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

TEST REPORT #26

Compressor Calorimeter Test of Refrigerant R-32 in a R-410A Rotary Type Compressor

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1. Introduction

In this report, we compare the performance of alternative refrigerant R32 with its baseline R410A in a hermetic rotary type compressor. To determine how well the compressor works when using R32 comprehensively, we carried out tests under standard rating conditions and performance map reporting conditions for both baseline and alternative refrigerants. All the compressor calorimeter tests were conducted in Shanghai Hitachi's explosion-proof laboratory. It took nearly 30 working days to complete testing.

2. Test Setup

The compressor being used in the calorimeter test is a hermetic rotary type compressor manufactured by Shanghai Hitachi. The original compressor model is specially designed for refrigerant R410A with a nominal displacement of 28.0 cc. The compressor is driven by a constant-speed electric motor which holds a nameplate size of 2.5 hp. Single phase source with 220V and 50Hz is used to supply power. A POE type oil is employed as lubricant. The lubricant is the same as the R410 compressor. And its Kin-Viscsity is about 68 mm/s^2（40℃）.

According to theoretical thermodynamic calculation, comparing with R410A, R32 will have a 20℃ higher discharge temperature, which may bring about a negative impact on the reliability of motor and compressor. In order to control the potential high discharge temp, we have made some modifications to the original model for injection function. During test, we connect the injection pipe of the testing equipment with our compressor and introduce sub-cooled discharge-side liquid refrigerant into the compressor when necessary, so that the discharge temperature of R32 could be reduced to a proper value. The injection quantity could be adjusted manually. It's worth mentioning that we employ the same modified compressor to complete all the calorimeter tests for low GWP refrigerant R32 and baseline R410A.

Since the testing compressor is positive displacement type, all calorimeter tests were done in accordance with ASHARE Standard 23-2010. Our testing equipments are designed on the basis of secondary refrigerant calorimeter method, the test loop of which can be described as figure 1 below, and confirming test method is the liquid refrigerant flow meter method. Differences of refrigerant flow rate obtained from primary test method and confirming method are within ±3% as stated.

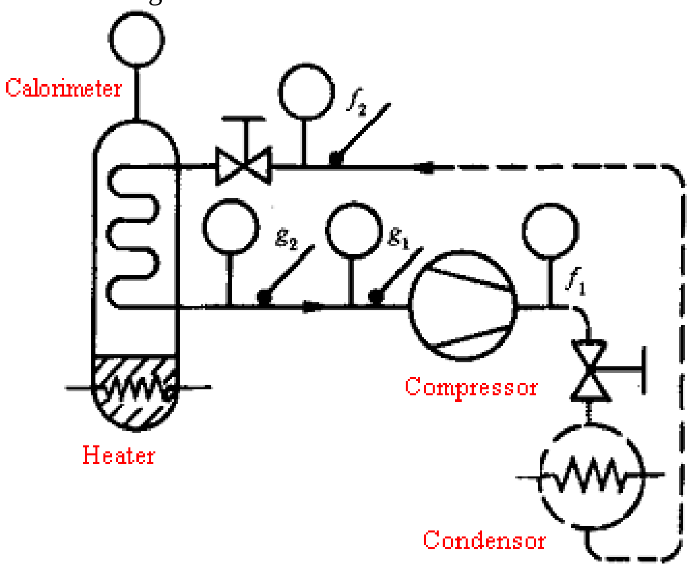


Figure1. Test Loop Schematic using Secondary Refrigerant Calorimeter Method

Instruments equipped in testing bench are selected to meet the error limits specified in ASHARE Standard 23-2010. Measurement accuracy requirement of some parameters are listed in table 1.

Table1. Measurement Accuracy

Items	Stated measurement accuracy	Sensor accuracy
Temperature	±0.3K	±0.1℃(suc,exi) , ±0.2℃(dis)
Pressure	±1.0%	±0.01Mpa(dis), ±0.005Mpa(suc)
Liquid Flow Rate	±1.0%	±0.2%
Power input	±1.0%	±0.2%
Shaft rotational speed	±1.0%	±1.0%
Time	±0.5%	±0.1%
Weight	±0.2%	±0.2%

3. Test Conditions

In Low-GWP AREP participants' handbook, 8 different standard rating conditions for compressors used in air-conditioners and heat pumps are provided. Considering the operating range of our testing compressor and the limitations of our test rig, we determine to conduct tests under following conditions as listed in table2.

Table2. Standard Rating Conditions

Test Point	Suction Dew Point Temperature	Discharge Dew Point Temperature	Expand Valve Inlet Temperature	Return Gas Temperature
	℃	℃	℃	℃
A	7.2	54.4	46.1	18
B	7.2	46.1	37.8	18
C	7.2	37.8	29.5	18
D	-1.1	43.3	35	10

As to testing conditions for performance map reporting, due to our laboratories' limitations, we had to omit some test points proposed in participants' handbook. Meanwhile, since we are used to regard centigrade as the unit of temperature, some modifications are made to fit such practice. Our tests for getting performance map were conducted over temperature conditions provided in table3 below.

Table3. Performance Map Reporting Conditions for Air-conditioning

NO.	Suction Dew Point Temperature	Discharge Dew Point Temperature	Expand Valve Inlet Temperature	Superheat
	℃	℃	℃	℃
1.	-8	60	51.7	11.1
2.	-5			
3.	4			
4.	7			
5.	13			

Table3.

NO.	Suction Dew Point Temperature	Discharge Dew Point Temperature	Expand Valve Inlet Temperature	Superheat
	℃	℃	℃	℃
6.	-5	55	46.7	11.1
7.	0			
***8.**	5			
***9.**	7			
***10.**	10			
11.	-5	50	41.7	
***12.**	0			
***13.**	5			
14.	10			
***15.**	-5	45	36.7	
***16.**	0			
***17.**	5			
***18.**	7			
***19.**	-5	40	31.7	
***20.**	0			
21.	5			
***22.**	7			
***23.**	-5	37	28.7	
***24.**	0			
***25.**	3	40	31.7	
***26**	7	50	41.7	

Those numbers with the symbol "*" are performance map testing conditions for refrigerant R32 (16 in all), while testing data under almost all conditions listed above (except no.25&26) have been employed to get R410A's 10-coefficient.

4. Result and Discussion

1） Comparison of Tabular Data in the Compessor Calorimeter Test

Detailed compressor testing data under standard conditions could be found in table 4, appendix A. In order to directly compare the compressor performance of alternative refrigerant R32 with its baseline R410A, some major parameters are illustrated in the form of bar graphs as the four figures below.

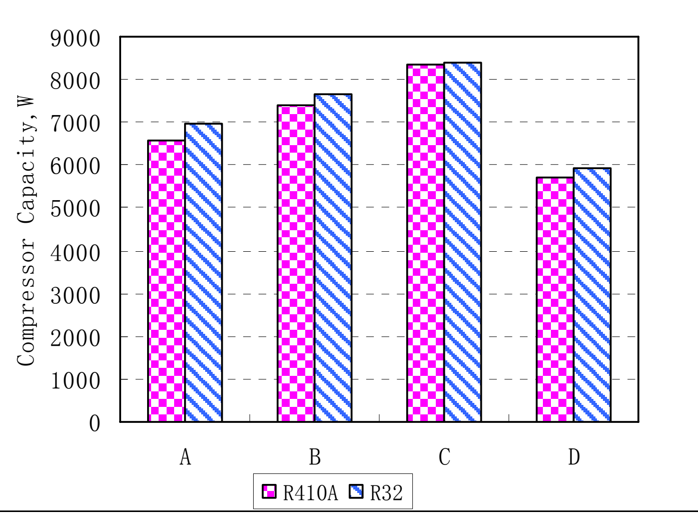


Figure 2. Compressor Capacity of R410A and R32

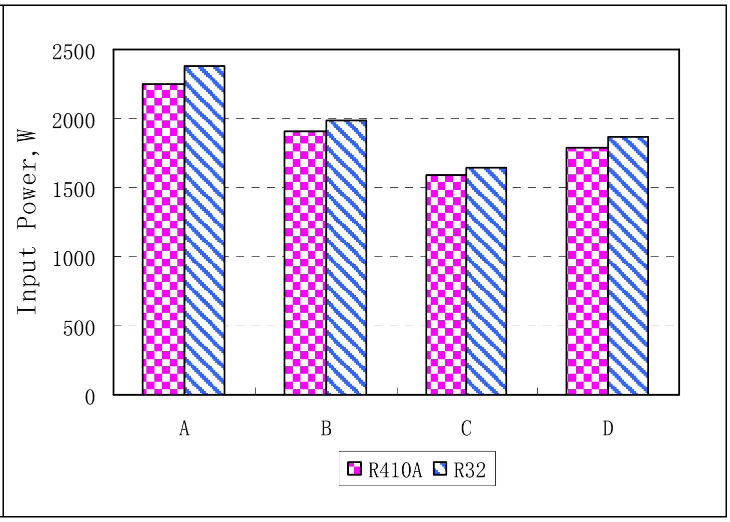


Figure 3. Input Power Input of R410A and R32

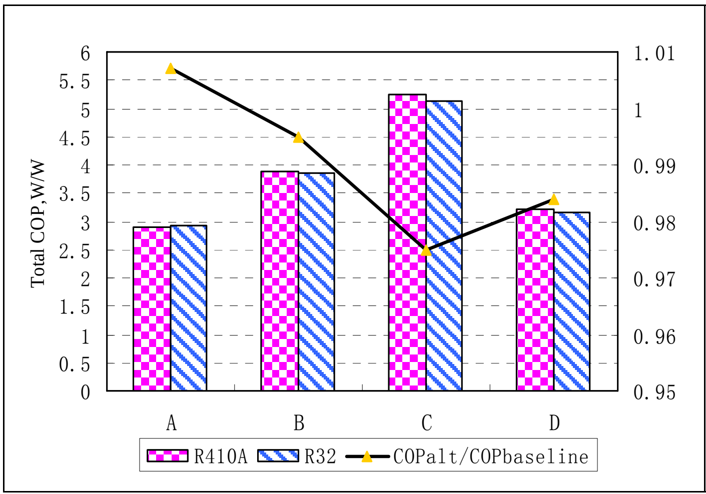


Figure 4. COP of R410A and R32

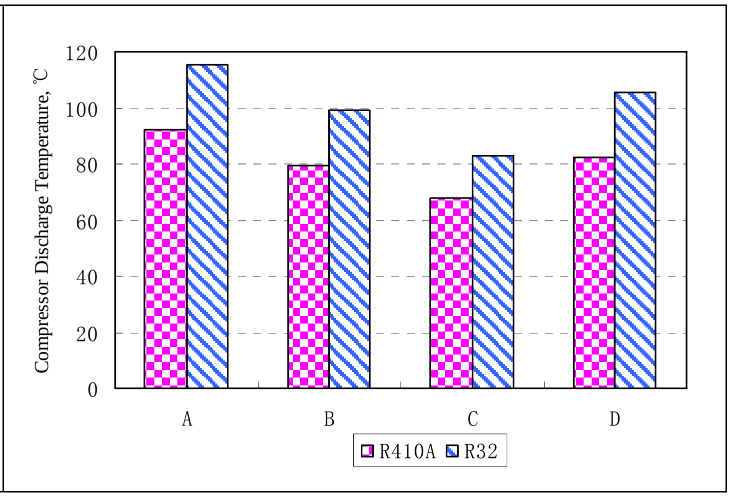


Figure 5. Discharge Temperature of R410A and R32

On the basis of the graphs above, we may conclude that refrigerant R32 has a capacity advantage over R410A with a nearly 30% lower refrigerant flow rate, while R32 compressor needs a higher input power than R410A. The relative COP of R32 to R410A changes with the testing condition is as figure 4 shows.

At the given evaporator temperature of 7.2 ℃, the ratio of COP_{alt} to $COP_{Baseline}$ rises with the increment of condenser temperature. When used as refrigerant in our testing compressor, Capacity is better for R32 and COP is better for R410A at point B and C.

Concerning compressor discharge temperature, Figure 5 proves that R32 may have a 15-to-25 higher discharge temperature over baseline R410A.

2） Comparative Analysis of Performance maps

It is mentioned in the Participants Handbook that a third degree polynomial equation of ten coefficients obtained from calorimeter tests should be employed to represent the tubular data at different working conditions.

The equation is in the form of:

$$X=C1+C2*(S)+C3*D+C4*(S^2)+C5*(S*D)+C6*(D^2)+C7*(S^3)+C8*(D*S^2)+C9*(S*D^2)+C10*(D^3)$$

Where,

C= Equation Coefficient, represents compressor performance

S= Suction dew point temperature, ℃

D=Discharge dew point temperature, ℃

X=Compressor performance (mass flow rate, capacity, power and COP)

The 10 coefficients of baseline R410A are listed in table5 in Appendix B, and 10 coefficients of alternative R32 are set forth in table6.

Figure6 and Figure7 are 2 sets of performance maps respectively for baseline and alternative refrigerants, where capacity, input power and COP respectively act as a function of evaporator temperature for given condensing temperature. Although the value range of each performance parameter is different, the variation tendency of capacity, COP and flow rate seem to be similar. That is, testing compressor will get a better performance at a condition with a higher evaporating temperature and a lower condensing temperature, which is totally in line with the theoretical cycle tendency.

Figure8 presents the comparison directly. With testing range, the relative COP (COP_{alt} / $COP_{Baseline}$) varies from 0.98 to 1.03. We could also tell from Figure8 that during low evaporator temperature range, compressor performance with refrigerant R32 is not so well as the same compressor with R410A, but with the increment of evaporator temperature, the R32 is gradually getting better.

Appendix A

Table4. Tabular Data in the Compressor Calorimeter Test

test conditions		A		B		C		D	
refrigerants		**R410A**	**R32**	**R410A**	**R32**	**R410A**	**R32**	**R410A**	**R32**
evaporating temperature	℃	7. 2		7. 2		7. 3	7. 2	−1. 1	
condensing temperature	℃	54. 4		46. 1		37. 8		43. 3	
discharge temperature	℃	92. 4	115. 5	79. 2	99	68	83. 2	82. 4	105. 8
applicable superheating	℃	10. 9	10. 8	10. 9	10. 8	10. 7	10. 8	11. 1	11. 1
applicable subcooling	℃	8. 3	8. 3	8. 3	8. 3	8. 3	8. 3	8. 3	8. 3
compressor capacity	W	6561. 6	6955. 7	7397. 6	7668. 3	8337. 6	8400. 3	5718. 5	5907. 2
refrigerant mass flow rate	kg/h	148. 9	103. 4	153. 2	106. 4	159. 4	109. 6	117	80. 8
amperes	A	10. 5	11	8. 8	9. 2	7. 4	7. 6	8. 3	8. 6
input power	W	2264. 3	2381. 6	1907. 7	1986	1589. 3	1640. 2	1783. 6	1869. 3
COP	W/W	2. 90	2. 92	3. 88	3. 86	5. 25	5. 12	3. 21	3. 16
$COP_{alt}/COP_{baseline}$		1	1. 01	1	0. 995	1	0. 98	1	0. 98

Note: During the test for R32 under condition A, refrigerant injection method was adopted to reduce the over high discharge temperature and liquid refrigerant injection flow rate was 8L/h. When calculating compressor capacity, the liquid refrigerant injection mass flow rate is not taken into account in accordance with ASHRAE Standard 23-2010.

Appendix B

Performance Maps

1. Regarding baseline R410A

- 10-Coefficient polynomial equation for R410A, which is obtained from test results under conditions listed in table 2 and 3, is set forth in table 5 below :

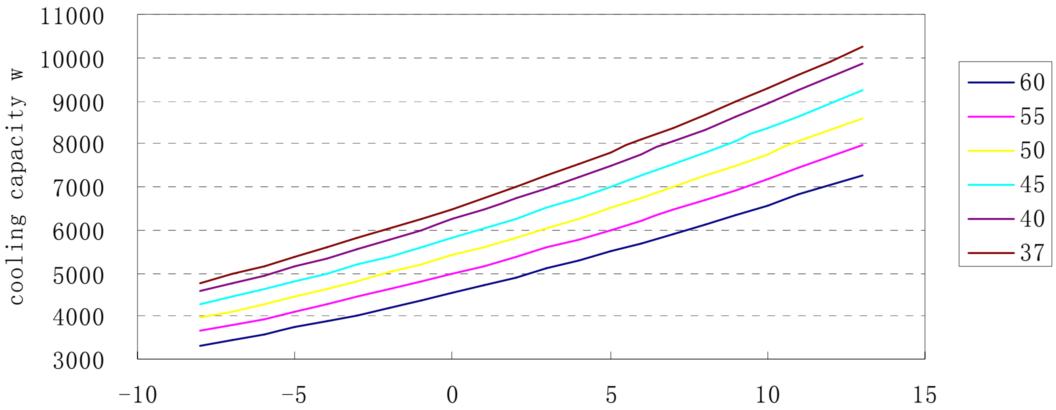
$$X=C1+C2*(S)+C3*D+C4*(S^2)+C5*(S*D)+C6*(D^2)+C7*(S^3)+C8*(D*S^2)+C9*(S*D^2)+C10*(D^3)$$

Table5. 10 Coefficients for R410A (compressor model: ASH280*)

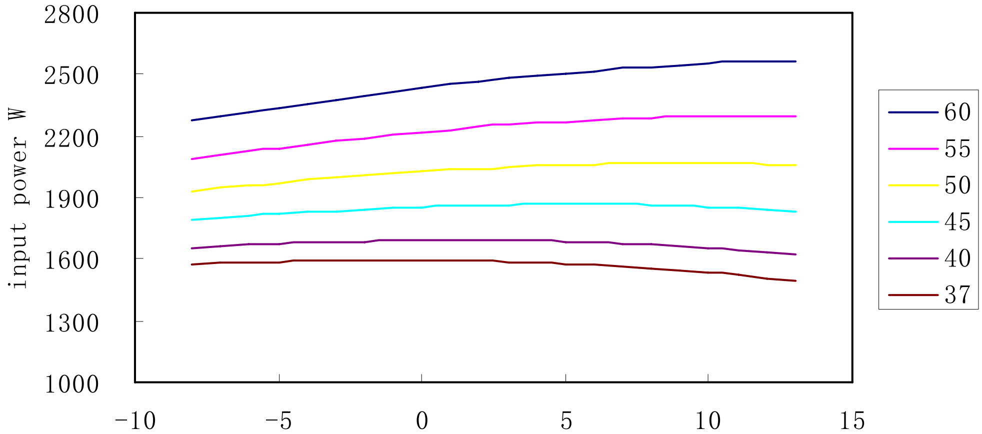
X	Power	Capacity	COP	FLOW
C1	-2.35E+02	1.13E+04	1.37E+01	1.59E+02
C2	-2.54E+01	3.47E+02	5.38E-01	5.00E+00
C3	8.09E+01	-1.96E+02	-4.24E-01	-1.63E+00
C4	-3.91E-01	4.90E+00	6.79E-03	7.24E-02
C5	5.83E-01	-2.73E+00	-1.40E-02	-1.52E-02
C6	-1.24E+00	2.42E+00	5.47E-03	2.62E-02
C7	-6.20E-03	-7.60E-03	1.65E-05	5.63E-04
C8	-9.69E-04	-3.50E-02	-9.65E-05	-3.07E-04
C9	2.07E-03	-1.91E-03	1.01E-04	-2.30E-05
C10	1.06E-02	-1.72E-02	-2.82E-05	-2.01E-04

- Following figures are compressor performance maps for R410A.

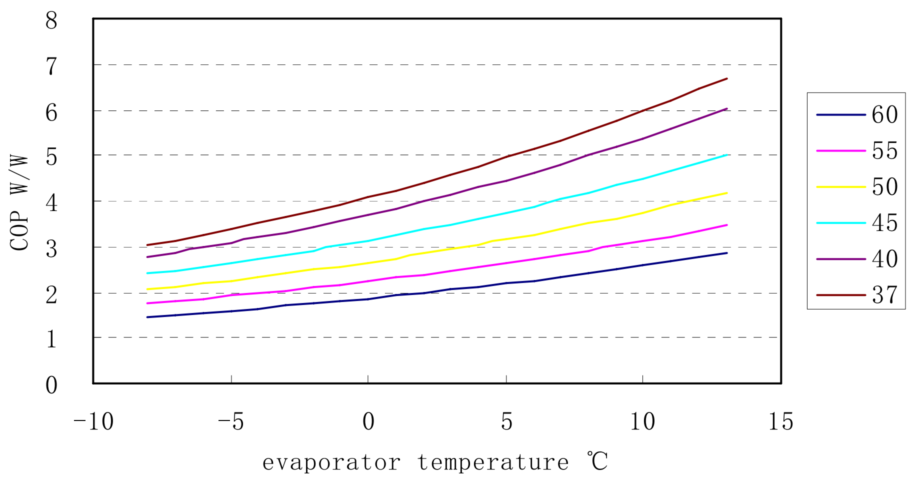
R410A Capacity Map



R410A power map



R410A COP Map



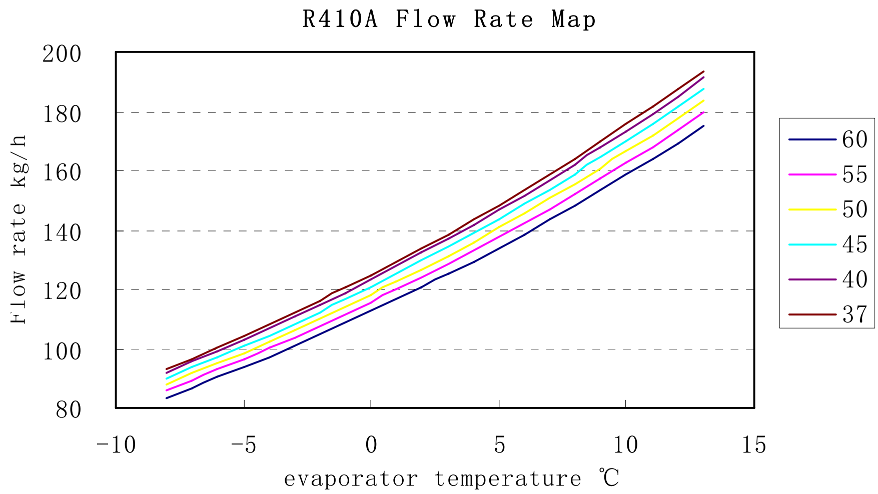


Figure 6 Performance Map for baseline refrigerant R410A

2. Regarding alternative R32

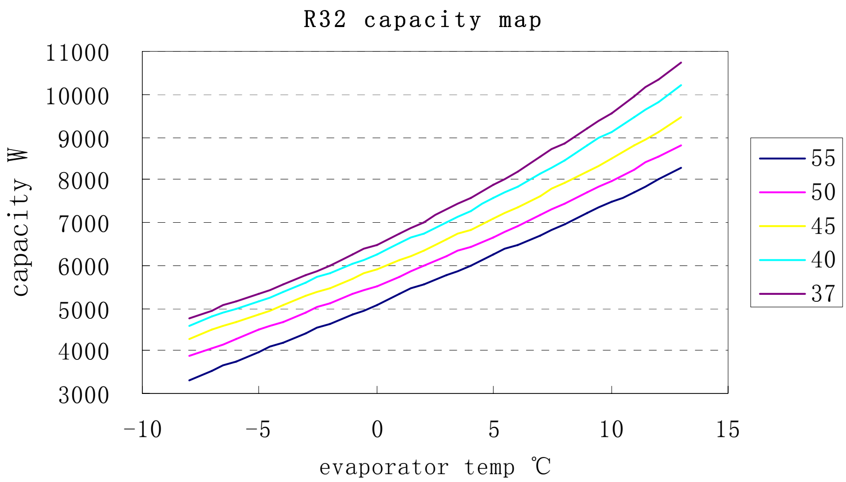
- 10 Coefficients for R32 are set forth in table 6 below. All the coefficients are fitted from test results under conditions listed in table 3.

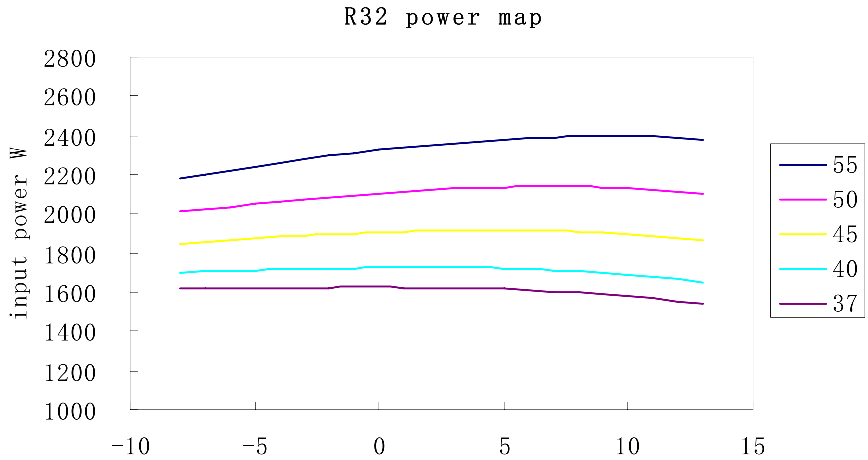
$X=C1+C2*(S)+C3*D+C4*(S^2)+C5*(S*D)+C6*(D^2)+C7*(S^3)+C8*(D*S^2)+C9*(S*D^2)+C10*(D^3)$

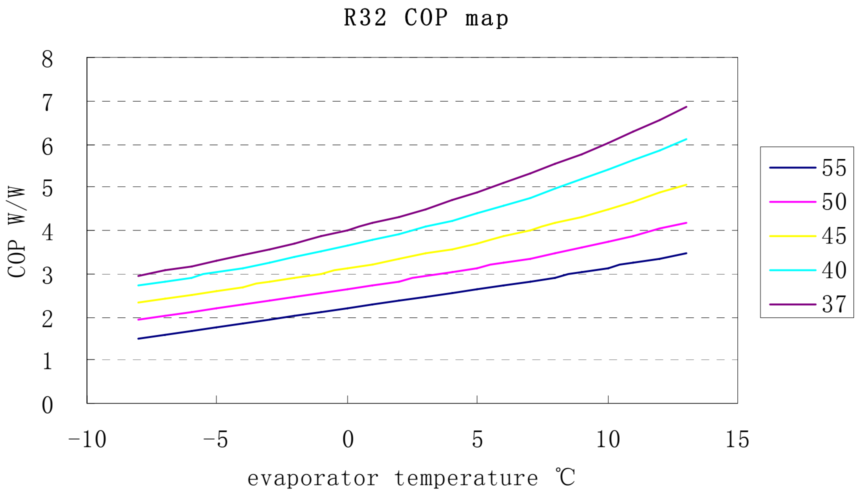
Table6. 10 Coefficients for R32 (compressor model: ASH280*)

X	Power	Capacity	COP	Flow
C1	8.90E+02	1.46E+04	1.43E+01	1.26E+02
C2	1.19E+01	7.68E+02	6.90E-01	9.88E+00
C3	9.00E+00	-4.52E+02	-4.92E-01	-2.34E+00
C4	3.31E-01	1.37E+01	1.17E-02	2.11E-01
C5	-1.09E+00	-2.23E+01	-2.15E-02	-3.06E-01
C6	2.58E-01	8.77E+00	7.49E-03	4.79E-02
C7	-1.61E-02	6.78E-02	8.16E-05	1.84E-03
C8	-1.63E-02	-2.36E-01	-2.13E-04	-3.85E-03
C9	2.06E-02	2.26E-01	1.91E-04	3.39E-03
C10	9.60E-04	-6.74E-02	-4.62E-05	-3.90E-04

- The following sets of graphs are compressor performance maps for low GWP refrigerant R32.


R32 capacity map
capacity W
11000
10000
9000
8000
7000
6000
5000
4000
3000
-10
-5
0
5
10
15
evaporator temp ℃
55
50
45
40
37


R32 power map
input power W
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
-10
-5
0
5
10
15
55
50
45
40
37


R32 COP map
COP W/W
8
7
6
5
4
3
2
1
0
-10
-5
0
5
10
15
evaporator temperature ℃
55
50
45
40
37

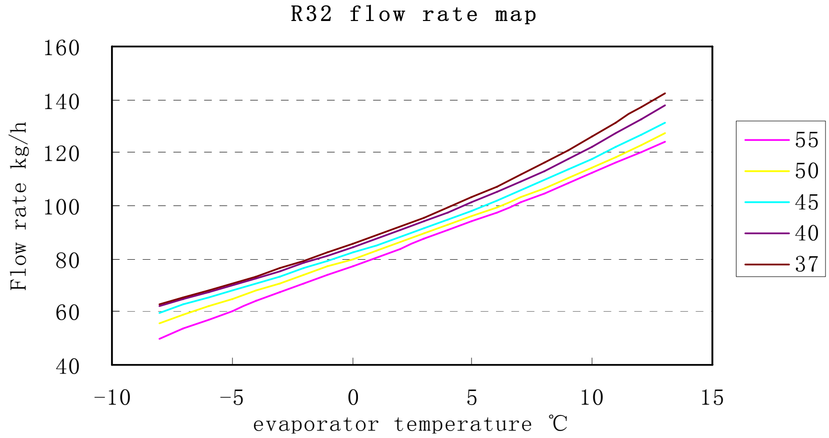


Figure7. Performance Map for alternative refrigerant R32

3. Comparative Analysis

Having the value $COP_{alt}/COP_{Baseline}$ as a function of evaporator temperature at given condenser temperatures, the curves are as the figure below shows.

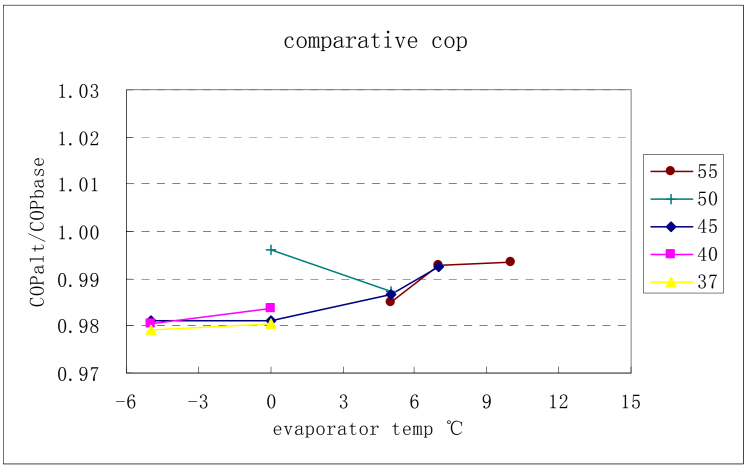


Figure8. COP Comparison of the two Refrigerants

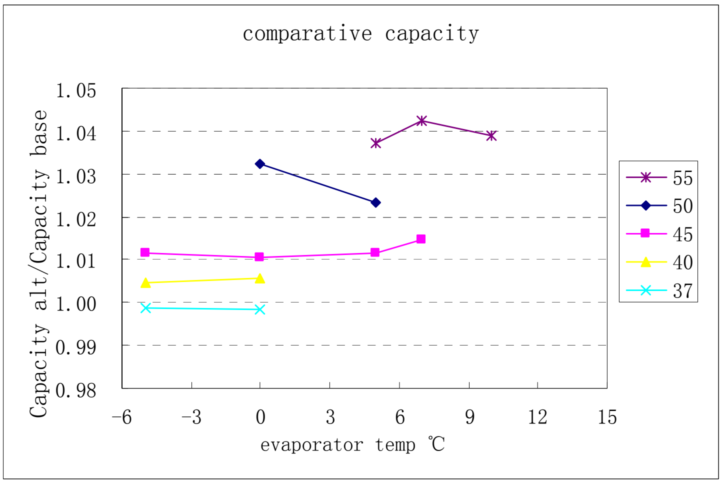


Figure9. Capacity Comparison of the two Refrigerants