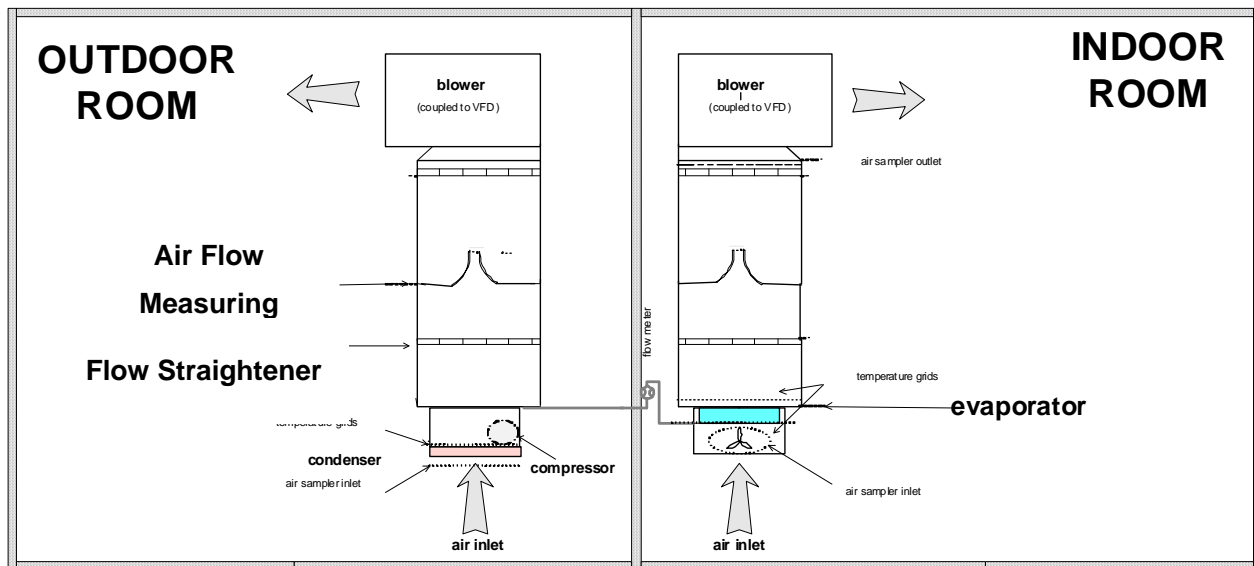


Figure 3. Experimental setup.

All tests were performed inside environmental chambers equipped with instrumentation to measure both air-side and refrigerant-side parameters (Figure 3). 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 [2]; AHRI, 2008 [1]). All primary measurement sensors were calibrated to  $\pm 0.27^\circ\text{F}$  ( $0.15^\circ\text{C}$ ) for temperatures and  $\pm 0.25$  psi for pressure. Overall system uncertainties (capacity and efficiency) were in average  $\pm 5\%$ .

Although vending systems have usually closed-coupled connections, our evaluation required splitting the system in indoor (evaporator-fan) and outdoor units (condenser-fan-compressor). These units were placed at the inlet of the each tunnel which were located as close as possible to minimize connecting lines length. Pressure drop in the suction line was below the maximum recommended ( $1.8^\circ\text{F}$  or  $1^\circ\text{C}$ ). Air flow was set as expected in the actual system: free flow for the condensing unit and standard air-side pressure drop for the evaporator (0.1 inch of water).

### 4.3 Overall system Performance

Table 3 and Figure 4 show results of the evaluation. HFO-1234yf confirms being an excellent replacement for R-134a by giving similar capacity and efficiency. Both capacity and efficiency differences are in the range of experimental uncertainty. Due to the use of a larger compressor, HFO-1234ze shows an average of 12% larger capacity and 8% lower efficiency. The higher capacity was expected due to the use of a larger displacement commercially-available compressor, still this penalized the performance of the system. This performance loss can be recovered using a compressor designed for HFO-1234ze.

Table 3. Summary of evaluations.

Fluids / Tests		Overall System			Heat Exchangers					
		Cap.	COP	Mass Flow	Cond. Temp	Evap. Temp	Disch. Temp.	$\Delta T$ -sat suction line	$\Delta T$ -sat Evap	$\Delta T$ -sat Cond
		% of R134a	% of R134a	% of R134a	% of R134a	% of R134a	°C	°C	°C	°C
R134a	Eff. Test	100%	100%	100%	100%	100%	82	0.3	1.1	0.2
	Cap. Test	100%	100%	100%	100%	100%	91	0.5	1.1	0.2
1234yf	Eff. Test	105%	99%	127%	105%	112%	75	0.6	1.5	0.3
	Cap. Test	102%	98%	119%	104%	106%	84	0.6	1.4	0.2
1234ze	Eff. Test	113%	93%	125%	104%	112%	87	0.5	2.7	0.3
	Cap. Test	111%	91%	123%	103%	109%	97	0.5	2.6	0.3

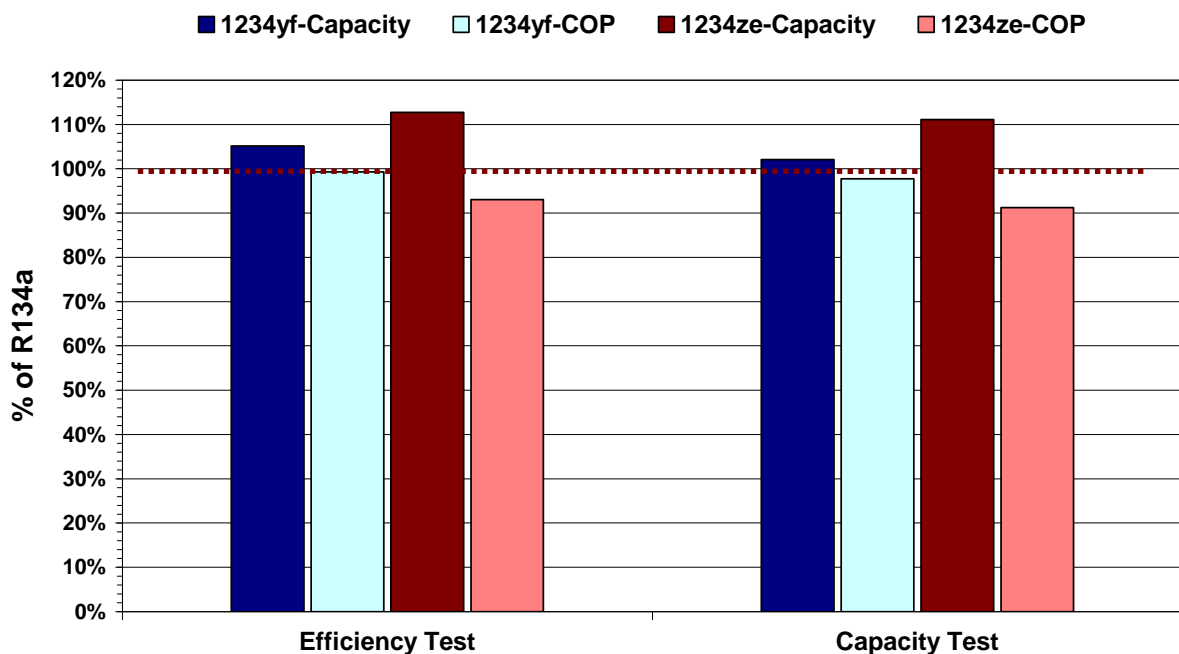


Figure 4. Overall system performance results.

#### 4.4 Heat Exchangers Analysis

Table 3 shows condensing and evaporating temperatures of both HFO refrigerants compared to R-134a. HFOs show slightly higher condensing and evaporating temperatures. The higher condensing temperature indicates that some improvements in the design are possible. On the other hand, the higher evaporating temperature is explained by the larger mass flow improving the in-tube heat transfer.

Figure 5 reinforces the above by showing significant differences in saturated pressure drop penalties between R-134a and the new HFOs. Since evaporator impact on performance is usually more significant, some minor modifications to the evaporator design can further improve the performance, especially for HFO-1234ze.

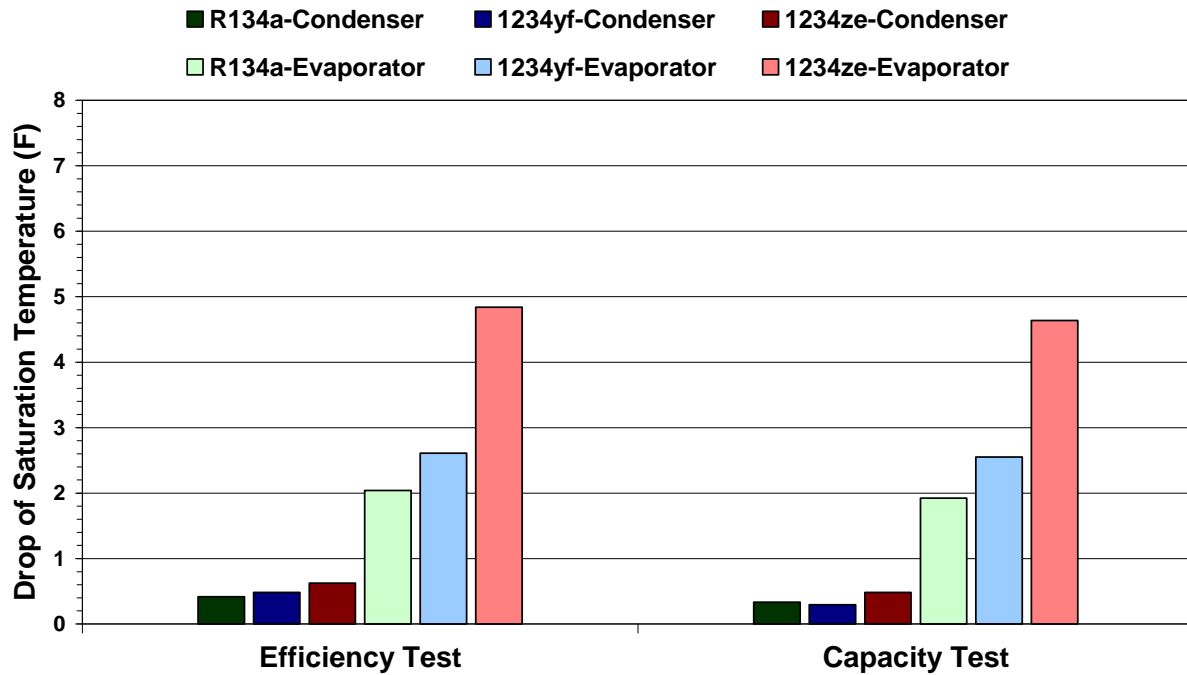


Figure 5. Drop of saturated temperature in heat exchangers

## 5 CONCLUSIONS

HFO-1234yf and HFO-1234ze have potential in applications such as small commercial and residential refrigeration systems and other areas where a medium pressure refrigerant can be efficiently employed and where low global warming refrigerants are needed or desired.

This study reported detailed performance evaluation of these HFO refrigerants in an actual vending system. Overall results show that comparable performance to R-134a can be achieved without significant hardware modification. The good interaction with POE oils used in these applications has also been demonstrated.

HFO-1234ze efficiencies were lower than R-134a and HFO-1234yf. This was mainly due to pressure drop losses in the evaporator and compressor penalties (suction passages and electric motor sized for R-134a). Nevertheless HFO-1234ze had a COP of 1.11 (efficiency), which is above the minimum level (1.0) mentioned by previous studies (DeAngelis and Hrnjak, 2005 [5]). We believe that this loss of efficiency can be recovered using a compressor properly sized and designed for HFO-1234ze as well as some minor modifications to the evaporator.

HFO-1234yf performance is comparable to R-134a using current vending systems designs. Better efficiencies are possible with minor design changes in the compressor and by the use of Suction-Line/Liquid-Line (SL-LL) heat exchangers. This is to exploit HFO-1234yf's low discharge temperature and compression ratio. The use of capillary tubes as expansion device and SL-LL heat exchanger, similarly to domestic refrigerators, is suggested.

This study showed that using HFO fluids can enable the design of vending systems with low environmental impact. This is achievable by reducing direct (low GWP) and indirect emissions (good efficiency). Further investigations for these applications should include additional performance evaluations as well as flammability risk assessments where appropriate.

## **REFERENCES**

1. AHRI, Standard 210/240-2008, Unitary A/C and Air Source Heat Pump Standard, Arlington, VA, 2008.
2. ASHRAE, Standard 41.2 Methods for Laboratory Airflow Measurements, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1992.
3. ASHRAE, Standard 34 Designation and Safety Classification of Refrigerants, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2010.
4. Lemmon, Eric W., McLinden, Mark O. and Huber, Marcia L., NIST Reference Fluid Thermodynamic and Transport Properties – Refprop 7.0, NIST Std. Database, 2002
5. DeAngelis, J.M. and Hrnjak, Experimental Study of System Performance Improvements in Transcritical R744 Systems with Applications to Bottle Coolers, ACRC CR-57, 2005.
6. Seeton C.J. and P.S. Hrnjak, Measurements of Solubility, Liquid Density, and Liquid Viscosity for CO<sub>2</sub>-Lubricant Mixtures, 3rd IIR Conference on Thermophysical Properties and Transport Processes of Refrigerants. Boulder, CO. 2009.

## **DISCLAIMER**

Although all statements and information contained herein are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve the user from the responsibility of carrying out its own tests and experiments, and the user assumes all risks and liability for use of the information and results obtained. Statements or suggestions concerning the use of materials and processes are made without representation or warranty that any such use is free of patent infringement and are not recommendations to infringe on any patents. The user should not assume that all toxicity data and safety measures are indicated herein or that other measures may not be require.