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R32 Compressor Development for Air Conditioning Applications in China

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ABSTRACT

This paper evaluates the compressor performance and reliability impact by using R32 refrigerant for air conditioning (residential and commercial system); Performance and reliability impacts are compared with different popular refrigerants used in China, for example, R410A & R22 for AC. The design improvement on the scroll compressor will be discussed in order to reach required efficiency and reliability; these improvements include lubrication, internal heat management, motor design, and vapor injection technologies, etc.

Key words: Refrigerant, R32, Oil, Vapor Injection, Performance, Reliability

1. INTRODUCTION

HCFCs refrigerant R22 as the representative of its damage to the ozone layer has been identified, and there is restrictions on the use and required to be eliminated within a certain period. In China, a lot of efforts have been put to make R32 a substitute for R22. The theoretical volume cooling capacity of R32 is higher than R410A, and its price is low. R32 is with good prospects of application; its lower cost in China provides incentive for investing development time for mitigating its disadvantages through compressor and system design optimization.

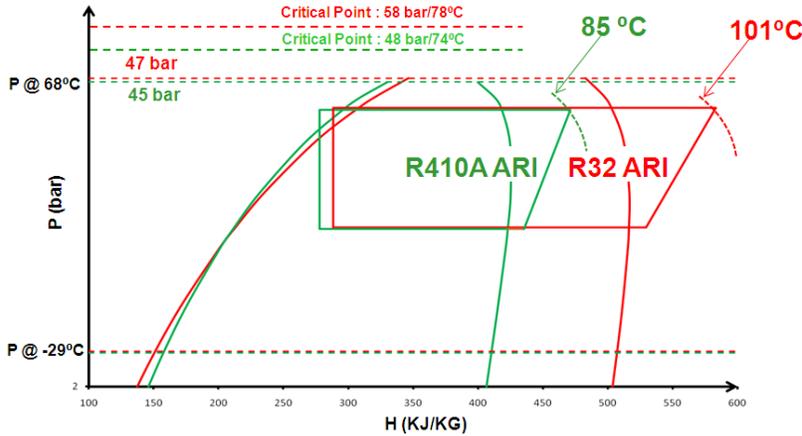
Because R32 and R410A have very similar thermal property, R410A compressor is taken as a baseline. Through theoretical calculation and initial drop-in test, it seems R32 offers more advantage than disadvantage over R410A, for example, lower liquid density results in lower system charge; lower system mass flow leads to lower pressure drop; higher liquid thermal conductivity leads to higher heat transfer coefficient; etc. Meanwhile, the compressor development mainly focus on solving the higher discharge temperature issue as well as developing new POE oil for R32 application. By far the effective results have been achieved. This paper will review future R32 compressor design with improved performance and enhanced reliability. In this paper, a real China R32 system test has been introduced, and the further system design improvement is discussed.

2. Scroll Compressor Performance Comparison - R32 v.s. R410A

R410A is taken as a baseline for all the analysis and comparison for R32 in this discussion.

2.1 Theoretical Performance Analysis

Figure 1 shows respectively the comparisons between theoretical volumetric capacity and energy efficiency ratio (TEER) of R32 over R410A at ARI condition. The testing set up is based upon standard 20Ksuperheat and 15K sub-cooling per AHRI 540 standard, while assuming equal volumetric and equal overall isentropic efficiency at ARI. All the properties of R32 and R410A are cited from the NIST software REFPROP7.



Refrigerant	Displacement	Mass Flow	Delta H	Capacity	Power	EER
R410A	100%	100%	100%	100%	100%	100%
R32A	100%	72.4%	152%	111%	108%	103%

Calculation Based On 100% Isotropic Efficiency

Figure 1: PH Diagram Comparison R32 v.s. R410A at ARI Condition

As the diagram shows, in theory, R32 has 11% higher capacity and 3% higher efficiency at ARI rated condition. The relative gains will be increased when the Te (Saturated Evaporating Temperature) and the Tc (Saturated Condensing Temperature) is getting higher.

Figure2 and Figure3 show the theoretical capacity and EER under the different operating conditions. As the diagram shows, the capacity and EER ratio of R32/R410A increases when the condensing temperature increase. It indicates the gains on both capacity and EER at high condensing temperature conditions for R32 compressor is more than R410A compressor.

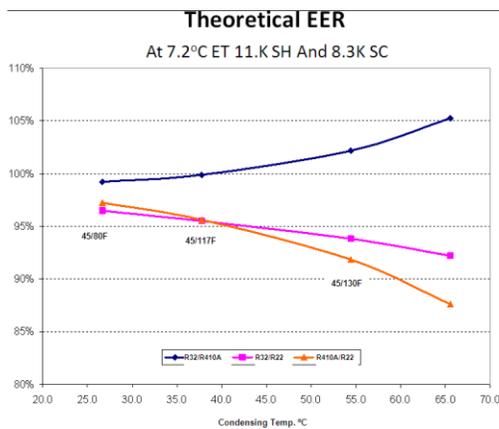


Figure 2: Comparison of Theoretical EER

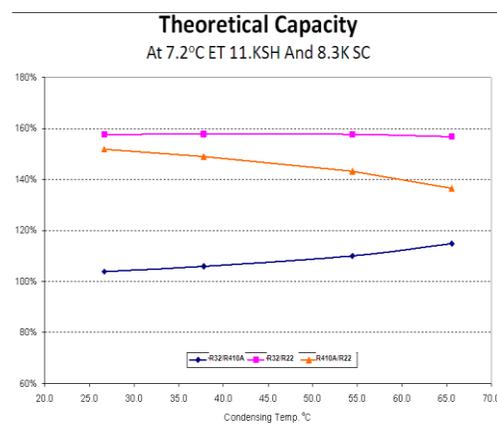


Figure 3: Comparison of Theoretical Performance

2.2 Compressor Drop in Test Comparison - R32 v.s.R410A

Considering the working pressure of R32 and R410A is comparable, a R410A optimized compressor was employed to do the drop in test at ARI condition. The test result is shown in table 1.

Table 1: Compressor drop-in test At ARI condition

Model	Refrigeration	Capacity	Power	EER	DLT
Unit		kW	kW	W/W	°C/°K
3HP	R410A	6.5	2.2	3.0	94
	R32	6.9	2.3	3.0	119
	R32/R410A	5.7%	7.2%	0.0%	25
5HP	R410A	12.7	4.0	3.2	93
	R32	13.5	4.3	3.2	115
	R32/R410A	6.3%	7.5%	0.0%	22
12HP	R410A	35.1	10.8	3.3	93
	R32	36.9	11.5	3.2	115
	R32/R410A	4.8%	6.4%	-3.0%	22

DLT: Discharge Line Temperature

As the diagram shows, on average, the tested R32 compressor capacity is 6% lower than the theoretical calculation. It is mainly because of higher suction super heat. The higher polytropic exponent and the lower mass flow are the major two facts to cause higher suction superheat, therefore results in volumetric efficiency reduction. 31% lower mass flow has been observed during the testing, which is believed to be the primary reason why the discharge line temperature is higher than R410A. Correspondingly, on average, the tested compressor EER is about 3-4% lower than theoretical calculation due to lower overall isentropic efficiency. It is expected that the compressor capacity and efficiency will get worse at higher compression ratio conditions.

2.3 Design Improvement Opportunity for Performance Enhancement

2.3.1 EVI Technology

Enhance Vapor Injection (EVI) is an effective approach for R32 compressor performance improvement. As shown in Table 2, the actual capacity and EER for a 10-ton scroll compressor at have 15% capacity gain at cooling condition, and 20% capacity gain at heat pump condition, respectively, while 7-9% efficiency gain at both conditions.

Table 2: EVI On/Off Comparison Test

Refrigerant	ET/CT °C/°C	EVI	Capacity kW	Power kW	EER W/W	DLT °C	Capacity Gain	EER Gain
R32	7/54	Off	33.9	11.0	3.1	118		
R32	7/54	On	39.1	11.8	3.3	102	15%	7%
R32	-12/32	Off	21.3	6.4	3.3	103		
R32	-12/32	On	25.6	7.0	3.6	92	20%	9%

ET: Evaporating Temperature, CT: Condensing Temperature, DLT: Discharge Line Temperature

2.3.2 Scroll Element Optimization

Considering different thermodynamic properties of R32 and R410A, the design optimizations for R32 scroll sets are needed. Firstly, the scroll suction inlet is to be optimized to get lower suction superheat. Secondly, scroll wrap is to be designed to take care of higher R32 running temperature. Drop-in test shows those two improvements are effective.

3. R32 Scroll Compressor Reliability

Higher loads have been observed in a R32 scroll compressor. Meanwhile, the high discharge line temperature is a concern to compressor reliability. New technologies and design improvements have been assessed as show below.

3.1 Lubricant

Many POE oils are widely used in R410A applications. However, it is not suitable for R32 application due to the miscibility issue as shows in Figure 4. Clearly, the POE oil A does not meet the needed miscibility requirements for R32 applications.

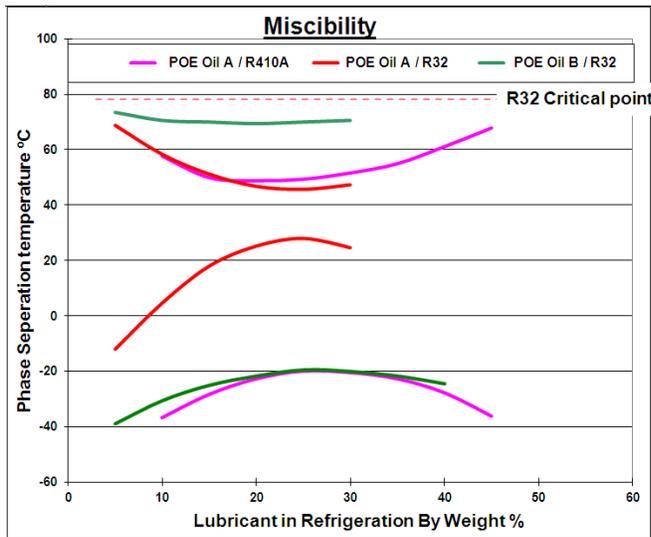


Figure 4: Oil Miscibility Diagram

POE Oil B is a newly-developed oil for R32. It has passed all the bench tests and compressor reliability tests (Table 3). The new POE oil B significantly reduces the wear at the inner wrap of the scroll sets in the compressor. With the vapor injection technology, the new oil performs the best in terms of wear resistance characteristics.

Table 3: R32 Compressor Reliability Result with Different Oil

Refrigerant	Oil	Tear Down Result		Remark
		Fixed Scroll	Orbit Scroll	
R32	POE OIL A			Severe Wear
R32	POE OIL B			Better
R32	POE OIL B + EVI			Best

3.2 Discharge Line Temperature Control

As discussed previously, the R32 compressor has higher compressor discharge temperature compared to other refrigerants. This challenge is to be addressed before launch R32 product to market. Several design changes has been deployed to lower the discharge temperature; however, there are trade-offs between compressor efficiency and reliability.

As Table 2 shows, Enhanced Vapor Injection is an effective approach to control discharge temperature. An acceptable discharge temperature could be set by controlling vapor injection flow rate. Liquid injections into the scroll pockets or compressor suction line are alternatives to control discharge temperature; however, by using liquid injection, the performance penalty will be anticipated, as power consumption will increase and efficiency will decrease.

A big part of the increased discharge temperature in a R32 compressor v.s. a R410A compressor is due to the increased suction superheat. Because of lower mass flow, R32 suction gas is easier to be heated up by motor inside, especially in a low-side compressor. As one of the solutions, a design change is deployed to shorten the distance between the compressor suction line and scroll set suction inlet, which results in the superheat reduction by 20-30K. When testing on different working conditions, more reduction on suction superheat at lower mass flow condition has been observed.

Meanwhile, R32 scroll set is to be designed at a higher build-in volume ratio in order to reduce the recompression heat and lower discharge temperature under high compression ratio conditions.

Table 4 is shown, with better internal heat management and higher volume ratio design scroll, more than 25K discharge temperature reduction is observed. It is expected to get more benefits at higher compression ratio conditions.

Table 4: Discharge Temperature Reduction with Different System Pressure Compression Ratio

Conditions	ET 7°C/CT 60 °C	ET -23°C/CT 38 °C
System Pressure Ratio	4.8	6.5
Discharge Line Temperature Reduction	25°K	52°K

Due to lower mass flow in R32 compressor and system, at any low mass flow condition, for example, low ambient heating application, the compressor is easily getting higher discharge line temperature and it put risk on compressor reliability. At such condition, the lubricant oil quantity sucked by scroll set becomes not enough for sealing and lubrication. One technology developed by Emerson Climate Inc. is deployed to increase oil quantity in scroll set to reduce scroll internal leakage, therefore reduce discharge temperature and improve compressor performance as well.

In Table 5, with more oil put into the scroll set, more than 8K discharge temperature reduction is observed and also with 5% performance gain in low mass flow condition.

Table 5: Discharge Temperature Reduction & EER Improve With More Oil Circulation Rate in Scroll Set

ET/CT °C/°C	Improved Oil Circulation	Capacity kW	Power Watt	EER WW	DLT °C
7/54	Off	6.96	2423	2.87	118
	On	6.98	2380	2.93	113
	Delta	+0.2%	-1.8%	+2.0%	-5 °K
-23/38	Off	2.53	1598	1.58	150
	On	2.63	1578	1.66	142
	Delta	+3.8%	-1.3%	+5.0%	-8 °K

4. R32 System Performance with Enhanced Vapor Injection Technology

Although many different compressor technologies have been discussed in above chapters, EVI (Enhanced Vapor Injection) has magnificent advantage over rest of the technologies, in terms of system capacity as we as EER/COPs. Hereby we will discuss a typical Chinese 65kw chiller system test with two10HP EVI compressors.

4.1 System Configuration

Normally, a typical chiller system includes an EVI compressor, a water heat exchanger and an air heat exchanger, a TXV or an EXV, an accumulator and a receiver. What's more, for EVI system, an economizer heat exchanger is deployed to inject vapor. Schematic is showed as Figure5.

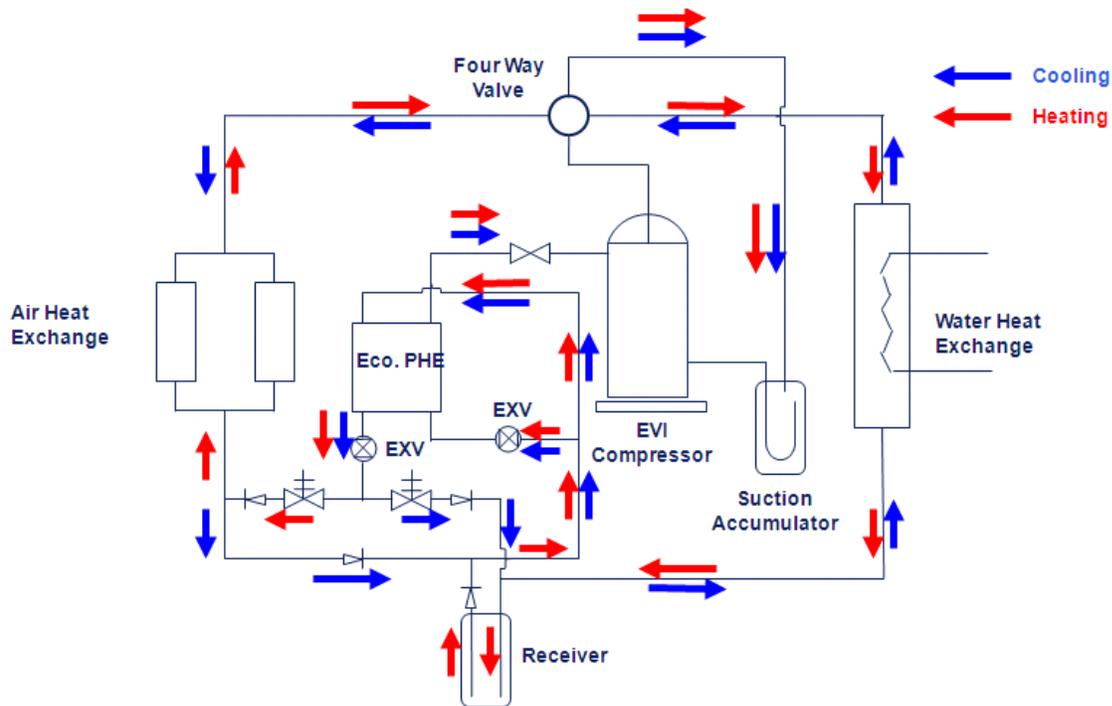


Figure5: Vapor Injection System Schematic

4.2 System Test Data

This is a drop-in test to a typical Chinese R410A system with some modifications made according to R32 compressor. Two pieces of R410A compressors were replaced by two pieces 10HP R32 EVI scroll compressors with EVI function. And an economizer was added which includes a heat exchanger and an EXV. System refrigerant charge amount is optimized. The comparison tests between EVI on and EVI off were done in an enthalpy test lab. The test condition follows GB18430.1-2007 standard and it showed in table 6. Figure 6 and 7 show capacity and EER comparison respectively, in different conditions.

Table 6: Chiller system test conditions

Test Condition	T indoor Temp.		T outdoor Temp.	
	T water_out		T outdoor_dry	T outdoor_wet
	(°C)		(°C)	(°C)
Rated Cooling	7		35	-
Max Cooling	15		43	-
Rated Heating	45		7	6
Max Heating	50		21	16

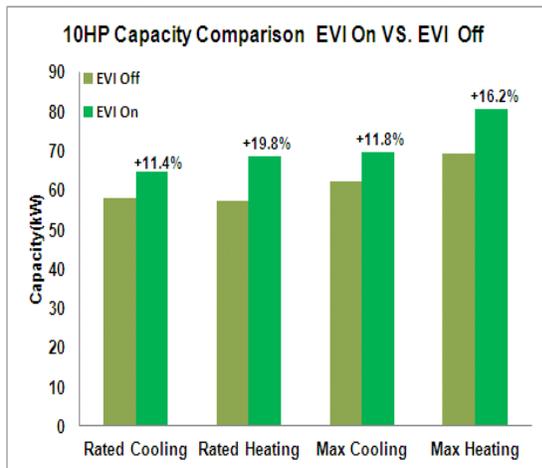


Figure6: Capacity Comparison

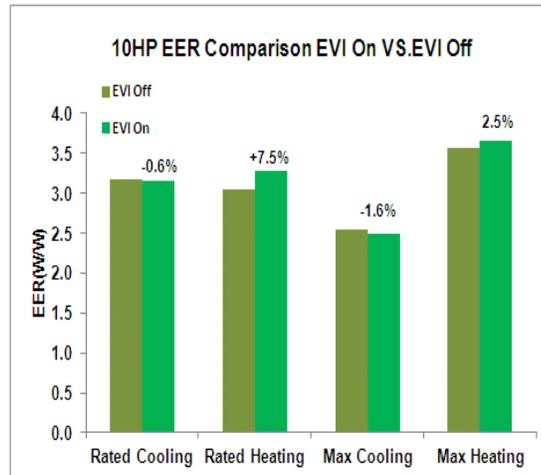


Figure7: EER Comparison

Figure 6 shows capacities increased by 11% with EVI on in cooling condition and 16%~19% gain in heating condition. In other words, with EVI technology, a smaller compressor can be used. Figure 7 shows EER with EVI on is 0.6% lower than EVI off in cooling condition. Because condenser Temperature for EVI on is about 1 °K higher than EVI off, it caused more power. However, in heating condition, 2.5%-7.5% EER gain observed. In summary, EVI Compressor showed more Benefits on cooling and heating capacity and heating EER.

4.3 System Design Optimization

R32 EVI system design could be based upon a similar R410A system. To obtain a better performance and system reliability, some system design changes are needed. For example, heat exchanger of water side and air side are both needed to be optimized for EVI system. The R32 system charging amount also needs to be optimized which should be smaller than original R410A system charging. The economizer EXV control should be set to maintain a safety discharging temperature. Wet injection could be needed under high system compression ratio. Besides, the design of key system components, such as compressor and expansion device, should be modified or re-designed according to R32.

5. Conclusions

Base upon above studies, R32 could be a cost-effective, Low-GWP/Low-LCCP refrigerant solution for China's air conditioning applications. Among all different R32 compressor technologies, vapor injection technology has inherent advantages on both efficiency and reliability. It provides 7~9% efficiency gain at rated heating, while comparable efficiency at rated cooling condition, comparing to non-injection technology. Through EVI technology, the ability to controlled discharge temperature has been enhanced. However, considering diversity of China's air conditioning systems and the sensitivity on system cost, managing discharge temperature without injection is attractive for R32 system builders. As third alternative, liquid injection is another solution. Although liquid injection has less cost adder to EVI system, it potentially has performance penalty.

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