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April 26, 2011

Findings Report No. 100344703COL-001FR
Project No. G100344703

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Subject: Performance Comparison Evaluation of Five Refrigerants as Drop In Replacements for R-134a, Namely:
HCR-188C/R441A, Propane, Butane, Isobutane, Ethane

Dear Mr. Maruya,

This letter represents the results of the evaluation of the above referenced refrigerants per a custom test method designed to compare optimum refrigerant charge amounts, operating pressures, and energy consumption. As no standardized test method was available, this method was developed and agreed upon by A. S. Trust & Holdings Inc and Intertek as being a good method to be able to control various operating parameters, thus allowing these three variable parameters to be observed and measured.

This investigation was authorized by signed application number 500286178, dated February 23, 2011. A. S. Trust & Holdings Inc provided the HCR-188C/R441A refrigerant for the test. Intertek provided the R-134a, Propane, Butane, Isobutane, and Ethane for the test. The refrigerants were tested from April 8, 2011 to April 22, 2011 at the Intertek Columbus, OH facility.

The evaluation was to determine which of the five replacement refrigerants best matched the performance characteristics of R-134a when used in a drop in replacement scenario. A bench test type refrigeration system test loop was used for the testing. The loop consisted of a compressor, water-cooled condenser, pressure actuated water flow control valve, a coil-in-shell heat exchanger, valves to regulate refrigerant flow through the heat exchanger or bypassing it, a filter drier, and four capillary tubes. A power meter was added to measure compressor energy consumption. A pressure gauge was T'd with isolation valves between the compressor suction and discharge lines to measure operating pressures. Thermocouples were added at various points along the loop to measure refrigerant temperatures. The loop was first configured one way and all refrigerants were tested. Then the loop was configured a different way and all the refrigerants were again tested. A description of the test equipment and the two configurations follows. Following that, the data from each test is tabulated. Finally, graphs showing the comparison of the refrigerant charge amounts, operating pressures, and energy consumption are displayed.

TABLE OF TEST EQUIPMENT USED

Item	Equipment Type	Equipment #	Cal. Due Date
1	***Refrigeration System Test Loop***		
2	Compressor – Copeland model ZP25K5E-PFV-130 charged with 1000 grams of POE		
3	Tube in Tube Water Cooled Condenser – Standard Refrigeration Company model ELT200		
4	Coil in Shell Heat Exchanger – Standard Refrigeration Company model VSE-2		
5	Brass Valves – Mueller		
6	Filter Drier – Emerson EK-053		
7	Capillary Tubes – 4 ea. 21 inches long, 0.036 ID		
8	Blower – Tjernlund Products model HSUL-1		
9	Water Flow Regulating Valve – Johnson Controls model V46AB-1		
10	***Data Measurement Equipment***		
11	Power Meter – Yokogawa model WT230	E148	March 8, 2012
12	Digital Pressure Gauge – CeComp Electronics 1 - 500 psig	E184	June 9, 2011
13	Thermocouple Thermometer – Omega model HH23A	E237	March 9, 2012
14	***Charge Determination Equipment***		
15	Refrigerant Recovery Equipment		
16	Liquid Nitrogen in Dewer		
17	Weight Scale – GSE model 450	CE1078	September 9, 2011
18	Vacuum Pump		
19	***Test Refrigerants***		
20	Cylinder of Virgin R-134a		
21	Cylinder of HCR-188C/R441A		
22	Cylinder of Instrument Grade Propane		
23	Cylinder of Instrument Grade Butane		
24	Cylinder of Instrument Grade Isobutane		

Test Loop Configuration 1

Prior to testing, the refrigeration system test loop was flushed and evacuated to remove all traces of previous refrigerants and lubricants. While under vacuum, the compressor was charged with 1000 grams of new POE. The system was then partially charged with R-134a and energized. Then, over several hours, the various control parameters of the loop were adjusted to achieve optimal operating conditions for R-134a. Namely, the Water Flow Regulating Valve was adjusted to control water flow to the condenser such that a typical compressor discharge pressure was achieved. Also, the Brass Valves were adjusted such that most of the refrigerant flow went through the Coil in Shell Heat Exchanger, but a portion was diverted around the heat exchanger such that the compressor suction temperature was typical. Room ambient conditions were adjusted to approximately 70°F. Lastly, additional R-134a was added to the system to the point that all four capillary tubes were receiving liquid refrigerant and the system loop sight glass was full. As the system approached optimal conditions, data recording was started and monitored until stabilized conditions were reached. That data is shown in the following Test Data Sheets, the rightmost column showing the final numbers. Following the collection of data, the system was de-energized and the R-134a charge was recovered with the Refrigerant Recovery Equipment into a pre-weighed cylinder. Isolation valves insured that no refrigerant was lost. The recovered weight was recorded. The remainder of R-134a in the system and the recovery equipment was then captured into a pre-weighed sampling cyclinder which was immersed in Liquid Nitrogen in a Dewer, and then the additional recovered weight was recorded and added to the first.

Next, the refrigeration system test loop was evacuated and then charged with a partial charge of HCR-188C/R441A and energized. The control parameters were left exactly the same as the final setting in the R-134a test. The only variable to control was the charge amount of the HCR-188C/R441A. Charge was slowly added until the loop was operating at the same suction pressure condition with all four capillary tubes receiving liquid refrigerant. Data was recorded as before, and once stabilized conditions were reached, the HCR-188C/R441A in the system was recovered and weighed. This process was then repeated for Propane, Butane and Isobutane. The test could not be conducted on Ethane as the saturation pressures were much too high and would have exceeded the pressure limits of the loop. The data for all tests follows.

It should be observed that from this configuration of the test, the suction and discharge pressures were controlled to be the same for all refrigerants, thus the compressor power consumption was roughly the same for all the tests. The differences were manifest in the amount of refrigerant charge that was required for each refrigerant to be at proper conditions and the amount of cooling water that was needed to keep the system in balance, that being a function of how high the discharge pressure of the system wanted to be based on the saturation pressure of the given refrigerant. Due to the very low pressure of Butane, it was not able to operate at the same discharge pressure and thus its results are skewed.

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane   Test #: 1

Date: APRIL 8, 2011   Test Engineer: Brandon Button

Test Refrigerant: R-134a

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	24.6	25.3	26.8	27.3	28.9
TEMPERATURE					
Compressor Discharge (°F)	180.1	182.8	187.5	187.1	186.6
Liquid Entering Cap Tubes (°F)	88.0	90.6	91.0	90.3	89.4
Vapor Leaving Cap Tubes (°F)	24.8	26.5	22.4	23.0	24.0
Compressor Suction (°F)	72.2	76.1	72.5	75.2	71.0
Condenser Water In (°F)	57.5	58.9	59.2	59.2	59.2
Condenser Water Out (°F)	85.0	87.7	87.4	87.9	87.2
Air Ambient (°F)	71.5	71.2	70.0	69.7	68.0
FLOW					
Water Flow (lbs/minute)	1.19	1.09	1.15	1.15	1.10
PRESSURE					
Suction Pressure (PSIG)	21	21	19	19	19
Discharge Pressure (PSIG)	118	125	124	124	124
COMPRESSOR POWER					
Frequency (Hz)	59.99	59.99	60.00	59.98	59.99
Voltage (V)	211.8	212.2	211.9	211.5	211.1
Amps (A)	4.11	4.20	4.19	4.17	4.16
Watts (W)	801	826	827	827	826
REFRIGERANT CHARGE					
Total Charge (lbs)					5.05

Calculations:

RECOVERY CYLINDER	LIQUID NITROGEN
14.25	2.40
18.85	2.85
4.60	0.45

SUMMARY

REFRIGERANT PERFORMANCE COMPARISON
TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane Test #: 2

Date: APRIL 11-12, 2011 Test Engineer: Brandon Button

Test Refrigerant: HCR-188C

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	45.6	50.2	50.9	52.1	52.9
TEMPERATURE					
Compressor Discharge (°F)	239.8	222.4	222.1	198.6	200.1
Liquid Entering Cap Tubes (°F)	88.2	86.2	85.8	86.3	85.4
Vapor Leaving Cap Tubes (°F)	35.2	5.7	4.7	12.2	13.0
Compressor Suction (°F)	79.4	79.2	78.8	81.2	80.4
Condenser Water In (°F)	60.7	59.7	59.8	59.7	59.7
Condenser Water Out (°F)	97.4	98.6	98.1	101.0	100.2
Air Ambient (°F)	71.3	72.0	69.3	70.1	69.1
FLOW					
Water Flow (lbs/minute)	0.75	0.83	0.79	0.74	0.78
PRESSURE					
Suction Pressure (PSIG)	8	13	13	19	19
Discharge Pressure (PSIG)	126	127	126	124	124
COMPRESSOR POWER					
Frequency (Hz)	59.99	60.01	60.02	59.98	59.99
Voltage (V)	212.1	211.2	211.2	211.7	212.2
Amps (A)	4.20	4.21	4.18	4.17	4.14
Watts (W)	838	837	831	833	827
REFRIGERANT CHARGE					
Total Charge (lbs)					1.55

Calculations:

RECOVERY CYLINDER	LIQUID NITROGEN
17.30	2.40
18.75	2.50
1.45	0.10

SUMMARY

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane — Test #: 3

Date: April 13, 2011

Test Engineer: Brandon Button

Test Refrigerant: Propane

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	55.2	55.8	57.3	58.0	59.1
TEMPERATURE					
Compressor Discharge (°F)	200.1	196.2	186.1	191.9	193.0
Liquid Entering Cap Tubes (°F)	77.3	76.5	76.1	76.2	76.8
Vapor Leaving Cap Tubes (°F)	-4.8	-2.0	2.9	-3.2	-5.4
Compressor Suction (°F)	62.8	63.2	62.4	62.4	62.1
Condenser Water In (°F)	54.4	54.4	54.8	54.8	55.3
Condenser Water Out (°F)	65.0	64.7	64.2	64.7	64.8
Air Ambient (°F)	68.9	69.6	72.6	72.4	70.0
FLOW					
Water Flow (lbs/minute)	4.31	4.58	5.14	4.91	4.84
PRESSURE					
Suction Pressure (PSIG)	16	18	21	19	19
Discharge Pressure (PSIG)	126	126	125	125	124
COMPRESSOR POWER					
Frequency (Hz)	60.01	59.98	59.99	59.97	59.99
Voltage (V)	211.4	211.2	211.0	208.8	210.6
Amps (A)	4.22	4.19	4.20	4.17	4.21
Watts (W)	846	841	833	821	833
REFRIGERANT CHARGE					
Total Charge (lbs)					1.55

Calculations:

Recovery Cylinder	Liquid Nitrogen
32.60	2.40
34.10	2.45
1.50	0.05

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET

(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane   Test #: 4

Date: APRIL 14, 2011   Test Engineer: Brandon Button

Test Refrigerant: BUTANE

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	62.4	62.9	64.1	64.8	65.5
TEMPERATURE					
Compressor Discharge (°F)	186.9	190.2	195.0	195.2	198.4
Liquid Entering Cap Tubes (°F)	131.1	134.6	137.1	136.3	138.0
Vapor Leaving Cap Tubes (°F)	81.0	80.3	76.7	75.2	74.2
Compressor Suction (°F)	117.7	120.2	121.1	119.7	121.3
Condenser Water In (°F)					
Condenser Water Out (°F)					
Air Ambient (°F)	70.2	72.7	73.7	74.7	75.9
FLOW					
Water Flow (lbs/minute)	Ø	Ø	Ø	Ø	Ø
PRESSURE					
Suction Pressure (PSIG)	23	22	20	19	19
Discharge Pressure (PSIG)	88	91	93	91	93
COMPRESSOR POWER					
Frequency (Hz)	60.00	59.99	60.00	60.02	60.01
Voltage (V)	210.7	211.6	209.8	210.3	209.0
Amps (A)	3.69	3.71	3.59	3.57	3.60
Watts (W)	710	716	680	671	679
REFRIGERANT CHARGE					
Total Charge (lbs)					1.15

Calculations:

RECOVERY CYLINDER	LIQUID NITROGEN
40.15	2.40
41.20	2.50
1.05	0.10

REFRIGERANT PERFORMANCE COMPARISON
TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya
Project Number: G100344703
Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane   Test #: 6
Date: APRIL 15, 2011   Test Engineer: Brandon Button [signature]
Test Refrigerant: ISOBUTANE

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	66.9	68.4	69.7	71.2	72.7
TEMPERATURE					
Compressor Discharge (°F)	198.5	209.5	206.1	208.8	212.6
Liquid Entering Cap Tubes (°F)	132.5	133.1	135.1	134.7	136.2
Vapor Leaving Cap Tubes (°F)	64.1	57.7	57.1	54.3	53.3
Compressor Suction (°F)	118.4	115.7	114.9	114.7	115.2
Condenser Water In (°F)	75.2	77.7	78.7	80.7	79.6
Condenser Water Out (°F)	150.9	155.8	153.5	154.0	159.8
Air Ambient (°F)	75.7	79.4	78.1	79.3	76.4
FLOW					
Water Flow (lbs/minute)	0.13	0.14	0.07	0.07	0.07
PRESSURE					
Suction Pressure (PSIG)	23	21	20	19	19
Discharge Pressure (PSIG)	126	127	123	124	124
COMPRESSOR POWER					
Frequency (Hz)	59.99	60.02	59.99	60.00	60.00
Voltage (V)	211.3	210.2	208.3	210.9	210.2
Amps (A)	4.10	4.21	4.18	4.15	4.16
Watts (W)	806	825	808	822	823
REFRIGERANT CHARGE					
Total Charge (lbs)					1.00

Calculations:

Recovery Cylinder	Liquid Nitrogen
38.60	2.40
39.60	2.40
1.00	0

Test Loop Configuration 1 Summary

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET

(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

TEST REFRIGERANT

Refrigerant	R-134a	HCR-188C /R441A	Propane	Butane	Isobutane

TEMPERATURE

Compressor Discharge (℉)	186.6	200.1	193.0	198.4	212.6
Liquid Entering Cap Tubes (℉)	89.4	85.4	76.8	138. 0	136.2
Vapor Leaving Cap Tubes (℉)	24.0	13.0	-5.4	74.2	5 3.3
Compressor Suction (℉)	71.0	80.4	62.1	121.3	115.2
Condenser Water In (℉)	59.2	59.7	55.3	N/A	79.6
Condenser Water Out (℉)	87.2	100.2	64.8	N/A	159.8
Air Ambient (℉)	68.0	69.1	70.0	75.9	76.4

FLOW

Water Flow (lbs/minute)	1.10	0.78	4.84	0.00	0.07

PRESSURE

Suction Pressure (PSIG)	19	19	19	19	19
Discharge Pressure (PSIG)	124	124	124	93	124

COMPRESSOR POWER

Frequency (Hz)	59.99	59.99	59.99	60.01	60.00
Voltage (V)	211.1	212.2	210.6	209.0	210.2
Amps (A)	4.16	4.14	4.21	3.60	4.16
Watts (W)	826	827	833	679	823

REFRIGERANT CHARGE

Total Charge (lbs)	5.05	1.55	1.55	1.15	1.00

Test Loop Configuration 2

It was determined that the first round of testing did not yield very informative results. Therefore it was decided to change the parameters of the test and then repeat on each refrigerant. For the second round of testing, variable water flow was eliminated. The water flow was completely turned off. To recover the necessary cooling, all refrigerant was routed through the Coil in Shell Heat Exchanger. This had two effects however. It did not allow some bypass gas to cool the suction gas to the compressor and it did not dissipate the excess mechanical heat from the compressor. Therefore a small one speed blower was positioned to blow air across the exposed copper tubing of the loop. This provided some cooling of the suction gas and dissipated enough of the mechanical heat such that the system could stabilize at normal operating conditions. For these tests, the room ambient was maintained at approximately 75°F.

These changes allowed each test run to stabilize at that refrigerant's unique operating conditions. This translated into differing suction and discharge pressures, which thus translated into differing energy consumption by the compressor. This was also a good verification of the different charge requirements for the different refrigerants. This method was more representative of what could be expected if the substitute refrigerants were used instead of R-134a in an R-134a system. The cooling temperatures observed after the capillary tubes, indicate steady state temperatures, but do not indicate cooling capacity and should not be interpreted as such. Likewise, the power consumption is a steady state value and should not be used to calculate daily power consumption.

This sequence of tests was performed as before, first running the test with R-134a and then followed by the other refrigerants. Data was collected in the same manner, and refrigerant charge weights were obtained by the same recovery method. The test with Propane was not able to be completed because it caused the compressor to operate at such a high temperature that it shut off on thermal overload. As in the first configuration tests, the test could not be conducted on Ethane as the saturation pressures were much too high and would have exceeded the pressure limits of the loop. The data for all tests follows.

REFRIGERANT PERFORMANCE COMPARISON
TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya
Project Number: G100344703
Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane   Test #: 6
Date: APRIL 18, 2011   Test Engineer: Brandon Button
Test Refrigerant: R-134a

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	76.9	77.3	78.0	78.6	79.4
TEMPERATURE					
Compressor Discharge (°F)	239.1	248.1	252.3	256.2	234.2
Liquid Entering Cap Tubes (°F)	118.8	123.9	126.4	128.9	113.9
Vapor Leaving Cap Tubes (°F)	37.5	36.6	37.8	40.3	36.8
Compressor Suction (°F)	111.5	112.8	114.1	117.0	107.1
Condenser Water In (°F)					
Condenser Water Out (°F)					
Air Ambient (°F)	76.7	76.7	76.5	76.3	74.5
FLOW					
Water Flow (lbs/minute) FAN	Ø	Ø	Ø	Ø	Ø
PRESSURE					
Suction Pressure (PSIG)	30	30	30	33	30
Discharge Pressure (PSIG)	207	218	225	242	200
COMPRESSOR POWER					
Frequency (Hz)	60.00	60.00	59.99	59.98	59.99
Voltage (V)	208.0	207.4	208.9	208.2	209.4
Amps (A)	6.06	6.28	6.49	6.79	5.79
Watts (W)	1210	1264	1316	1376	1166
REFRIGERANT CHARGE					
Total Charge (lbs)					2.80

Calculations:

RECOVERY CYLINDER
18.90
21.60
2.70

LIQUID NITROGEN
2.40
2.50
0.10

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane   Test #: 7

Date: April 19, 2011   Test Engineer:

Test Refrigerant: HCR-188C   Brandon Button [signature]

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	82.0	82.6	83.5		84.3
TEMPERATURE					
Compressor Discharge (°F)	243.1	244.7	242.7		245.1
Liquid Entering Cap Tubes (°F)	101.6	102.0	104.0		105.4
Vapor Leaving Cap Tubes (°F)	19.4	19.7	21.2		22.2
Compressor Suction (°F)	98.3	98.8	101.2		102.0
Condenser Water In (°F)					
Condenser Water Out (°F)					
Air Ambient (°F)	73.7	73.9	73.9		74.6
FLOW					
Water Flow (lbs/minute)	Ø	Ø	Ø		Ø
PRESSURE					
Suction Pressure (PSIG)	15	15	17		17
Discharge Pressure (PSIG)	144	146	152		155
COMPRESSOR POWER					
Frequency (Hz)	60.02	60.01	59.99		60.02
Voltage (V)	211.4	210.8	211.5		210.5
Amps (A)	4.59	4.63	4.71		4.80
Watts (W)	921	928	953		969

REFRIGERANT CHARGE

Total Charge (lbs): 0.95

Recovery Cylinder	Liquid Nitrogen
~~20.90~~	2.40
18.60	2.45
19.50	0.05
0.90	

Calculations 22.65 - ~~21.85~~ 21.75 = 0.9   CHARGING

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane Test #: 8

Date: APRIL 20, 2011 Test Engineer: Brandon Button

Test Refrigerant: PROPANE

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	86.4	87.7	@ 87.9		
TEMPERATURE					
Compressor Discharge (°F)	315.2	320.4	COMPRESSOR SHUT OFF ON THERMAL OVERLOAD.		
Liquid Entering Cap Tubes (°F)	141.3	149.0			
Vapor Leaving Cap Tubes (°F)	32.0	38.1			
Compressor Suction (°F)	133.1	142.9			
Condenser Water In (°F)					
Condenser Water Out (°F)					
Air Ambient (°F)	73.7	73.7			
FLOW					
Water Flow (lbs/minute)	ø	ø			
PRESSURE					
Suction Pressure (PSIG)	48	58			
Discharge Pressure (PSIG)	351	391			
COMPRESSOR POWER					
Frequency (Hz)	60.01	60.01			
Voltage (V)	210.7	210.8			
Amps (A)	9.57	10.56			
Watts (W)	1981	2185			
REFRIGERANT CHARGE					
Total Charge (lbs)					1.30

Calculations:

RECOVERY CYLINDER	LIQUID NITROGEN
32.75	2.40
34.00	2.45
1.25	0.05

REFRIGERANT PERFORMANCE COMPARISON
TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane Test #: 9

Date: April 21, 2011 Test Engineer:

Test Refrigerant: Butane Brandon Button

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	89.0	90.4	91.2	91.8 →	
TEMPERATURE					
Compressor Discharge (°F)	139.6	142.2	144.2	144.8	
Liquid Entering Cap Tubes (°F)	84.4	89.6	89.1	90.3	
Vapor Leaving Cap Tubes (°F)	56.5	61.9	59.2	59.3	
Compressor Suction (°F)	80.4	84.4	84.9	85.5	
Condenser Water In (°F)					
Condenser Water Out (°F)					
Air Ambient (°F)	71.6	74.0	73.9	74.9	
FLOW					
Water Flow (lbs/minute) FAN	Ø	Ø	Ø	Ø	
PRESSURE					
Suction Pressure (PSIG)	8	11	10	10	
Discharge Pressure (PSIG)	32	35	35	36	
COMPRESSOR POWER					
Frequency (Hz)	59.99	59.99	60.00	59.99	
Voltage (V)	210.9	211.6	209.7	209.2	
Amps (A)	2.47	2.53	2.50	2.47	
Watts (W)	407	422	423	416 →	
REFRIGERANT CHARGE					
Total Charge (lbs)					0.90

Calculations:

Recovery Cylinder
39.85
40.75
0.90

Liquid Nitrogen
2.40
2.40
0

REFRIGERANT PERFORMANCE COMPARISON

TEST DATA SHEET
(PERFORMED ON CAPILLARY TUBE TEST STAND)

Intertek

Client: A.S. Trust / Richard Maruya

Project Number: G100344703

Sample: HCR-188C compared to R-134a, Propane, Butane, IsoButane   Test #: 10

Date: APRIL 22, 2011   Test Engineer: Brandon Button

Test Refrigerant: ISOBUTANE

	Adjustment period readings				At Condition Reading
TEST STAND RUN TIME					
Total Time (hours)	113.4	114.3	115.1		115.8
TEMPERATURE					
Compressor Discharge (°F)	183.7	187.8	185.8		188.9
Liquid Entering Cap Tubes (°F)	94.4	97.4	99.0		99.8
Vapor Leaving Cap Tubes (°F)	29.3	26.7	31.9		30.2
Compressor Suction (°F)	85.1	87.8	89.7		90.0
Condenser Water In (°F)					
Condenser Water Out (°F)					
Air Ambient (°F)	72.3	73.9	74.7		75.0
FLOW					
Water Flow (lbs/minute)	Ø	Ø	Ø		Ø
PRESSURE					
Suction Pressure (PSIG)	5	5	6		6
Discharge Pressure (PSIG)	58	61	63		64
COMPRESSOR POWER					
Frequency (Hz)	59.99	59.99	59.99		59.99
Voltage (V)	212.0	211.1	212.2		212.5
Amps (A)	2.93	2.97	3.00		3.05
Watts (W)	536	545	551		561
REFRIGERANT CHARGE					
Total Charge (lbs)					0.75

Calculations:

RECOVERY CYLINDER	LIQUID NITROGEN
38.90	2.40
39.60	2.45
0.70	0.05

Test Loop Configuration 2 Summary

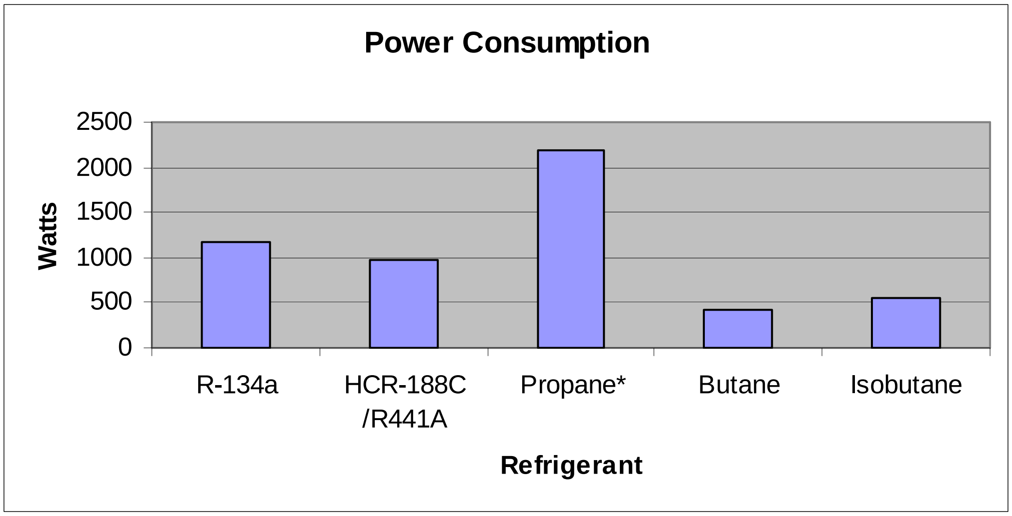
REFRIGERANT PERFORMANCE COMPARISON

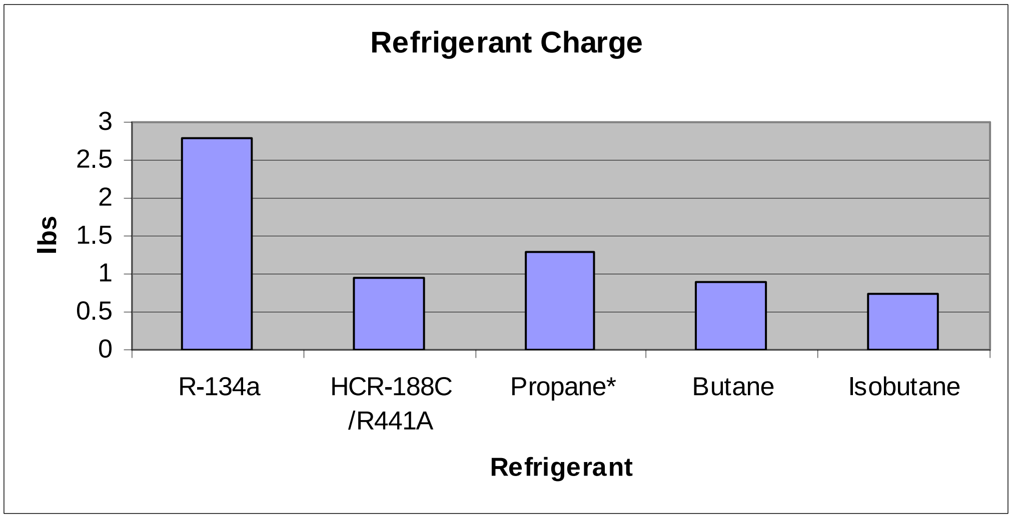
TEST DATA SHEET

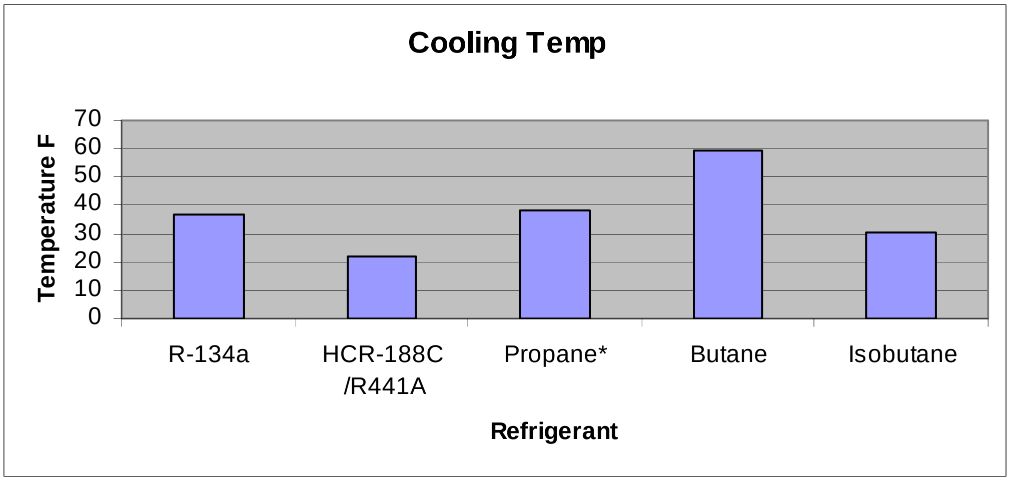
(PERFORMED ON CAPILLARY TUBE TEST STAND)

	R-134a	HCR-188C /R441A	Propane	Butane	Isobutane
TEST REFRIGERANT					
Refrigerant	R-134a	HCR-188C /R441A	Propane	Butane	Isobutane
TEMPERATURE					
Compressor Discharge (°F)	234.2	245.1	*	144.8	188. 9
Liquid Entering Cap Tubes (°F)	113.9	105.4	*	90.3	99.8
Vapor Leaving Cap Tubes (°F)	36.8	22.2	*	59.3	30.2
Compressor Suction (°F)	107.1	102.0	*	85.5	90.0
Condenser Water In (°F)	N/A	N/A	N/A	N/A	N/A
Condenser Water Out (°F)	N/A	N/A	N/A	N/A	N/A
Air Ambient (°F)	74.5	74.6	*	74.9	75.0
FLOW					
Water Flow (lbs/minute)	N/A	N/A	N/A	N/A	N/A
PRESSURE					
Suction Pressure (PSIG)	30	17	*	10	6
Discharge Pressure (PSIG)	200	155	*	36	64
COMPRESSOR POWER					
Frequency (Hz)	59.99	60.02	*	59.99	59.99
Voltage (V)	209.4	210.5	*	209.2	212.5
Amps (A)	5.79	4.80	*	2.47	3.05
Watts (W)	1166	969	*	416	561
REFRIGERANT CHARGE					
Total Charge (lbs)	2.80	0.95	*	0.90	0.75

*Compressor shut off on thermal overload; last obtained values graphed; but test could not be completed.


Power Consumption
Watts
2500
2000
1500
1000
500
0
R-134a
HCR-188C /R441A
Propane*
Butane
Isobutane
Refrigerant


Refrigerant Charge
lbs
3
2.5
2
1.5
1
0.5
0
R-134a
HCR-188C /R441A
Propane*
Butane
Isobutane
Refrigerant


Cooling Temp
Temperature F
70
60
50
40
30
20
10
0
R-134a
HCR-188C /R441A
Propane*
Butane
Isobutane
Refrigerant

Conclusion

Results of this evaluation indicate that of the five refrigerants tested as drop in replacements for R-134a, HCR-188C/R441A has the best properties to simulate R-134a and has the best performance with respect to charge amount and energy consumption when judged against system cooling capacity. Moreover, it was determined that the HCR-188C/R441A components, when used by themselves, do not make good replacement refrigerant candidates for R-134a. The reasoning for this conclusion is as follows:

Propane – An R-134a system, to which Propane is substituted, will not have sufficient refrigerant condensing capacity and therefore the discharge pressure will elevate, causing the energy consumption to rise dramatically and/or will cause the compressor to overheat and either shut off on thermal protection or burn up.

Butane – An R-134a system, to which Butane is substituted, will not experience sufficient cooling as the saturation pressure of Butane is much too low to cause much refrigerant phase change when passing through an R-134a system expansion device.

Isobutane – An R-134a system, to which Isobutane is substituted, would work better than Butane, but because of its similarly low saturation pressures, would likely not have nearly the same cooling capacity as R-134a or HCR-188C/R441A. This would likely be verified by calorimeter comparison testing.

Ethane – An R-134a system, to which Ethane is substituted, would not run because the excessively high saturation pressures of Ethane would either cause the equipment's high pressure switch to actuate and disable the unit, or the high pressure would cause the pressure relief device to vent out the Ethane charge.

HCR-188C/R441A, when substituted into a R-134a system, by the same logic relating to saturation pressures described above, appears that it would have a slightly lower cooling capacity than R-134a, but would require a refrigerant charge of only about 30% of the mass of R-134a, and the compressor would use slightly less energy than when used to operate with R-134a.

This findings report completes our evaluation.

If there are any questions regarding the results contained in this report, or any of the other services offered by Intertek, please do not hesitate to contact the undersigned.

Please note, this Findings Report does not represent authorization for the use of any Intertek certification marks.

Completed by:	Brandon Button	Reviewed by:	That Vo
Title:	Senior Associate Engineer	Title:	Engineer
Signature:		Signature	