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Bin Gao
Guangdong Meizhi Compressor Co., Ltd., China, gaob@chinagmcc.com

Canyu Qian
Guangdong Meizhi Compressor Co., Ltd., China, qiancy@chinagmcc.com

Zhenhua Chen
Guangdong Meizhi Compressor Co., Ltd., China, chenzhenhua@chinagmcc.com

Shuangjian Liang
Guangdong Meizhi Compressor Co., Ltd., China, liangshj@chinagmcc.com

Research and Development of R290 Less Oil Rotary Compressor

Bin GAO[*1], Chanyu QIAN[2], Zhenhua CHEN[3], Shuangjian LIANG[4]

R&D Section, Guangdong Meizhi Compressor Co. Ltd.,
Foshan City, Guangdong Province, China, 528333
Fax +86 757 22297554-830

[*1]Phone +86 757 22325565, E-mail: gaob@chinagmcc.com
[2]Phone +86 757 22329452, E-mail: qiancy@chinagmcc.com
[3]Phone +86 757 22329132, E-mail: chenzhenhua@chinagmcc.com
[4]Phone +86 757 22329235, E-mail: liangshj@chinagmcc.com

* Corresponding Author

ABSTRACT

Currently, the rotary compressors are widely employed in residential air conditioners. Less oil technique is one of the most important directions of rotary compressor development. This less oil technique research is based on R290 rolling piston rotary compressor for the purpose of decreasing R290 charge amount in room air conditioner to satisfy the demand of part ANNEX GG in IEC standard 60335-2-40.

Firstly, the less oil rolling piston rotary compressor was designed to resolve the oil supply issue, and the CFD simulation of the oil supply structure was validated. Secondly, the oil supply test, compressor performance and reliability tests of less oil compressor comparing to original compressor were completed. Thirdly, using the same R290 room air conditioner, the decrease of R290 charge amount was obtained by testing, also the system performance was confirmed. Lastly, the effects of oil charge amount decrease on oil working viscosity and oil film thickness were tested and calculated.

The results show that the less oil rotary compressor has good prospect, and the application of less oil technique not only effectively reduces the refrigerant charge amount of R290 room air conditioner but also achieves good performance and reliability of the compressor and system.

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, the 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 thermodynamic properties 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.

2. REFRIGERANT DISTRIBUTION

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.

First of all, in order to reduce the R290 charge amount, the refrigerant distribution in R290 system should be clarified by testing. The test plan is shown in figure 1. The testing R290 RAC system was modified by adding some electromagnetism globe valves and ports.

As shown in table 1. Under the standard cooling condition according to GB T7725-2004, the data of refrigerant distribution in the system was calculated.

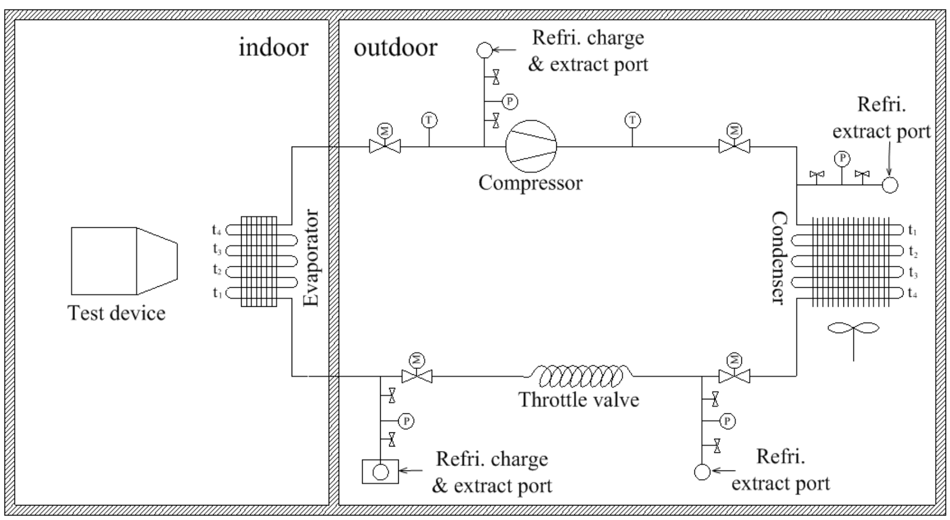

Figure 1: Refrigerant distribution test plan

Table 1: Refrigerant distribution in R290 RAC system

System	Test condition(K)		Comp.	Cond.	Evap.
R290 RAC	**outdoor(dry/wet)**	**indoor(dry/wet)**	**%**	**%**	**%**
	308.15/297.15	300.15/292.15	26%	6%	6%

In R290 RAC system, about 62% refrigerant stays in condenser, and about 26% refrigerant stays in compressor. According to the result, the best way to reduce the R290 charge amount is optimize the condenser, and then the compressor. In this regard, this result shows a new demand for R290 compressor design.

When the system is in operation, most of the refrigerant in compressor is absorbed by oil because of the very good solubility of R290 in oil. This Staying refrigerant in compressor doesn't join in the refrigerating cycle which makes the system lack of refrigerant. In other words, it is necessary to design the less oil compressor to reduce refrigerant to satisfy the standard demand.

3. LESS OIL COMPRESSOR STRUCTURE

Currently, the minimum oil height in rotary compressor is required more than 5 millimeter higher than the underside of cylinder. However, the oil height is affected by oil charge amount. The target of less oil technique is to allow rotary compressor to operate in a very low oil height circumstance without performance and reliability drop. In this regard, the oil supply capacity under low oil height is the issue needed to be resolved.

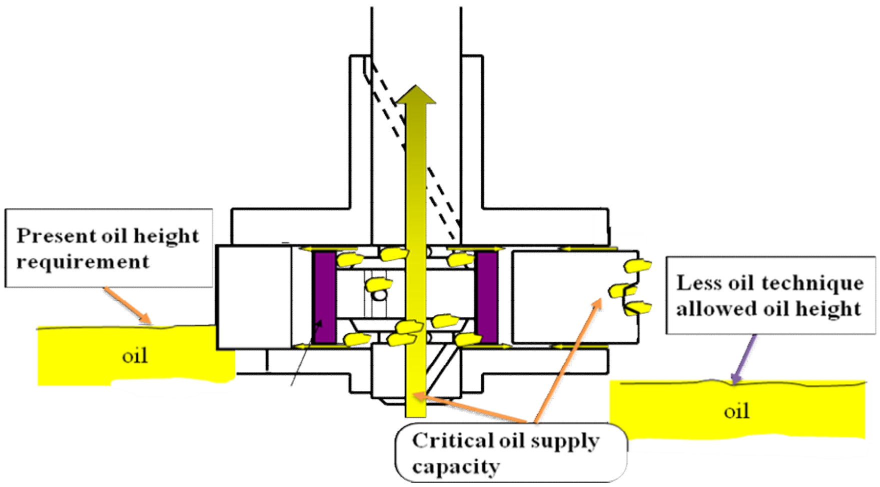

Figure 2: Oil height requirement in rotary compressor

The difference of oil height requirement between present rotary compressor and less oil compressor as shown in figure 2. In the less oil compressor, the two most critical friction surfaces are shaft and upper bearing & blade and cylinder. It is required to develop new oil supply structure for less oil compressor.

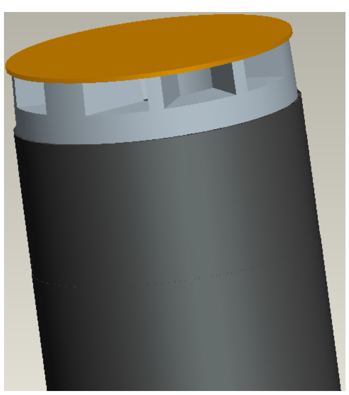

Figure 3: Rotor fan structure

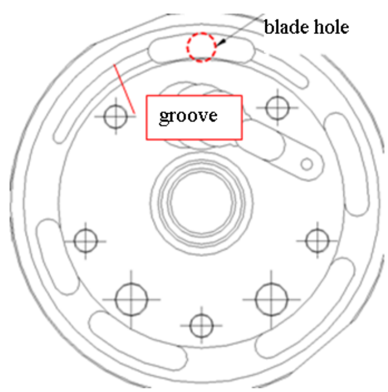

Figure 4: Oil collecting groove

The rotor fan structure as shown in figure 3 is designed to improve oil supply to the shaft and upper bearing. Along with the compressor rotating, the rotor fan makes the pressure of the shaft oil pump outlet go down, which increases the pressure difference between the inlet and outlet of the shaft oil pump system. This result benefits oil pump efficiency and oil supply height.

The oil collecting groove structure is designed to improve blade lubrication as shown in figure 4. A groove is manufactured on the upper bearing to collect and lead the oil flow to the back hole of the blade for lubrication. This structure increases the oil capacity through the blade surface, which should make sense to the blade lubrication.

The software Star CD was used to do the initial validation of the rotor fan structure. The results are shown in figure 5 and figure 6. Figure 5 shows the pressure difference of the two models, the unit of the result is Pa. Figure 6 is the VOF result in the compressor. The VOF is a ratio of oil content. This result can reflect the height of the oil distributions.

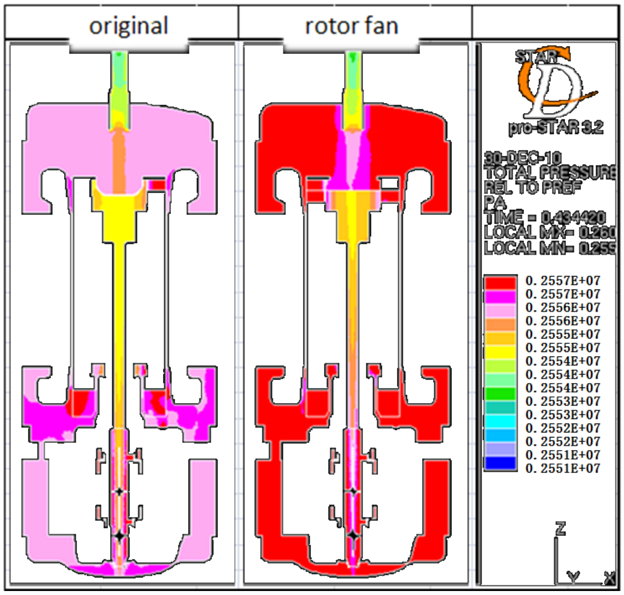

Figure 5: Pressure distribution result

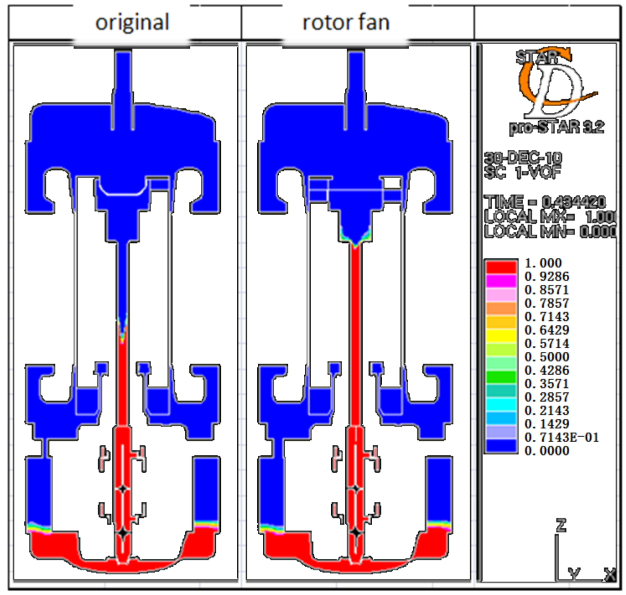

Figure 5: Pressure distribution result **Figure 6:** VOF distribution result in the compressor

According to the figure 5, through the comparison of the pressure difference between upper area and inlet port of the oil pump for the two models, we can figure out that this pressure difference of the model with rotor fan structure is higher than another one. In figure 6, the red color represent oil distribution, as we can see, the model with rotor fan has a higher oil height in the oil pump system than the original model. This simulation was calculated under the same oil charge amount circumstance of the models.

4. VALIDATION TESTS

Validation tests include compressor tests and system tests. Compressor tests comprise oil supply tests and performance and reliability tests, while system tests comprise performance test and oil state test. In these tests, the original compressor with normal oil charge amount and oil supply capacity is taken as base reference of 100%.

4.1 Oil Supply Tests

The oil supply tests include upper bearing test and blade test, the intention of the upper bearing test is to realize the lubrication between shaft and upper bearing, while the blade test is aimed at blade and cylinder. The result of upper bearing test reflects the rotor fan effect while the result of blade test reflects the oil collecting groove effect in the less oil compressor application.

The tests result was collected by contrasting the standard oil flow figure, and then the calculated data is shown in figure 7.

The oil charge amount of less oil compressor was set as 30% of the original compressor. Both the upper bearing test and blade test result of the less oil compressor were as good as original compressor when the rotor fan and oil collecting groove were applied.

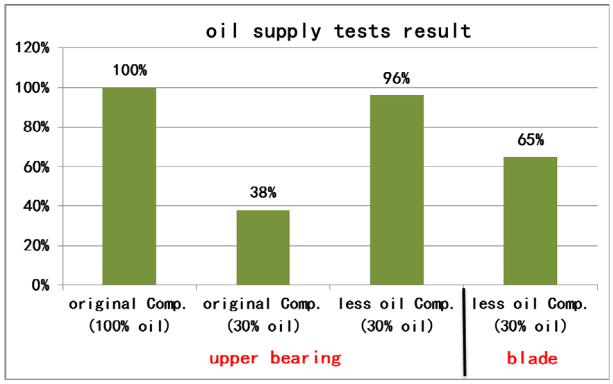

Figure 7: Result of oil supply tests

In this regard, the result of less oil compressor has significant improvement upon the one without such structures which is marked as original (30% oil) in figure 7. The tests result shows strong effect of the oil supply structures.

4.2 Compressor Performance and Reliability Test

The compressor performance and reliability tests are for the purpose of overall estimation of the oil charge amount decrease and oil supply structure. The result has strong reference to the feasibility estimation of less oil compressor.

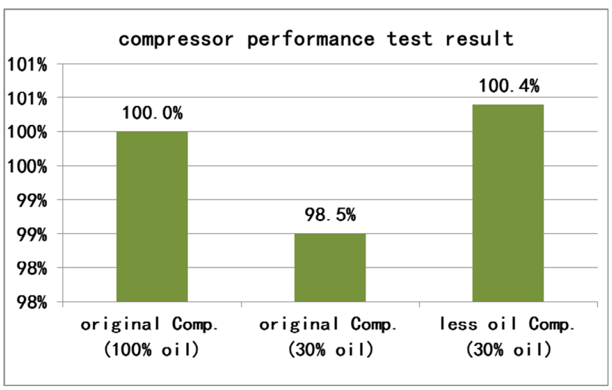

Figure 8: Compressor performance test result

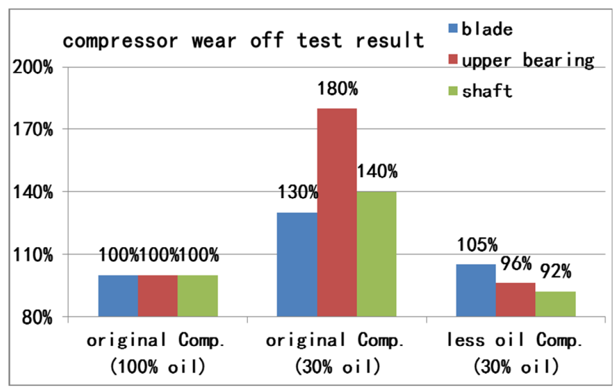

Figure 9: Compressor wear off test result

Figure 8 shows the performance test result. According to the result, the less oil compressor obtained a litter better performance due to a lower oil circulation, while the original compressor with 30% oil fell off about 1.5% comparing to the benchmark.

The reliability test result is shown in figure 9. This result was measured by specified device. The figure only shows result of concerned parts which include blade, upper bearing and shaft. After 1000 hours operation, the wear off of these parts in less oil compressor was as good as the original compressor. While the wear off apparently increased in the original compressor with 30% oil because of the bad lubrication.

According to the result, less oil compressor with the oil supply structure can guarantee the lubrication of moving parts so that keeps the compressor performance and reliability.

4.3 RAC System Performance Tests

The RAC system test result is the most important reference for the evaluation of less oil technique. The less oil compressor was tested in the same R290 RAC system by contrasting with the original compressor. The standard capacity of the compressor used for this test is about 3500W while the standard system load is about 1.5HP.

Here L.O.S is the abbreviation for R290 RAC system with less oil compressor and O.S is the abbreviation for the system with original compressor.

Under the standard cooling and heating test condition according to GB T7725-2004, the RAC psychometric type calorimeter is used, carried out the tests and recorded the data of R290 charge amount, system capacity and efficiency. The R290 charge amount of the test system was adjusted to obtain the best efficiency point under the cooling condition, and then only change the opening of expansion valve to finish the heating test under heating condition. The results are shown in figure 10 and figure 11.

Under the cooling condition, at the best EER point, the L.O.S obtained equivalent cooling performance to the O.S but only needed 83% R290 charge amount. That means the L.O.S can reduce about 17% R290 charge amount comparing to O.S. This result shows that the less oil compressor achieves significant effect on the decrease of R290 charge amount which can help the system satisfy the standard easier.

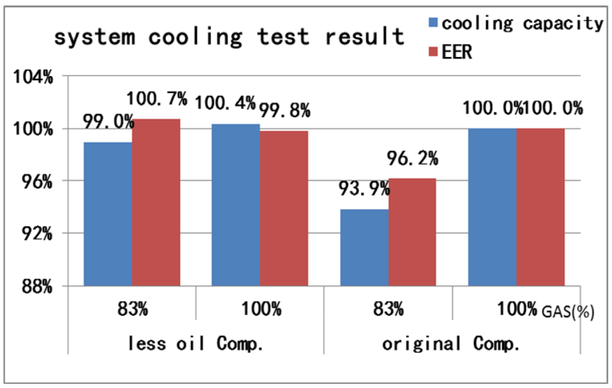

Figure 10: R290 RAC system cooling test result

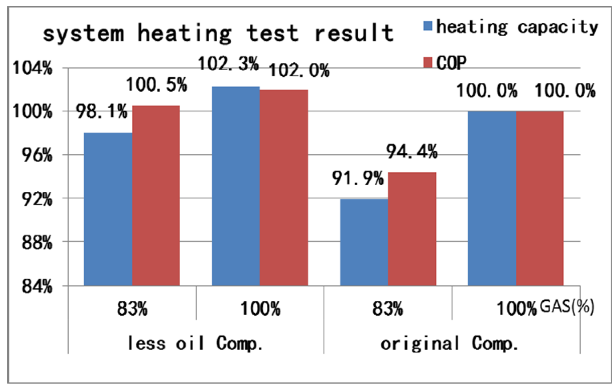

Figure 11: R290 RAC system heating test result

In addition, when changed the refrigerant charge amount from 100% to 83%, the L.O.S kept good stability of cooling performance, in contrast, the O.S dropped about 6% of cooling capacity and about 4% of EER. That means we can use less oil compressor to get the equivalent cooling performance with much lower refrigerant charge amount so that achieve more safety in R290 application.

Besides, the L.O.S shows better heating performance in R290 application. At the heating model, we can either adopt lower R290 charge amount to obtain acceptable performance or choose to obtain about 2% higher heating capacity and COP with the same R290 charge amount of O.S. Moreover, the heating performance of the O.S fell off significantly and show more severity than cooling performance along with the decrease of R290 charge amount.

4.4 Lubrication State Test

Oil working viscosity is the final data of how lubricate oil works for compressor. This viscosity is affected by pure oil viscosity and the solubility of refrigerant in oil. Furthermore, the solubility is affected by pressure and temperature. Since the oil charge amount decides oil height in compressor oil sump, the more oil charge amount, the higher oil height, and the bigger temperature difference of the oil at different height, which means the solubility of R290 in the oil is affected by oil charge amount.

In addition, the oil working viscosity will affect the oil film thickness between bearings and shaft, which has significant effect on compressor performance and reliability.

This test obtained the oil working viscosity by adding the viscosity sensor into the compressor oil sump, and then operated the L.O.S and O.S under different conditions. According to this viscosity result, considered the compressor structure parameter differences, calculated the oil film thickness as shown in figure 12.

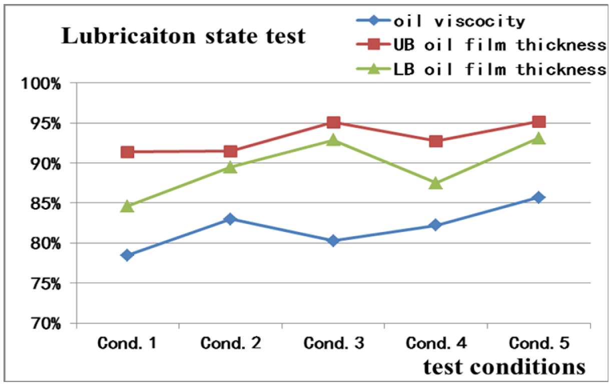

Figure 12: Oil and lubrication state test result

Under the same test condition, oil working viscosity fell off about 5%~10% alone with the decrease of oil charge amount. However, the maximal decline of oil film thickness between bearings and shaft was about 17% compare to the original compressor which was more serious than the viscosity data. That is to say, the compressor lubricating state was affected by the decrease of oil charge amount.

Consequently, for the less oil compressor, the oil with higher viscosity or lower solubility of refrigerant in oil is the better choice, so that the less oil compressor can obtain a suitable lubrication of moving parts comparing to the original compressor.

5. CONCLUSIONS

In R290 RAC system, about 62% refrigerant stays in condenser and 26% refrigerant stays in compressor. Refrigerant in compressor doesn't join in the refrigeration cycle which makes the short of the R290 charge amount of the system. The less oil technique is an effective way to reduce the refrigerant in compressor.

The oil supply issues of less oil compressor were presented and resolved by the new structures design. Also the feasibility of this design was validated. The validation tests show that the less oil compressor has good prospect which will be a very important direction of R290 compressor design.

However, the decrease of oil charge amount affects oil working viscosity and oil film thickness of compressor moving parts, the choice of lubricate oil for less oil compressor should be considered.

NOMENCLATURE

CFD	Computational Fluid Dynamics	(-)
HCFCs	Hydro-chlorofluorocarbons	(-)
HFCs	Hydro-fluorocarbons	(-)
LFL	Lower Flammable Limit	(kg/m^3)
RAC	Room air conditioner	(-)
Comp.	Compressor	(-)
Cond.	Condenser	(-)
Evap.	Evaporator	(-)
VOF	Volume of fluid	(-)
L.O.S	R290 RAC system with less oil compressor	(-)
O.S	R290 RAC system with original compressor	(-)
COP	Coefficient of performance	(-)
EER	Energy Efficiency Ratio	(-)
UB	Upper bearing	(-)
LB	Lower bearing	(-)

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