Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP)

TEST REPORT #25

System Drop-in Test of R134a Alternative Fluids R-1234ze(E) and D4Y in a 200 RT Air-Cooled Screw Chiller

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List of Tested Refrigerants' Compositions (Mass%)

D4Y	R-134a/R-1234yf (40/60)
R-1234ze(E)	R-1234ze(E) (100)

1. Introduction

This report documents the results from the testing of R1234ze(E) and D4Y as drop-in alternates for an air-cooled screw chiller (nominal size 200 Ton with R134a). The test was conducted in the air-cooled chiller test facilities of DaikinMcQuay located in Minneapolis, MN. Baseline tests were first conducted with R134a. These were followed by drop-in tests with R1234ze(E) and D4Y at the same conditions. All the tests were conducted using the same equipment and test facility without any modifications to the equipment, test facility or instrumentation. Testing was performed in accordance with AHRI Standard 550/590 requirements for air-cooled chiller testing.

2. Nomenclature

COP = Coefficient Of Performance
EEV = Electronic Expansion Valve
TXV = Thermal eXpansion Valve
HX = Heat eXchanger
PVE = PolyVinylEther
RTPF = Round Tube Plate Fin

3. Details of Test Setup

a. Description of System

The equipment used for this testing is an air-cooled chiller with these features:

- single refrigerant circuit
- variable speed screw compressor
- economizer refrigerant cycle

The test chiller is configured for a nominal full load capacity of 200 tons at AHRI 550/590 standard rating conditions. The chiller is designed for R134a and uses PVE oil for compressor lubrication. The evaporator of the chiller is a direct expansion type shell and tube HX with the refrigerant flowing inside the tubes. The air-cooled condenser of the chiller is a RTPF coil which consists of 3/8 inch (9.52 mm) diameter inner grooved copper tubes. The effective coil length is 282 inch (7.17 m) and total path length of the condenser is 564 inch (14.3 m). The exterior appearance of the test chiller is shown in Figure 1.

b. Description of Modification to System

There were no modifications to the chiller through the drop-in testing. The

chiller was first tested with R134a for the baseline performance. Then, R134a was removed from the chiller and tests were conducted with R1234ze(E). Again, repeating the same procedure, the chiller was tested with D4Y. All the tests were carried out with charging the same amount of lubricant oil, IDEMITSU FVC68D, to maintain the same oil influence. However, the lubricant-refrigerant mixture viscosity at the oil supply will not be the same due to different solubility characteristics of the oil with each refrigerant.

c. Description of Test Facility

The drop-in tests were carried out using the air-cooled chiller test facility located in Minneapolis, MN. The test facility is designed for air-cooled chiller product testing and is capable of testing up to 400 tons. Furthermore, this facility was approved by AHRI during 2011 for conducting witness testing as part of the ACCL Certification Program.

Figure 2 shows the refrigerant piping diagram of the test facility. Resistance temperature detectors (RTDs), pressure transducers and flow meters were installed as shown in the figure. Current transformers (CTs) were used to measure the power input to the whole product and compressor motor, respectively. Each sensor was calibrated to meet or exceed AHRI Standard 550/590 requirements for accuracy and all the data were acquired into the PC via LabVIEW program. The data acquisition frequency had been set to one second.

Table 1. Instrumentation Accuracy

Water Temperature	±0.1K
Water Flow Rate	±0.2%
Air Temperature	±0.1K
Electric Power	±0.15%RDG

d. Description of Tests Conducted

At the beginning of the drop-in test, R134a was charged to the chiller and the baseline data such as performance and COP were measured. After the first measurement, an additional 2.0 pounds (0.91 kg) refrigerant was added to the chiller and the same measurement was conducted. The same process was repeated until the COP reached a maximum. Inlet/outlet air temperature, inlet/outlet water temperature and outlet refrigerant super heat of the evaporator was referenced to determine whether the chiller reached a steady state.

After the baseline measurement for R134a, refrigerant inside the chiller was changed to the alternative refrigerants, R1234ze(E) and D4Y, respectively and the measurements were carried out in the same way. When changing the refrigerant, a nitrogen substitution method was employed to eliminate any non-condensable gases in the chiller. Steps in the refrigerant changing process: recover refrigerant from chiller until reaching a low pressure, evacuate, charge with nitrogen, evacuate again, then charge with new refrigerant (refrigerant circuit is never open to atmosphere). The vacuum process was continued until the inside pressure decreased below 500 micron of mercury (absolute pressure 67 Pa). In this drop-in test, IDEMITSU FVC68D, was used for the lubricant and its charge amount was always adjusted to 5.0 gal (18.9 Liter).

EEV of the test chiller was controlled automatically to maintain target values of superheat and subcooling. Compressor speed was set to the same value at the measuring condition regardless of the refrigerant. Water flow rate was changed manually to keep the inlet/outlet water temperature the same. Thus, water flow rate of R1234ze(E) was lower than other refrigerants by about 30% due to different refrigerant physical properties. After testing it was discovered that the water flow rate was out of tolerance from the AHRI Standard Rating Condition, but it was too late to repeat the testing due to test facility scheduling conflicts.

Table 2. Evaporator Water Flow

	Normalized Water Flow (gpm/Ton)					
Refrigerant	Nominal Target	Actual	Deviation from Nominal	Lower Tolerance	Upper Tolerance	Out of Tolerance
R134a	2.40	2.84	+0.44	2.28	2.52	+0.32
R1234ze(E)	2.40	2.58	+0.18	2.28	2.52	+0.06
D4Y	2.40	2.84	+0.44	2.28	2.52	+0.32

4. Results

Test data for each refrigerant are listed below in Test Data Form #1 and #2. Since the main objective of this drop-in test is to grasp the basic cycle characteristics of the candidate refrigerants, discharge/suction pressure of the compressor was treated same as the saturation pressure of condenser/evaporator. In addition, subcooling temperature of the condenser and inlet vapor quality of the

evaporator was defined by using discharge/suction pressure of the compressor, respectively. Therefore, refrigerant physical parameter changes caused by pressure drop within the evaporator were not considered.

Table 3 shows a comparison of the test results which consist of capacity, energy efficiency, refrigerant charge quantity of each refrigerant. Numerical values shown in the table represent the relative ratio against R134a and the numbers in parentheses indicate the prediction value which was calculated using physical properties of each refrigerant and a simple thermodynamic cycle model for vapor compression. From Table 3, it can be seen that the capacity of R1234ze(E) is 22.6% lower than that of R134a and the COP is 5.5% higher than R134a. Also, the capacity of D4Y is almost same as that of R134a and the COP is 2.6% lower than R134a. These results are showing a decent agreement with the predicted values. The refrigerant charge quantity at best full load COP for R134a, R1234ze(E) and D4Y was 185 kg, 193 kg and 205 kg, respectively.

Table 3. Performance comparison between candidates and R134a

	Capacity		COP		Refrigerant charge quantity
	(Predicted)	Actual	(Predicted)	Actual	Actual
R1234ze(E)	(75.0%)	77.4%	(101.0%)	105.5%	104.3%
D4Y	(97.0%)	99.9%	(98.0%)	97.4%	110.8%

Since the test chiller has an economizer controlled by TXV, cycle performance for the alternative refrigerant drop-in test might differ from the optimum point due to physical property differences. Therefore, actual optimum COP of the alternative candidate may be slightly better than this drop-in test result.

5. Conclusions

Two alternative refrigerant candidates R1234ze(E) and D4Y were tested in an air-cooled screw chiller as a drop-in test using a R134a as the baseline. The results showed reasonably good agreement with the predicted values and no special problems or issues were observed through the testing. Both candidates have merits to be considered for further evaluation, through a system optimization design process to achieve a suitable compromise between efficiency, capacity, and cost.

Figure 1. Photo of the Tested Air-Cooled Chiller

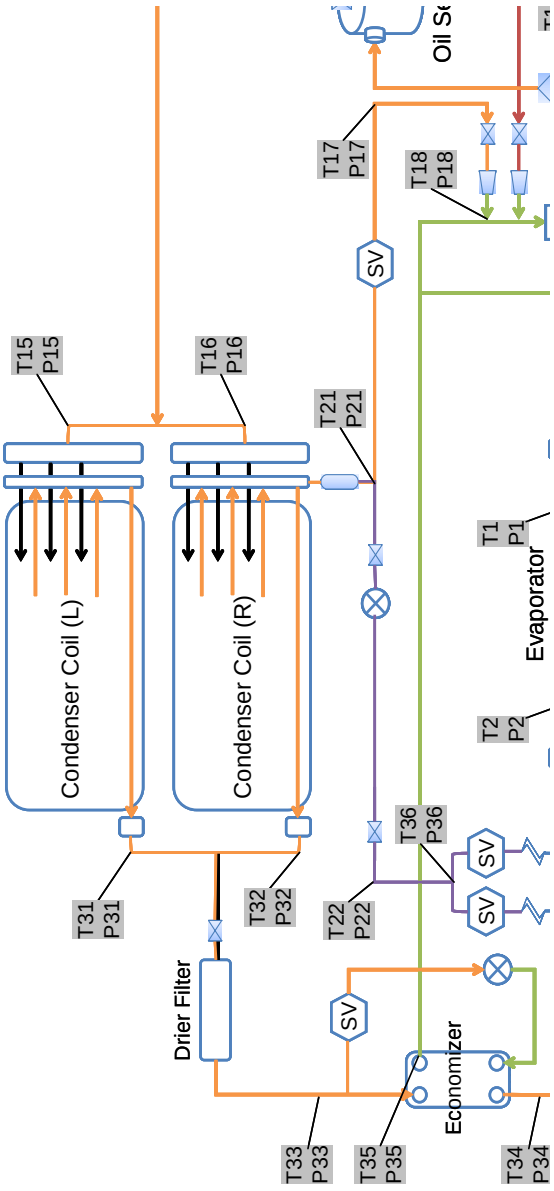

Figure 2. Schematic of the Tested Chiller with Measurement Locations

Low GWP AREP SYSTEM DROP-IN TEST DATA FORM – TEST#1

Manufacturer: DaikinMcQuay Manufacturer's Notation: INV Screw Chiller

Basic Information	
Alternative Refrigerant	**R1234ze(E)** Honeywell
Alternative Lubricant Type and ISO Viscosity	PVE, VG68 (IDEMITSU FVC68D)
Baseline Refrigerant and Lubricant	R134a, IDEMITSU FVC68D
Make and Model of System	INV Screw Chiller (Prototype)
Nominal Capacity and Type of System	200 Tons, Air-cooled screw chiller

Comparison Data		**Base.**	**Alt.**	**SI Units**	**Base.**	**Alt.**	**IP Units**	**Ratio**
Mode (Heating/Cooling)		Cooling						
Compressor Type		VFD Screw						
Compressor Displacement		16.78		m^3/min	592.6		ft^3/min	
Nominal Motor Size		260		kW	350		hp	
Motor Speed		6,240		rpm	6,240		rpm	
Expansion Device Type		EEV						
Lubricant Charge		18.9		L	5.0		gal	
Refrigerant Charge		185	193	kg	407.9	425.5	lb	1.043
Refrigerant Mass Flow Rate		255.8	211.9	kg/min	563.9	467.2	lb/min	0.828
Composition, at compr. Inlet if Applicable		n/a	n/a		n/a	n/a		
Chilled Water	Leaving Temp	6.9	6.9	°C	44.4	44.4	°F	
	Flow rate	2,118	1,494	L/min	559.6	394.8	gpm	0.705
Outdoor Air	Dry Bulb	35	35	°C	95	95	°F	
	Wet Bulb	n/a	n/a		n/a	n/a		
Total Capacity		693.7	537.2	kW	197.3	152.8	Tons	0.774
Sensible Capacity		n/a	n/a		n/a	n/a		
Total System Power Input		222.7	163.7	kW	222.7	163.7	kW	0.735
Compressor Power Input		210.3	151.4	kW	210.3	151.4	kW	0.719
Coeff. Of Performance (COP)		3.11	3.28	W/W	10.63	11.20	EER	1.055

Other System Changes

System Data	**Base.**	**Alt.**	**Ratio**
Degradation Coefficient - Cd	n/a	n/a	
Seasonal Energy Efficiency Ratio - SEER	n/a	n/a	
Heating Seasonal Performance Factor - HSPF	n/a	n/a	

Low GWP AREP SYSTEM DROP-IN TEST DATA FORM – TEST#1

Type of System: Air-Cooled Screw Chiller Alternate Refrigerant: **R1234ze(E)**

Air/Water Side Data	**Base.**	**Alt.**	**SI Units**	**Base.**	**Alt.**	**IP Units**	**Ratio**
Evaporator (DX shell & tube)							
Heat Exchange Fluid	Water						
Flow Rate	2,120	1,490	L/min	560	394	gpm	0.703
Inlet Temperature	11.6	12.0	°C	52.9	53.6	°F	
Outlet Temperature	6.9	6.9	°C	44.4	44.4	°F	
Condenser (RTPF coil)							
Heat Exchange Fluid	Air						
Flow Rate (gas)	n/a	n/a		n/a	n/a		
Inlet Temperature	35	35	°C	95	95	°F	
Outlet Temperature	n/a	n/a		n/a	n/a		

Refrigerant Side Data	**Baseline**		**Alternative**		**Baseline**		**Alternative**	
Temperature & Pressures	T [°C]	P [kPa]	T [°C]	P [kPa]	T [°F]	P [psia]	T [°F]	P [psia]
Compressor Suction	10.3	342.8	11.3	260.3	50.5	49.7	52.3	37.8
Compressor Discharge	70.5	1,402	62.3	988.5	158.9	203.3	144.1	143.4
Condenser Inlet								
Condenser Outlet								
Expansion Device Inlet	31.5		30.3		88.7		86.5	
Subcooling, at expan. device	21.0	(1,402)	19.4	(988.5)	69.8	(203.3)	66.9	(143.4)
Evaporator Inlet								
Evaporator Outlet								
Evaporator Superheat								

Data Source(s) for Refrigerant Properties
NIST Refprop V9.0 for R134a and R1234ze(E)

Additional Notes

Submitted by: Kazushige Kasai

Low GWP AREP SYSTEM DROP-IN TEST DATA FORM – TEST#2

Manufacturer: DaikinMcQuay Manufacturer's Notation: INV Screw Chiller

Basic Information	
Alternative Refrigerant	**D4Y** Daikin
Alternative Lubricant Type and ISO Viscosity	PVE, VG68 (IDEMITSU FVC68D)
Baseline Refrigerant and Lubricant	R134a, IDEMITSU FVC68D
Make and Model of System	INV Screw Chiller (Prototype)
Nominal Capacity and Type of System	200 Tons, Air-cooled screw chiller

Comparison Data		**Base.**	**Alt.**	**SI Units**	**Base.**	**Alt.**	**IP Units**	**Ratio**
Mode (Heating/Cooling)		Cooling						
Compressor Type		VFD Screw						
Compressor Displacement		16.78		m^3/min	592.5		ft^3/min	
Nominal Motor Size		260		kW	350		hp	
Motor Speed		6,240		Rpm	6,240		rpm	
Expansion Device Type		EEV						
Lubricant Charge		18.9		L	5.0		gal	
Refrigerant Charge		185	205	kg	407.9	451.9	lb	1.108
Refrigerant Mass Flow Rate		255.8	287.5	kg/min	563.9	633.8	lb/min	1.124
Composition, at compr. Inlet if applicable		n/a	n/a		n/a	n/a		
Chilled Water	Leaving Temp	6.9	6.9	°C	44.4	44.4	°F	
	Flow rate	2,118	2,118	L/min	559.6	559.6	gpm	1.000
Outdoor Air	Dry Bulb	35	34.9	°C	95	94.8	°F	
	Wet Bulb	n/a	n/a		n/a	n/a		
Total Capacity		693.7	692.8	kW	197.3	197.0	Tons	0.999
Sensible Capacity		n/a	n/a		n/a	n/a		
Total System Power Input		222.7	228.9	kW	222.7	228.9	kW	1.028
Compressor Power Input		210.3	216.3	kW	210.3	216.3	kW	1.029
Coeff. Of Performance (COP)		3.11	3.03	W/W	10.63	10.33	EER	0.974

Other System Changes

System Data	**Base.**	**Alt.**	**Ratio**
Degradation Coefficient - Cd	n/a	n/a	
Seasonal Energy Efficiency Ratio - SEER	n/a	n/a	
Heating Seasonal Performance Factor - HSPF	n/a	n/a	

Low GWP AREP SYSTEM DROP-IN TEST DATA FORM – TEST#2

Type of System: Air-Cooled Screw Chiller Alternate Refrigerant: **D4Y**

Air/Water Side Data	**Base.**	**Alt.**	**SI Units**	**Base.**	**Alt.**	**IP Units**	**Ratio**
Evaporator (DX shell & tube)							
Heat Exchange Fluid	Water						
Flow Rate	2,120	2,120	L/min	560	560	gpm	1.0
Inlet Temperature	11.6	12	°C	52.9	53.6	°F	
Outlet Temperature	6.9	6.9	°C	44.4	44.4	°F	
Condenser (RTPF coil)							
Heat Exchange Fluid	Air						
Flow Rate (gas)	n/a	n/a		n/a	n/a		
Inlet Temperature	35	35	°C	95	95	°F	
Outlet Temperature	n/a	n/a		n/a	n/a		

Refrigerant Side Data	**Baseline**		**Alternative**		**Baseline**		**Alternative**	
Temperature & Pressures	T [°C]	P [kPa]	T [°C]	P [kPa]	T [°F]	P [psia]	T [°F]	P [psia]
Compressor Suction	10.3	342.8	11.6	354.4	50.5	49.7	52.9	51.4
Compressor Discharge	70.5	1,402	69.3	1,477	158.9	203.3	156.7	214.2
Condenser Inlet								
Condenser Outlet								
Expansion Device Inlet	31.5		30.7		88.7		87.3	
Subcooling, at expan. device	21.0	(1,402)	24.3	(1,477)	69.8	(203.3)	75.7	(214.2)
Evaporator Inlet								
Evaporator Outlet								
Evaporator Superheat								

Data Source(s) for Refrigerant Properties
NIST Refprop V9.0 for R134a
Daikin for D4Y

Additional Notes

Submitted by: Kazushige Kasai