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Abstract

During the process of refrigerant alternative, R290 (propane), as a nature refrigerant used in Room Air Condition (RAC) system, is thought as a long-team substance and has attracted great attention. This paper simply introduced the characteristics and standard demands of R290 application, then, based on a 1HP R290 DC INV. RAC system at first, then finished the comparison test when a one-cylinder and a two-cylinder rotary compressor was matched, in addition, deeply analyzed the connection between RAC system performance and refrigerant charge amount according to the test results. Lastly, comprehensive consideration of the refrigerant charge amount, analyzed the different demands of R290 compressor and traditional compressor, put forward the techniques of R290 rotary compressor structure design.

1. INTRODUCTION

In order to protect the stratospheric ozone layer, hydro-chlorofluorocarbons (HCFCs), such as R22, are in process of regulation and will be phased out in the near future. Although the hydro-fluorocarbons (HFCs), such as R410A, can solve the issue of ozone layer protection, Global Warming Potential (GWP) of these refrigerants is still very high, so it is certain that they will be phased out in the next few years. As a natural refrigerant, the hydrocarbons, such as R290 (propane), has similar property to R22, with zero Ozone Depleting Potential (ODP) and very low GWP, are thought as the next generation refrigerant, is gaining widespread acceptance for applications, both commercial and domestic air conditioning system.

2. SAFETY REQUIREMENTS

As a saturated hydrocarbon, R290 (propane) is non-toxic but highly flammable, it is classified as “A3” according to ANSI/ASHRAE Standard 34-2010. Due to this highly flammable property, the safety against leakage is the most important issue of RAC systems application. At present, several standards about use of flammable refrigerant, charge limitation and its related equipment are available in IEC60335-2-40，EN378-1 and the latest UL484.

For most residential RAC system using range, the maximum charge in a room shall be in accordance with the following:

$$m_{\max} = 2.5 \times (LFL)^{(5/4)} \times h_0 \times (A)^{1/2} \tag{1}$$

Where:

m_{max}: Allowable maximum charge in a room in kg;
A: Room area in m^2;
LFL: Lower Flammable Limit (LFL) in kg/m^3;
h_0: Installation height of the appliance in m:
0.6 m for floor location/1.8 m for wall mounted/1.0 m for window mounted/2.2 m for ceiling mounted.

Some examples of the results of the calculations according to the above formula are given in Table1.

Table1: Maximum charge (kg)

Refrigerant	LFL (kg/m^3)	h0 (m)	Floor area(m^2)						
			4	7	10	15	20	30	50
R290	0.038	0.6	0.05	0.07	0.08	0.1	0.11	0.14	0.18
		1	0.08	0.11	0.13	0.16	0.19	0.23	0.3
		1.8	0.15	0.2	0.24	0.29	0.34	0.41	0.53
		2.2	0.18	0.24	0.29	0.36	0.41	0.51	0.65

3. REFRIGERANT DISTRIBUTING TEST

The RAC system comprise compressor, heat exchangers, throttle valve and connecting pipes. The refrigerant charge in the system will not proportionally distributing by the volume because of the pressure difference when system in operation. In order to find out which component contains the most refrigerant, we designed this refrigerant distributing test, so that we can get the refrigerant distributing proportion in every component of the RAC system.

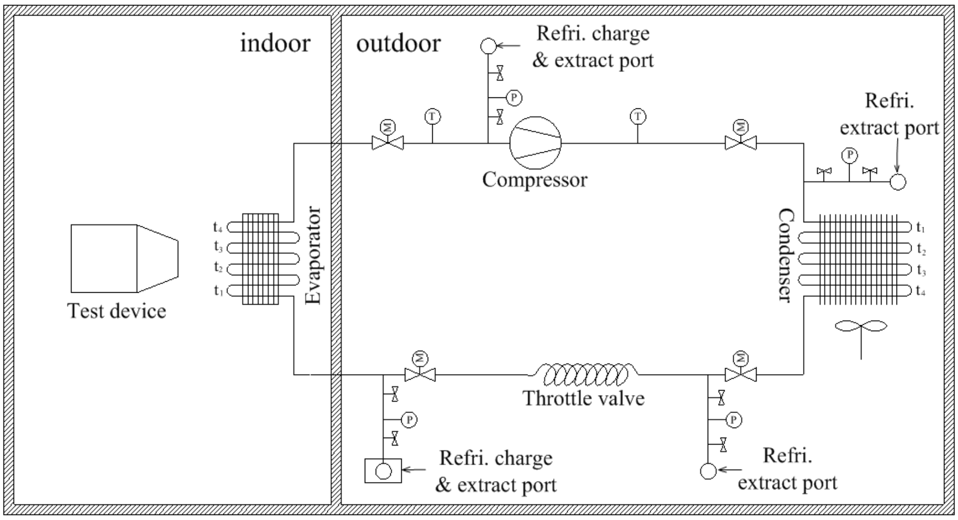

Figure 1: Refrigerant distributing test layout

The system layout of the test is shown in figure 1. Both the system and compressor used in the test are special designed for R290 refrigerant. Firstly, we rebuilt the connecting pipes by added some electromagnetic stop valves and switch ports, then, set the condition of indoor temperature (dry/wet) at 27℃/19℃ and outdoor temperature (dry/wet) at 35℃/24℃, startup the compressor until the system at steady operation state, turn off the compressor and make the stop valve cut off the pipeline at the same time, lastly, weigh in every component and figure out the refrigerant content to get the proportion of the refrigerant distributing, the result is shown in table 2.

Table2: Refrigerant distributing test result

system	Condition(℃) (dry/wet)		Compressor	Evaporator	Condenser	Throttle and Connecting pipe
R290 RAC system	outdoor	indoor	% of charge amount	% of charge amount	% of charge amount	% of charge amount
	35/24	27/19	26.4%	5.2%	62.1%	6.3%

In this R290 RAC system, the condenser contains about 62.1% of total refrigerant charge amount while the compressor has next in 26.4%. The other components contain evaporator, throttle valve and connecting pipes take up the rest 11.5%. Therefore, to decrease the refrigerant charge amount of R290 RAC system, we should consider on the optimization design of condenser and compressor.

In the RAC system, because condenser have the biggest volume and have the request of liquid refrigerant stay, makes the condenser contains more than half refrigerants when system in operation. Although the application of micro-channel heat exchanger technique can decrease the condenser volume which causes a notable reduce of refrigerant content, it still limited by the issues like frosting and demand of heat capacity etc. In general, the optimization of condenser can't be the only way to decrease system charge amount. That is to say, we should endeavor to decrease the refrigerant content in compressor to satisfy the regulation of charge limitation.

4. SYSTEM PERFORMANCE TEST

As an "A3" refrigerant, R290 using in RAC system has very strict charge limitation regulation, for example, a 1HP RAC system using in an area of $15m^2$ and install at 1.8m height unventilated room, the maximum refrigerant charge quality is 0.29 kg, only about 45% of that in regular R22 1HP RAC system.

Within this 0.29kg, we designed a test to find out the relationship between system performance and refrigerant amount. Using a R290 RAC system, at the rated condition, charge the refrigerant to get the best EER step by step, then draw the curvilinear trend of the results which as shown in figure 2 (take the EER at 0.29 kg as a reference of 100%).

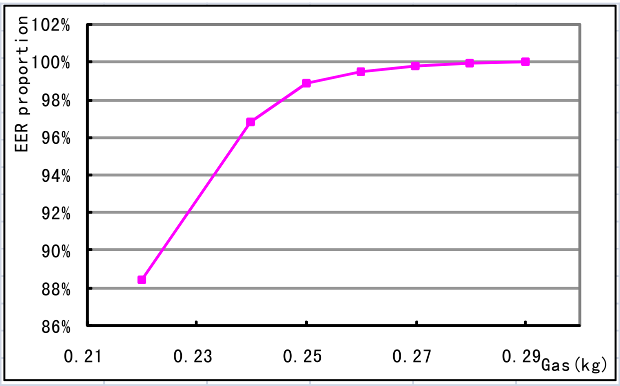

Figure 2: Relationship between EER and refrigerant quality

As results show in Figure 2, the refrigerant quality in system obviously affect performance, the EER is growing by increasing of refrigerant quality. The refrigerant charge in system is consists of circular refrigerant and stopping refrigerant, where the stopping refrigerant is the refrigerant not participate working circle, like refrigerant absorbed in compressor oil and staying in the compressor inside chamber. Due to the strict limitation, we can improve the performance of R290 RAC system by increase the circular refrigerant or decrease the stopping refrigerant.

If the stopping refrigerant decreases, considering the system performance, under the same refrigerant charge amount, the system performance will improve because the circular refrigerant increases, on the other hand, the system performance will not change due to the same circular refrigerant, but the total refrigerant charge amount can decreases while the system safety is enhanced.

We set up a comparison test by adopt two types of compressor. One is a two-cylinder compressor and another is a one-cylinder compressor. The difference of these two compressors is the two-cylinder compressor has more lubrication oil inside, so that more refrigerant will absorb in the oil. When system is operating at the same refrigerant charge amount, the circular refrigerant with the two-cylinder compressor will less than one-cylinder system. That is to say, to achieve the same performance, two-cylinder system may need more refrigerant charge amount than the one-cylinder system.

To confirm this analysis, firstly, we finished the single compressor performance test to find out the performance difference between the two compressors. At the condition similar with system operation, without the refrigerant charge amount affect, the test result is shown in table 3.

Table3: Single compressor comparison

Compressor	**Displacement volume(m^3/rev)**	**Oil (m^3)**	**chamber volume(m^3)**	**Capacity (W)**	**Power (W)**	**COP (%)**
One-Cylinder	1.5e-5	2e-4	9e-4	100%	100%	100%
Two-Cylinder	1.5e-5	4.2e-4	1e-3	99.5%	99.8%	99.7%

Then, we finished the comparison test by using the same R290 RAC system. At the rated condition, we obtained the best EER of each compressor by adjusting the charge amount. As we can see the results show in table 4, the two-cylinder system needs 0.055 kg refrigerant more than one-cylinder one to obtain a considerable EER.

Table4: System test result comparison

System	**Compressor**	**Condition(℃) (dry/wet)**		**Capacity (W)**	**Power (W)**	**EER (%)**	**Refrigerant (kg)**
R290 RAC system	One-Cylinder	outdoor	indoor	100%	100%	100%	0.350
	Two-Cylinder	35/24	27/19	101%	101.2%	99.9%	0.405

When the system in steady operation, record the pressure and temperature value, then according to the solubility of R290 and the oil at this condition, the stopping refrigerant in compressor which include the refrigerant absorbed in oil and refrigerant stay in chamber was calculated, as show in table 5.

Table5: Refrigerant content result comparison

Compressor	**Condition(℃) (dry/wet)**		**Oil (m^3)**	**Solubility (%)**	**Refrigerant in oil(kg)**	**chamber volume(m^3)**	**Refrigerant in chamber(kg)**	**Difference in sum(kg)**
One-Cylinder	outdoor	indoor	2e-4	25%	0.050	9e-4	0.031	0.058
Two-Cylinder	35/24	27/19	4.2e-4	25%	0.105	1e-3	0.034	

At saturated dilution state, the refrigerant in two-cylinder compressor has 0.058 kg more the one-cylinder. This is due to the difference of lubricating oil charge volume in compressor which brings notable quality difference of the refrigerant absorbed in oil. As we can see, the calculated data is accord with the system test result.

5. KEYS FOR R290 COMPRESSOR DESIGN

In RAC system, compressor is one of the most important components which can apparently affect system performance and reliability, noise and vibration. High efficiency and reliability, low noise and vibration are the directions of compressor design. Beside these common demands, considering the refrigerant contain in compressor is another important key point for R290 compressor.

Decrease the refrigerant absorbed in oil and refrigerant stay in compressor inside chamber is two major methods to decrease the refrigerant contain in compressor. At the certain pressure and temperature, the quality of refrigerant stay in chamber is decided by compressor inside volume. With certain type of lubricating oil, the refrigerant absorbed in oil only related to the amount of the oil. In summary, the special demands for R290 compressor design should contain two points: low oil charge and miniaturization.

Comparatively, the consideration of low oil charge is more significant than miniaturization, because the quality of refrigerant absorbed in oil is more considerable than refrigerant stay in compressor. Considering the structure difference, the two-cylinder compressor needs much more lubricating oil to ensure the upper cylinder lubrication which induce more gas absorbed in oil, it is seemed that the one-cylinder structure is more suitable for R290 according to the test results above. However, the two-cylinder compressor has special advantages than one-cylinder compressor, especially in DC inverter and large compressor application, the endeavor of oil supply design for upper cylinder at low oil level is also very important in the future.

From another point of view, R290 compressor will not required too much oil charge to avoid the dilution because of the limitation of charge amount. Therefore, the application of low oil charge technique will be inevitable as long as the oil supply can meet the requirement of part lubrication at low oil level.

Simply speaking, miniaturization is to reduce the refrigerant stay in chamber by minimize the compressor size of height and diameter. Compare to R22, when the displacement volume is the same, the power consume of R290 compressor is about 85% of that of R22, so it is possible to use smaller motor in R290 compressor with the same mechanical structure. In fact, miniaturization also can help achieve low oil charge application. However, we also need more efficient method to control the oil discharge in miniaturization structure compressor.

Table6: Effect of low oil charge and miniaturization

Compressor	Oil amount (m^3)	Refrigerant in oil (kg)	Refrigerant in chamber (kg)	Sum (kg)	Difference in sum (kg)	Charge limitation (kg)	Proportion (%)
A	4.4e-4	0.110	0.013	0.123	0.054	0.290	18.6%
B	2e-4	0.050	0.019	0.069			

As shown in table 6, at the rated condition, the compressor (B) which applies the low oil charge technique and miniaturization structure can reduce 0.054 kg refrigerant content than that in original compressor (A), this quality difference take up a notable proportion of 18.4% of the total charge limitation.

6. CONCLUSION

As a nature refrigerant, R290 is gaining widespread acceptance for applications, the safety against leakage is the most important issue need to be considered, which is currently controlled by charge limitation. In R290 RAC system, most refrigerant is distributing in condenser and compressor with the proportion of 62.1% and 26.4%. Since reduce the condenser volume will bring other influence, the consideration of reduce refrigerant contain in compressor is become necessary under the strict charge limitation. Reduce the refrigerant content in compressor can improve the circular refrigerant amount to enhance the system performance or safety. In general, the directions of R290 compressor design need to apply low oil charge technique and miniaturization structure to achieve widespread application.

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