Experimental Investigation on the Influence of the Oil Return Hole on the Performance of R-32 Wet Compression Cycle

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ABSTRACT

R32 has been being one of the hot candidates for refrigerant substitute because of its better thermodynamic performance. In this study, the influence of wet compression on R32 system performance was researched by experimental test firstly. The result showed that, with the suction vapor quality decreasing, the discharge temperature and the system performance decreased simultaneously. And then, on the base of the wet compression experiment test, the experiment that the influence of the oil return hole on system performance of R32 wet compression was carried out. The experimental results showed that, in wet compression, the decreasing rate, that the cooling capacity and EER decreased with the discharge temperature decreasing, decreased with the increase of the oil return hole size. The increase of the oil return hole size was benefit to improve the system performance in wet compression. But it increased the risk of over wet compression or liquid impact for compressor under frosting and defrosting condition.

1. INTRODUCTION

R32 refrigerant，one component of R410A，has lower flammability (burning rate =6.7cm/s<10cm/s) and no toxicity. It is in safety class A2L according to ANSI/ASHRAE Standard 34-2010 and has zero ODP and a GWP100 of 657. Taking flammability of R32 into consideration, it has been only as one component of some alternative refrigerants for long due to its excellent thermodynamic properties. With the work progress of alternative refrigerants, it shows that low GWP and no flammability are incompatible. A compromise between complete use safety and environmental protection is proposed and some minor flammable refrigerants and natural work fluids are repurposed. And many flammable refrigerants or natural gases have been applied to certain applications (Jung et al., 2000). For instance, isobutene (R600a) has dominated the European refrigerator/freezer sector for the past decade and is being used even in India and China, while propane (R290) and propylene (R1270) are proposed and actually used for heat pumping applications in Europe. Compared with those natural refrigerants such as R290, the flammability of R32 seems negligible in the near future. The effects on climate and on refrigeration system performance of R32 have become investigation focus these days.

But, the discharge temperature of R32 is 10~25℃ higher than that of R410A. Higher temperature would bring series of reliability problem, such as quickening the lubricating oil cracking, and making the nonmetal materials in compressor bad, and increasing the abrasion between the axletree by reducing the viscosity of lubricating oil. Theoretical investigation found that, under the condition that the evaporation temperature was -20℃ and the condensation temperature was 45℃, the discharge temperature would be kept below 135℃ when the suction vapor quality of compressor was controlled at 0.93 (Yajima et al., 2011). So the higher temperature problem could be solved by controlling the suction vapor quality of compressor. Controlling the suction vapor quality means controlling the refrigerant at the suction of compressor to be gas-liquid mixture (the suction vapor quality is less than 1). The compression is wet compression when the suction vapor quality is less than 1.

2. WET COMPRESSION AND ITS INFLUENCE ON SYSTEM PERFORMANCE

2.1 Experimental Equipment

For investigating the influence of wet compression on system performance, a R410A variable speed air conditioner with rotary compressor was selected. The system drop-in test of R32 for wet compression was tested under different conditions (Table 1). The experiment was tested according to air enthalpy test method in ISO 5151.
The experiment system concludes two parts, air enthalpy test system and the air conditioner tested. The air enthalpy test system was built according to ISO 5151. The air conditioner tested and the compressor frequency were shown in Figure 1. In Figure 1, the pressure was measured by the pressure sensor, the temperature was measured by T-type thermocouple, and the system refrigerant mass flow was measured by mass flow meter. The suction vapor quality was controlled by controlling the refrigerant mass flow in the evaporator. The power of compressor was the difference of the power of air conditioner with and without the compressor worked.

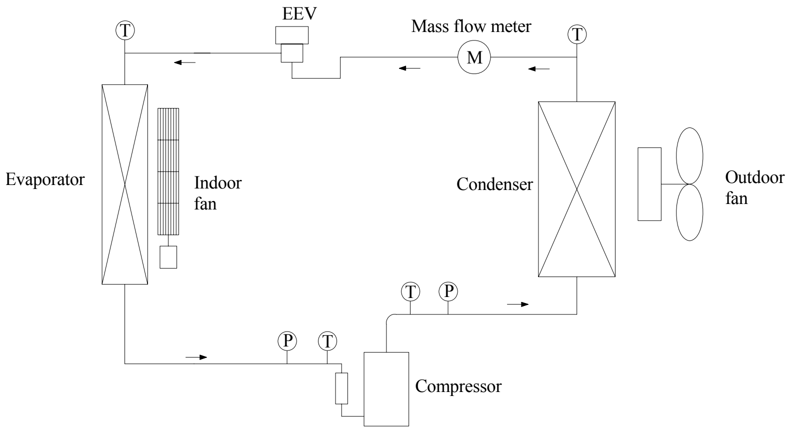


Figure 1: Air conditioner tested
P was pressure measured point，T was temperature measured point

From the heat equilibrium of refrigerant and air in evaporator, the specific enthalpy of refrigerant leaving evaporator can be calculated from the follow equation.

$$Q_c = M \times (h_{out} - h_{eev}) \tag{1}$$

$$x = (h - h_f)/(h_g - h_f) \tag{2}$$

Table 1: Test conditions

Indoor dry bulb temperature, ℃	27
Indoor wet bulb temperature, ℃	19
Outdoor dry bulb temperature , ℃	38/42/45
Outdoor wet bulb temperature , ℃	25/26/28
Compressor frequency, Hz	80/68/67

From equation (1), the specific enthalpy of refrigerant leaving evaporator h_{out} was calculated, and then the suction specific enthalpy of refrigerant entering compressor was equal to h_{out} (the heat leaking was neglected), so the suction vapor quality of compressor can be calculated from equation (2). The error of the suction vapor quality calculating by the method before was less than 3%.

2.2 Result and Discussion

The curves that cooling capacity, the EER, and the power of conditioner changed with the suction vapor quality under different outdoor temperature were shown in Figure 2, Figure 3 and Figure 4. In these Figures, the values of the cooling capacity, the EER and the power of conditioner were relative to the fiducially value when the suction vapor quality of compressor was bigger than 1 and the superheat temperature at the outlet of evaporator was within 2℃. Figure 2 to Figure 4 showed that, the cooling capacity, the EER and the power of conditioner decreased with the decrease of the suction vapor quality under the test conditions and the suction vapor quality was between 0.93 and 1.01. But the decrease rate was different for different outdoor temperature. For example, when the outdoor temperature was 42℃, the cooling capacity decreased 2.2%, the power of conditioner decreased 0.6% and the EER decreased 1.9% when the suction vapor quality decreased from 1.01 to 0.96. The cooling capacity decreased 4.2%, the power of conditioner decreased 0.9%, and the EER decreased 3.3% when the suction vapor quality decreased from 1.01 to 0.935. It could see from the curves that the decrease rate of the conditioner power was lower than that of the cooling capacity, so the EER decreased markedly.

The curve that discharge temperature changed with the suction vapor quality was shown in Figure 5. With the decrease of the suction vapor quality, the discharge temperature decreased markedly. For example, when the outdoor temperature was 45℃, the discharge temperature was 105.6℃ when the suction vapor quality was 1.01 and the discharge temperature decreased to 96.9℃, 91.8℃ and 88.4℃respectively when the suction vapor quality decreased to 0.97, 0.95 and 0.94.

The curves that specific enthalpy difference of the inlet and outlet of evaporator, the specific power of compressor and the refrigerant mass flow rate changed with the suction vapor quality under different outdoor temperature(the Tout meant the outdoor dry bulb temperature) were showed from Figure 6 to Figure 8. Figure 6 and Figure 8 showed that, the specific enthalpy difference of the inlet and outlet of evaporator decreased and the refrigerant mass flow rate increased when the suction vapor quality decreased. The cooling capacity decreased rapidly because it was affected more by the specific enthalpy difference of the inlet and outlet of evaporator. But the specific power of compressor decreased when the suction vapor quality decreased (showed in Figure 7). The power of compressor decreased slowly with the decrease of the suction vapor quality because it was affected more by the specific power of compressor. Because the power of conditioner was affected mainly by the power of compressor, so the power of conditioner decreased slowly with the decrease of the suction vapor quality. Thus, the cooling capacity decreased rapidly and the power of conditioner decreased slowly when the suction vapor quality decreased, so the EER decreased.

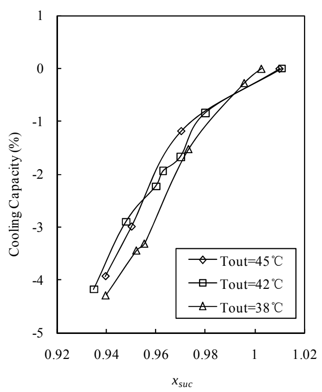


Figure 2: The cooling capacity changed with the suction vapor quality

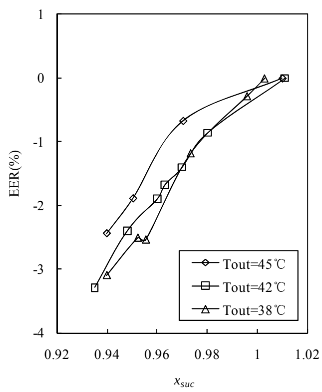


Figure 3: The EER changed with the suction vapor quality

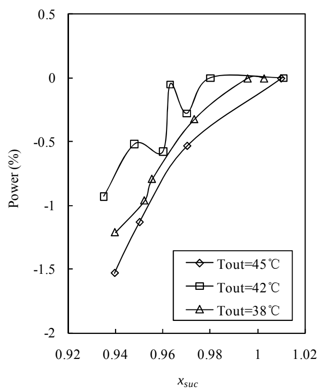


Figure 4: The power of conditioner changed with the suction vapor quality

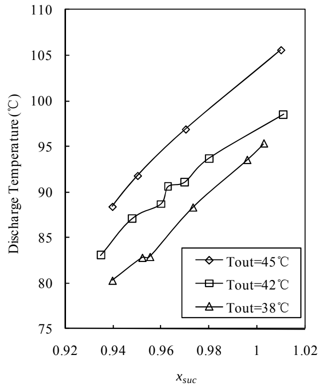


Figure 5: The discharge temperature changed with the suction vapor quality

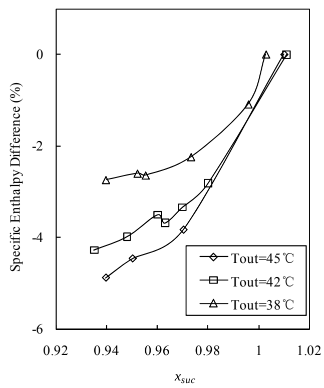


Figure 6: The specific enthalpy difference changed with the suction vapor quality

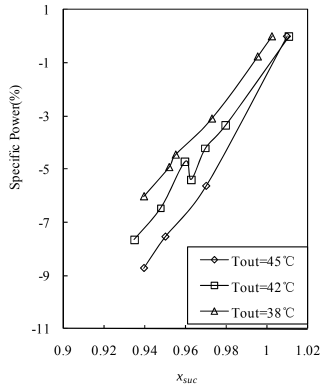


Figure 7: The specific power changed with the suction vapor quality

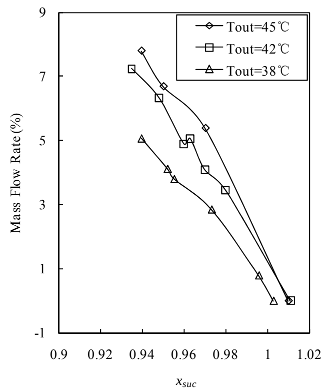


Figure 8: The Refrigerant mass flow rate changed with the suction vapor quality

3. OIL RETURN HOLE AND ITS INFLUENCE ON SYSTEM PERFORMANCE

It could see from the data analysis of the wet compression experiment that the cooling capacity and the EER decreased with the decrease of the suction vapor quality for rotary compressor. Because the liquid refrigerant entering into the separator of rotary compressor must pass the oil return hole in the separator and then come into the cylinder, so the size of the oil return hole would affect the effect of wet compression. Therefore, the oil return hole experiment was carried out.

3.1 Experimental Equipment

Because the wet compression occurs under high environment temperature and high compressor speed, so the oil return hole experiment was tested under the condition of 48℃(dry bulb temperature) and 30℃ (wet bulb temperature) for outdoor, and the indoor condition is 27℃(dry bulb temperature) and 19℃ (wet bulb temperature).
The oil return hole in the gas-liquid separator was shown in Figure 9 and the size was listed in Table 2. In Table 2, 1.2mm was the original size of the oil return hole, and other three sizes were bigger than the original size for analyzing its effect on wet compression and system performance. For avoiding the adverse factors, four separators with different size of oil return hole were parallel connected by pipe and on-off valve (Figure 10).

Table 2: Size of oil return hole

	Separator 1	Separator 2	Separator 3	Separator 4
Size of suction pipe, mm	14	14	14	14
Size of oil return hole, mm	1.2	2	3	4
Number of oil return hole	2	2	2	2

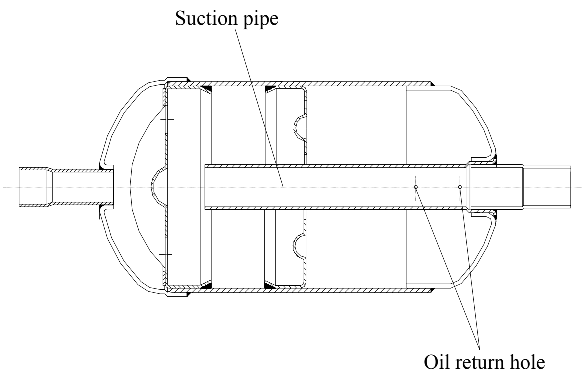


Figure 9: Gas-liquid separator and oil return hole

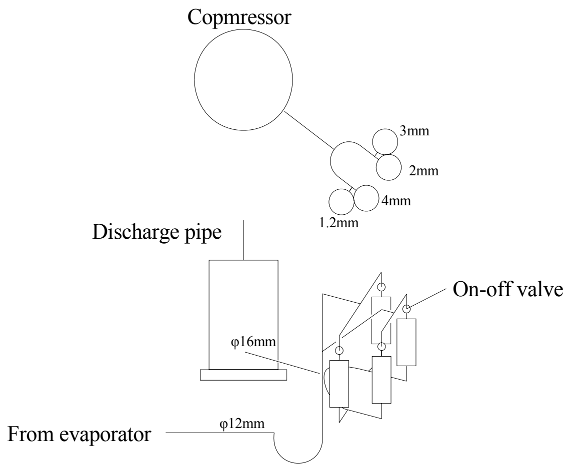


Figure 10: Four separators installation sketch map

3.2 Result and Discussion

The curves that the cooling capacity changed with the discharge temperature for different size of oil return hole when the outdoor temperature was 48℃ and the compressor frequency was 67Hz were shown in Figure 11. It could see from Figure 11 that, the cooling capacity decreased 52.3% with the discharge temperature decreased from 109.8℃ to 71.1℃ when the size of oil return hole was 1.2mm (i.e. φ=1.2mm), and the cooling capacity decreased 21.6% with the discharge temperature decreased from 110.6℃ to 75.1℃ when the size of oil return hole was 3mm (i.e. φ=3mm), and the cooling capacity decreased 16.2% with the discharge temperature decreased from 111.3℃ to 71.3℃ when the size of oil return hole was 4mm (i.e. φ=4mm). Therefore, the cooling capacity decreased slowly firstly and then quickly with the decrease of discharge temperature, and the decreased extent increased with the decrease of the size of oil return hole. For same decreased rate of cooling capacity, the discharge temperature increased with the decrease of the size of oil return hole. It was because that, the liquid refrigerant in the gas-liquid separator could return to the cylinder through the oil return hole to participate the system circulation when the oil return hole were bigger, but the smaller oil return hole limited the liquid refrigerant returning to the cylinder, so some liquid refrigerant accumulated in the gas-liquid separator. Thus, the cooling capacity decreased quickly.

It also showed in Figure 11 that, the decreased rate of cooling capacity increased when the discharge temperature was lower than 90℃ and the size of oil return hole was 1.2mm (i.e. φ=1.2mm). But the decreased rate of cooling capacity slower when the size of oil return hole increased to 3mm and 4mm. It was because that, with the decrease of discharge temperature, the suction vapor quality of compressor decreased rapidly, smaller size of oil return hole was not convenient for liquid refrigerant returning into the cylinder of compressor, so the decreased rate of the cooling capacity increased rapidly. It could see from the analysis above that, the influence of oil return hole on the cooling capacity changed with the decrease of discharge temperature decreased when the size of oil return hole was bigger to enough.

The curves that the EER changed with the discharge temperature or different size of oil return hole when the outdoor temperature was 48℃ and the compressor frequency was 67Hz were shown in Figure 12. In Figure 12, the changed trend of the EER was according with that of the cooling capacity.

The increase of oil return hole size surely affected the liquid refrigerant return to the compressor under frosting and defrosting. Then, the frosting and defrosting experiment were carried out under frosting condition (the outdoor dry temperature was 2℃, the outdoor bulb temperature was 1℃, and the indoor dry temperature was 20℃). The curves of power under frosting and defrosting for different size of oil return hole were shown in Figure 13. It could see from the Figure 13 that, the undulation of power under latter frosting became larger with the increase of the size of oil return hole. And this meant that the liquid refrigerant returning into the cylinder of compressor increased with the increase of the size of oil return hole. When the compressor restarted after defrosting, the curve of power was smooth when the size of oil return hole was 1.2mm. But the curve of power appeared extremum and jumped during little time when the size of oil return hole increased to 3mm and 4mm, and this meant a great lot refrigerant liquid returning into the cylinder of compressor instantaneously. Thus, the increase of oil return hole size increased the risk of over wet compression or liquid impact for compressor under frosting and defrosting condition.

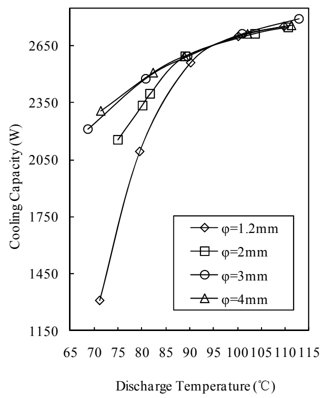


Figure 11: The cooling capacity changed according to discharge temperature

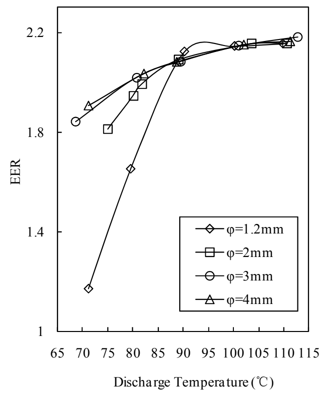
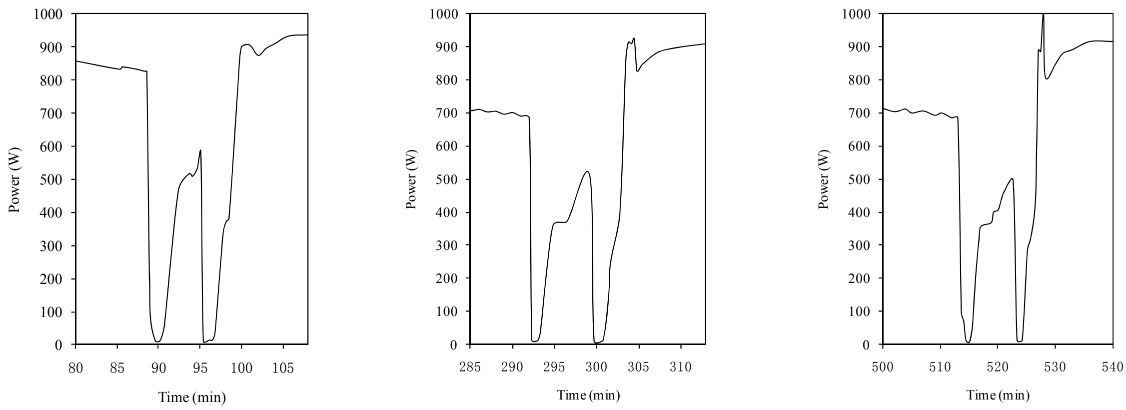


Figure 12: The EER changed according to discharge temperature



(a) φ=1.2mm (b) φ=3mm (c) φ=4mm

Figure 13: The curves of power under frosting and defrosting

4. CONCLUSIONS AND DISCUSSIONS

In this study, the influence of wet compression and oil return hole on R32 system performance was researched by experimental test. The analysis shows that, with the decrease of the suction vapor quality, the discharge temperature and the system performance decreased simultaneously.

The increase of oil return hole was convenient for liquid refrigerant returning into the cylinder of compressor. So, with the increase of oil return hole, the cooling capacity decreased slower with the decrease of discharge temperature. This could larger the discharge temperature adjusting zone for rotary compressor under high temperature cooling condition, and decrease the decreased rate of the air condition performance, and increase the reliability of compressor. But, the risk of over wet compression or liquid impact for rotary compressor under frosting and defrosting condition increased and the reliability decreased when the size of oil return hole increased. This means that, the size of oil return hole should be chose after lots of experiments, including the performance experiments and reliability experiments.

NOMENCLATURE

h	specific enthalpy	(kJ/kg)
M	refrigerant mass flow	(kg/h)
Q	capacity	(W)
x	suction vapor quality	(–)

Subscript

eev	entering the EEV
f	saturation liquid
g	saturation gas
out	leaving the evaporator

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