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Donglim Nam
Doowon Heavy Industrial, Korea, Republic of (South Korea), dlnam@doowonhi.com

Poyoung Lee
Doowon Heavy Industrial, Korea, Republic of (South Korea), niceguy40@doowonhi.com

Geonho Lee
Doowon Technical University College, Republic of (South Korea), ghlee@doowon.ac.kr

Yunki Kwon
Doowon Technical University College, Republic of (South Korea), ykkwon@doowon.ac.kr

Jinho Lee
Yonsei University, Republic of (South Korea), jinholee@yonsei.ac.kr

Experimental Study about an Amount of Oil Charge on Electric Driven Scroll Compressor for Electric Vehicle

Donglim NAM[1], Poyoung LEE[1] , Geonho LEE[2], Yunki KWON[3], Jinho LEE[4]

[1] R&D Center of Doowon Heavy Industrial Co., Ltd.,
Ansung city, Republic of KOREA (+823180567324, +823180567352,dlnam@doowonhi.com)
[2] Department of Building Engineering Services, Doowon Technical University College,
Ansung city, Republic of KOREA
[3] Department of Computer Aided Design, Doowon Technical University College,
Ansung city, Republic of KOREA
[4] Department of Mechanical Engineering, Yonsei University,
Seoul city, Republic of KOREA

ABSTRACT

The main roles of the oil in scroll compressor are to lubricate the friction parts, and to reduce the compressor driving power and to improve the durability of the compressor consequently. However, it has another side that could make decrease the efficiency of the heat exchanger and whole air-conditioning system. In the case of compressor, if the oil is charged too much, the compressor driving power will be increased and the compressor overall efficiency will be decreased. Therefore, the initial charge amount of the oil in the compressor should be determined appropriately.

This study has performed to optimize the initial charge amount of the oil on the electric driven scroll compressor for eco-friendly vehicles. We have used an electric driven scroll compressor has a back pressure chamber which make up of oil. About the various initial charge amount of the oil, the remaining oil was evaluated at each of steps of the complex durability test and each of conditions of performance test. The various initial charge amount of the oil had increased 20g intervals from 40g to 120g. Through the evaluation, the optimum amount of the Oil is determined by the back pressure. So we have found the optimum amount of Oil. Also the performance of a system is compared through pull-down test in the actual air conditioning system. We could get the optimal amount of oil which has the best performance in air conditioning system.

1. INTRODUCTION

Since its introduction in 1983, the demand and application range of scroll compressor has been increased due to its high efficiency and reduced noise compared to the other type of compressors. In particular, in response to global environmental problems, the research and development has been focusing on hybrid and electric vehicle along with advanced air conditioner systems. Unlike the conventional gasoline engine, on a hybrid electric vehicle, air conditioning system equipped with the electric compressor is mounted.

The scroll compressor should be designed to circulate the appropriate amount of oil for moving parts to reduce friction. The oil in the compressor prevents the abrasion between parts and the leakage of the refrigerant from the scroll compressor. In case of the back pressure type scroll compressor, the oil in the compressor is especially important both for performance and reliability perspectives as hermetic sealing around the axial leakage gap is controlled by the back pressure power of the orbiting scroll bottom. However compressor oil is discharged to the system when the refrigerant gas is compressed and released out to the system along with the discharge gas. Once oil from the compressor flows into the evaporator of the system, the heat transfer coefficient of the heat exchanger decreases and the overall performance of the refrigeration system gets lowered. The initial amount of oil in the compressor affects the oil circulation rate in the A/C system and system performance. Therefore the appropriate amount should be determined for the best performance and durability of both system and the air conditioning system.

Extensive research has been carried out on the lubrication system and oil for a hermetic compressor in an air conditioning system. Drost et al.(1992) performed a numerical experimental study of the scroll compressor lubricating system, and Shin et al.(1998) numerically analyzed the oil supply system of the scroll compressor. For scroll compressors, computational fluid dynamics (CFD) simulation of an oil-pumping system was performed by Bernardi (2000). With regard to electrically driven scroll compressors for vehicles, Cuevas et al. (2012) evaluated the efficiency of the DC/AC converter and compressor according to driving conditions.

This research investigated the A/C system of real vehicles in order to determine the appropriate amount of oil in the electrically driven scroll compressor for environmentally friendly hybrid or electric vehicles. For the experiment, the temperature cross-over method was used to determine the amount of refrigerant charge level for the system. The oil amount was evaluated on 20g intervals from 120g to 40g. The experiment measured the amount of residual oil in the compressor after the test by a complex endurance step in the real vehicle's A/C system. This amount was measured at 3,000rpm and 8,600rpm after stabilizing in a basic condition and a high-pressure condition. The back pressure of the orbiting scroll lower part was measured, and the stabilization range of the compressor motion and the unstable range were evaluated. In addition, a pull-down test of the air conditioner system was undertaken. The experiment measured the difference of the vent temperature for each amount of oil. The results of these tests were integrated and the minimum amount of oil was determined. In addition, the method of determining the proper amount of oil is explained. A complex endurance test of the compressor while charging the appropriate amount of oil was carried out, and the durability was evaluated.

2. EXPERIMENTAL FACILITY AND METHODS

2.1 Electric driven scroll compressor

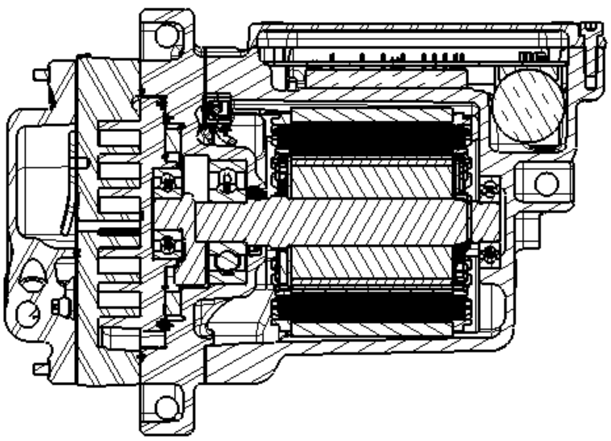

Figure 1 : Section view of electrically driven scroll compressor

Figure 1 shows the electrically driven scroll compressor that is used in this research. The compressor is composed of the scroll type compression part, the motor, and the inverter. The scroll compressor has an axial and radial leakage gap, and many approaches were taken to minimize this gap. The compressor in this research applied the oil back pressure to minimize the axial gap. Using the oil separator, the gas and oil exerted from the compression part is separated. Then the high-pressure oil is sent to the orbiting scroll lower part, and the orbiting scroll adheres closely to the fixed scroll. This method can minimize the axial gap. In addition, it lubricates the bearings in the back pressure chamber and improves the compressor durability. This experiment used R134a as the refrigerant in the vehicle and POE oil as the compressor oil.

2.2 Test equipment

Figure 2 displays the schematic diagram of the bench system of the vehicle air conditioning system for this experiment. As described above, the electrically driven scroll compressor is used, which includes an AC/DC converter to operate the compressor. As test equipment, sensors are installed to measure the pressure of back-pressure chamber, the suction/discharge refrigerant pressure, and the temperature of the compressor. The condenser and evaporator of the actual vehicle were also used, and an electric expansion valve(EEV) was used. In addition, a sensor to measure the refrigerant temperature was installed on the front side of the expansion valve. The temperature measurement module was mounted in order to measure the refrigerant temperature of the evaporator's front and back.

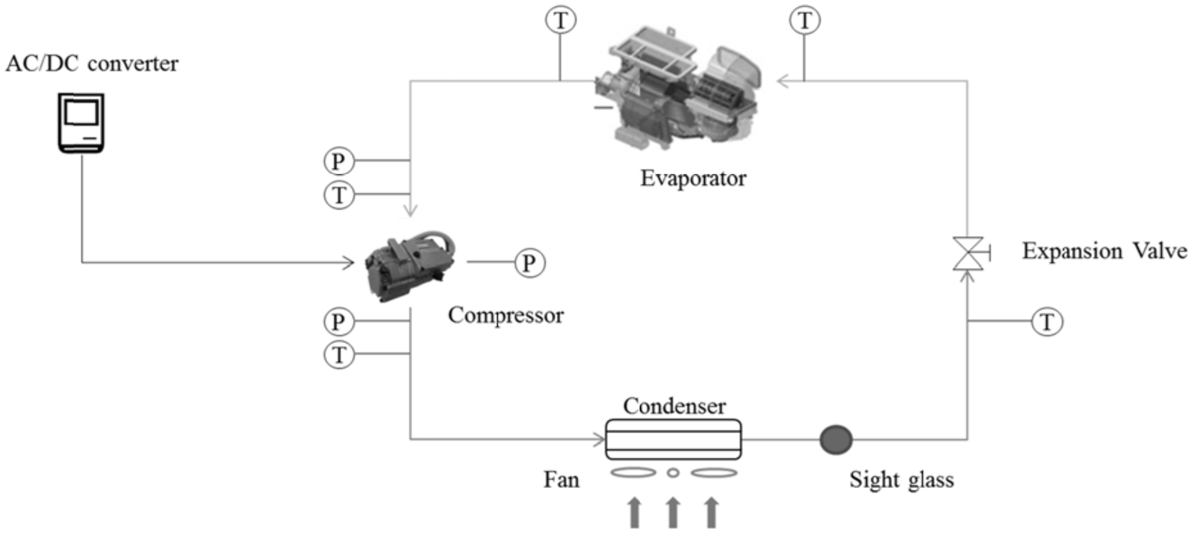

Figure 2 : Schematic diagram of the bench system

2.3 Test procedure

2.3.1 System refrigerant charge test

Tests to determine the correct amount of the refrigerant charge on the test equipment were carried out. For this purpose, the temperature-cross-over method proposed by Wandell al.(1997) in ACRC TR-128 was used. This method adds 10% to the refrigerant amount and then measures the refrigerant temperature of the evaporator inlet and outlet where they intersect. For the test condition, the fan speed of the condenser and evaporator was set to keep the performance test within a temperature range of 40~43°C and humidity within 17~21%. In addition, the EEV opening degree was fixed at that time. The refrigerant temperatures on the front and back of the evaporator were measured at 25g intervals, starting with 300g of refrigerant with fixed boundary conditions.

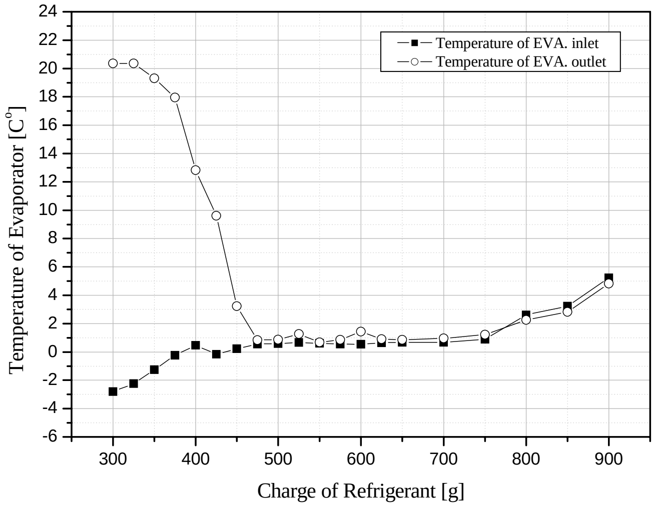

Figure 3 : Temperature of evaporator

As shown in graph 1, the refrigerant temperatures of the evaporator front and back intersect at the refrigerant amount of 475g. In addition, the refrigerant was confirmed to be at liquid status in the sight glass in the condenser backend. Therefore, the refrigerant charge resulted in 522.5g, a 10% increase over the amount of 475g. Finally, the amount of refrigerant was determined to be 525g for the optimum experiment.

2.3.2 Experimental conditions

The complex endurance test is a four-Step test to check the durability of the representative compressor conditions occurring in a vehicle. In this research, the amount of residual oil within the compressor was measured after the four step procedures of the endurance test according to the initial amount of oil in the compressor. The test was carried out with an initial amount of 120g to 40g of oil in the compressor. The steps of the complex endurance test are summarized in Table 1.

Step	Time [h]	Compressor speed [rpm]	Pd [kPa]	Ps [kPa]	Super Heat [°C]	Boundary Temperature [°C]
1	100	0-7000-0	2400±98	200±19.6	10±0.5	100±5
2	150	1500-7000-1500	2000±98	200±19.6	10±0.5	100±5
3	250	7000	1400±98	200±19.6	10±0.5	100±5
4	200	4000	1400±98	300±19.6	10±0.5	100±5

Table 1 : Complex endurance test conditions

The performance test evaluates compressor efficiency in representative conditions. In this research, after confirming the stability of the A/C system, the amount of residual oil within the compressor was measured at the performance test condition and the maximum compressor speed. The performance test conditions are shown in below Table 2.

No	Compressor speed [rpm]	Pd [kPa]	Ps [kPa]	Super Heat [°C]
1	3000	1400±98	200±9.8	10±0.5
2	3000	2400±98	200±9.8	10±0.5
3	8600	1500±98	200±9.8	10±0.5
4	8600	2500±98	200±9.8	10±0.5

Table 2 : Performance test conditions

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 The amount of residual oil in each condition

After system stabilization, the amount of residual oil within the compressor is measured at four different conditions for the aspect of durability and the performance, as shown in graph 2.

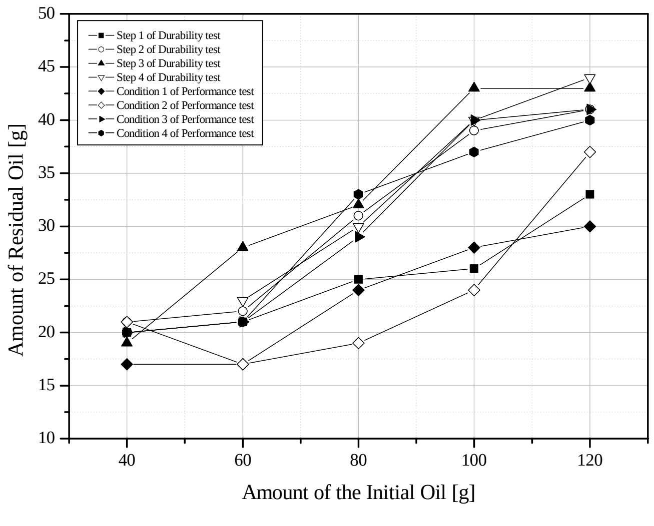

Figure 4 : Amount of residual oil

As shown in graph 2, the amount of residual oil is proportional to the amount of initial oil according to the durability and performance test condition. Therefore, the amount of initial oil cannot be determined by the residual measurement. However, the back pressure of the compressor is the important factor in determining the amount of oil. The back pressure variation at different amount of initial oil is summarized in graph 3. In all conditions, back pressure is maintained in constant level for the oil amounts of 120g, 100g, and 80g. However, in the case of 60g, 40g, the back pressure power was confirmed to be decreased.

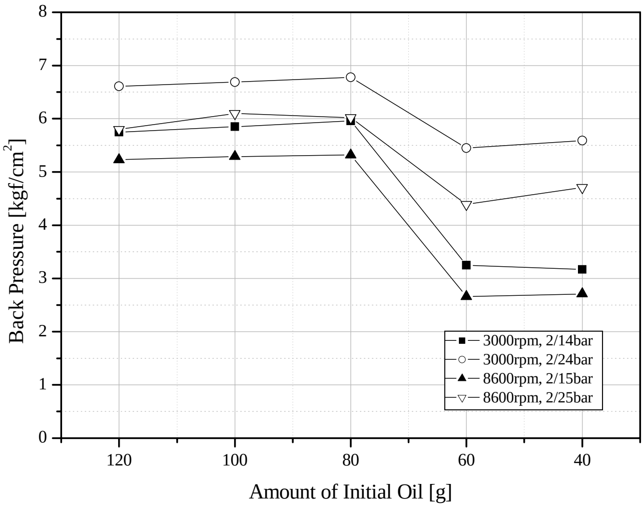

Figure 5 : Back pressure according to the amount of initial oil

The compressor used for the test has an oil back pressure structure, and by changing the suction/discharge pressure, the back pressure the control valve in the back pressure chamber was set so as to maintain the appropriate back pressure. Using the force of the spring when the back pressure was appropriate or greater, the valve for regulating the back pressure was opened to allow the oil of the back pressure chamber to pass, the oil was ejected, thus maintaining the back pressure chamber pressure. The initial amount of enclosed oil can be derived from the results; an amount of more than 80g is needed. With 80g or less, maintenance of the back pressure is impossible and the compressor efficiency and durability cannot be guaranteed. Of course, ensuring durability at 80g is critical factor.

3.2 A/C System pull-down test

For system evaluation, the pull-down test was conducted in two rooms while maintaining the temperature and humidity constant in order to provide equal real vehicle conditions. The below diagram displays the room and system configuration carried out for the evaluation.

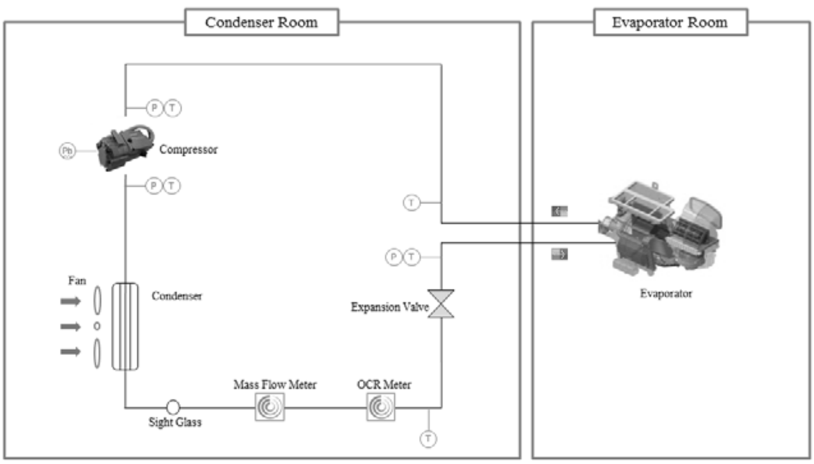

Figure 6 : Schematic diagram of system bench

Table 3 presents the temperature/humidity of the condenser room and the evaporator room in the pull-down evaluation conditions. At these conditions, the vent outlet air temperature of the evaporator was measured.

Pd [kgf/cm2.G]	Cond. T [℃]	Eva. T/RH [℃], [%]	Fan output	Compressor Speed [rpm]
19	40	35, 30	Fixed	4500

Table 3 : Pull-down test conditions

The temperature difference per the amount of oil was compared after the outlet air temperature was stabilized.

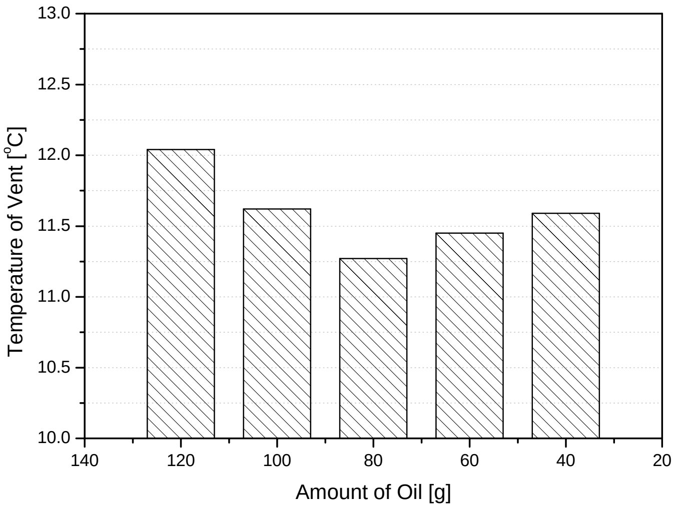

Figure 7 : Temperature of vent according to the amount of oil

The minimum value of the vent mean temperature was resulted at 11.27°C, which occurred at 80g of enclosed oil after system stabilization. This test indicates that the vent mean temperature decrease as the amount of oil is reduced from 120g to 80g, thus increasing the system performance. However, in case of 60g and 40g of oil, the system vent mean temperature is increased again. This is due to decreased back pressure of the compressed resulting from axial leakage of the compression part. This manifests as a reduction in the volumetric efficiency of the compressor. As a result, the whole A/C system performance degrades.

3.3 Results of endurance test at the titration amount of oil

The endurance test was performed with in initial amount of oil 80g based on the results of the back pressure test and the pull-down test. The endurance test was performed for 700h, following the four conditions in table 1. In addition, the endurance test with an oil amount of 120g was performed for comparison. The endurance tests with 80g and 120g of oil both completed 700h normally.

4. CONCLUSIONS

In this research, we devised a method of determining the appropriate amount of initial oil for the back pressure-type of electrically driven scroll compressor for eco-friendly vehicles. The following conclusions were obtained.

1) In order to determine the titration amount of oil, the amount of residual oil in the compressor by the complex endurance steps and performance condition was measured. But it was impossible to determine the titration amount of oil.
2) Throughout the tests, we closely monitored the change of the back pressure according to the oil amount. The smallest oil amount for the compressor was selected.
3) Through the system pull-down tests, we confirmed the maximum A/C system performance at the titration amount of oil. The vent outlet air temperature decreased about 6.4 percent at the titration oil amount of 80g.
4) The endurance test was performed with the smallest amount of oil and the durability was verified.
5) The initial oil amount of the back pressure type of electrically driven scroll compressor for eco-friendly vehicles was determined. But additional experiments are needed to consider various actual vehicle environments.

REFERENCES

R.T. Drost, J.F.Quesada, 1992, Analytical and Experimental Investigation of a Scroll Compressor Lubrication System, *1992 International Compressor Engineering Conference at Purdue*, p. 551~560.
C.J.Shin, J.S.Park, Y.I.chang, 1998, An Analytical Study of the Oil Supply System in Scroll Compressors, *1998 International Compressor Engineering Conference at Purdue*, p. 307~312.
J.de Bernardi, 2000, CFD Simulation of a Scroll Compressor Pumping System, *2000 International Compressor Engineering Conference at Purdue*, p. 707~714.
Cristian Cuevas, Nestor Fonseca, Vincent Lemort, 2012, Automotive electric scroll compressor: Testing and modeling, *International Journal of Refrigeration*, Vol. 35, p. 841~849.
E. W. Wandell, W. E. Dunn, and N. R. Miller, 1997, Experimental Investigation of Mobile Air Conditioning System Control for Improved Compressor Reliability, *ACRC TR-128*.