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HIGH PERFORMANCE SCROLL COMPRESSOR WITH LIQUID REFRIGERANT INJECTION

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ABSTRACT

Improvement of compressor efficiency using the alternative refrigerant is demanded strongly to reduce CO_2 emission, which causes the global warming. Especially the compressor using in frozen temperature level has long lifetime, and the correspondence to above-mentioned is one of the most important subjects. The scroll compressor is the promising structure to solve this problem. A technical point is the controlling mechanism of the discharge gas temperature. In HCFC-22 scroll compressor, the injection system of the liquid refrigerant to the compression chambers is put in practical use. The numerical calculation program for the performance simulation using the alternative refrigerant was created to develop the new scroll compressor with the liquid injection system. By using this simulation, the development period can be shortened in the conventional half.

NOMENCLATURE

C_p: Isobaric specific heat	(J/kg/K)	h: Specific enthalpy	(J/kg)
G: Mass flow rate	(kg/s)	T: Temperature	(K)
H: Latent heat	(J/kg)	m: Mass	(kg)
V: Volume	(m^3)	v: Specific volume	(m^3/kg)
Q: Heat	(W)	E: Energy	(W)

INTRODUCTION

Recently the protection of environment from the ozone layer destruction by emitting HCFC and the global warming by emitting CO_2 has been promoted in the world. The new compressors operated with the alternative refrigeration HFC have been developed by manufacturers. The improvement of their efficiency is required strongly to save the power and to reduce CO_2 emission. In this respect, the choice of the compressor type is very important and the most promising is a scroll-type compressor. It offers the higher level of efficiency and reliability. Compared to other type compressors, scroll compressors have lower vibration and noise level. Therefore, they have been applied widely to air conditioning and refrigeration. They are also used in the more demanding applications such as refrigeration and high discharge heating conditions. Moreover, the compressor using in frozen temperature level has long lifetime, and developing the scroll compressor for low temperature can contribute to the solutions of the above-mentioned problems. Its technical point is the controlling the discharge gas temperature. The discharge gas temperature at the high compression ratio is much higher than that at the normal one without controlling the temperature. This can cause the chemical degradation of the oil and refrigerant and the thermally induced mechanical failure. In HCFC-22 scroll compressor, the injection system of the liquid refrigerant to the compression chambers is put in practical use. So, the system was also applied to the development of the new scroll compressor for low temperature using the alternative refrigerant.

The experimental works have been carried out to improve the reliability of the compressor by lowering the discharge temperature with the liquid refrigerant injection. Hirano et al. [1] investigated the characteristics of the scroll compressor under liquid refrigerant injection to the compression chamber and under liquid bypass to the suction line. Dutta et al. [2] investigated the influence of liquid refrigerant injection on the performance of a scroll compressor.

The numerical calculation program of the performance simulation for the scroll compressor corresponding to the injection system using the alternative refrigerant was created to develop the new scroll compressor. By using the simulation, the development period of the new scroll compressor for low temperature can be shortened in the conventional half. This paper shows the analysis model of the liquid injection. The efficiency characteristics of the scroll compressor and the experimental verification are also described.

STRUCTURE OF THE SCROLL COMPRESSOR FOR LOW TEMPERATURE

The newly developed scroll compressors for low temperature are used in the refrigeration unit for cargo container shown in figure 1. Described previously, scroll compressors have the advantages in efficiency and vibration, and that is why they are often adapted. The detail of the their characteristics are as follows.

The scroll compressor has less dead volume than the other type. When driven at the higher compression ratio than the geometrically designed one, the compression power increases due to the re-compression work. The scroll compressor with less dead volume has the advantage in decreasing the re-compression loss. Because the scroll compressor does not need a suction valve, the loss in the suction process is small. In the scroll compressor, the compression process is much smoother and the several pairs of compression chambers are formed simultaneously. Therefore, the fluctuation of the torque in the scroll compressor is smaller than that in the other types, which leads to low vibration and low noise level.

Figure 2 shows the cross-sectional view of the scroll compressor. The liquid refrigerant injection was applied in order to cope with the operation at the low temperature, which cause the excessively high discharge gas temperature without the control. Figure 3 shows the refrigeration cycle with liquid refrigerant injection. The normal refrigeration cycle is 1-2-3-4-5-1 and the ideal refrigeration cycle with liquid refrigerant injection is 1-2-2’-3’-4-5-1 in figure 3. Liquid refrigerant is obtained from the point 6 and is injected to the compression chambers at the point 2 during the compression process. After mixing, the temperature in the compression chambers gets lower and the state becomes the point 2’. Therefore, the end of the compression process moves from the point 3 to the point 3’. This is the ideal case in which all amount of the liquid refrigerant is injected to the compression chambers instantly. The amount of the liquid injection varies due to the difference of the pressure between the compression chamber and injected liquid and then the pressure changed smoothly after liquid injection.

ANALYSIS MODEL OF THE LIQUID INJECTION

Experimental and theoretical works have been carried out on the liquid refrigerant injection. Yanagisawa et al investigated the performance of a scroll compressor under liquid refrigerant injection [2,3]. Figure 4 (a) shows their analysis model. The amount of the vaporization was determined by considering the heat transfer from the high temperature gas to the liquid refrigerant injected into the compression chamber. The evaporation time was considered and the amount of the vaporization was obtained by solving the energy equations for both the vapor and the liquid refrigerant in each time step. Hirano et al. [1] also investigated the operating characteristics of the scroll compressor with liquid refrigerant injection experimentally and theoretically.

In their evaporation model, the heat transfer was dealt with around the surface of the liquid refrigerant drop and the evaporation time was considered. In this paper, the prediction of the compressor performance and the discharge gas temperature has been carried out by using the easier analysis model in order to shorten the calculation time. The applied analysis model is shown in figure 4 (b). In the model, the liquid refrigerant is assumed to evaporate immediately after injection. In the analysis, the heat transfer coefficient, which is difficult to be obtained from the fundamental experiments, is not needed. The energy of the liquid and vapor refrigerant is changed to the energy of the cooled vapor refrigerant and the vapor refrigerant obtained by the evaporation of the liquid refrigerant. The energy equation can be obtained as follows.

$$C_{pl} G_{inj} T_{inj} + C_{pg} G_{gas} T_{gas} = C_{pg} (G_{inj} + G_{gas}) T + G_{inj} H \qquad (1)$$

where the subscripts in the equation are;

l: liquid phase $\qquad$ g: gas phase inj: liquid refrigerant *gas*: gas refrigerant

By using specific enthalpy, the following can be obtained.

$$T = \frac{(2h_{il} - h_{ig})G_{inj} + h_g G_{gas}}{C_p (G_{inj} + G_{gas})} \qquad (2)$$

where,

h_{il}: Specific enthalpy at the saturated liquid state

h_{ig}: Specific enthalpy at the saturated vapor state

h_g: Specific enthalpy of gas refrigerant in the compression chamber

The simulation with the calculation program was applied to the development of the scroll compressor using the alternative refrigerant. In this paper, the application to the new HFC-134a scroll, whose displacement V_{th} is 189cm^3/rev, is described. The operating condition is LRP condition, based on the NIST standard, and the rotational speed N_c is 60s^{-1}. Figure 5 shows the calculation and the experimental results of the discharge gas temperature versus the amount of the liquid injection. The amount of the injection is normalized and expressed by the ratio of the injection mass flow rate G_{inj} to the suction mass flow rate G_r. The effect of the liquid refrigerant injection on the decrease of discharge gas temperature is expressed by the difference of the temperature with injection T_d and that without injection T_{d0}. The results of the calculation agree very well with those of the experiments. Increasing the amount of the injection, it is sure that the discharge gas temperature is getting lower. From the results, the discharge gas temperature can be predicted accurately by using the simple model mentioned above. The accuracy was practically enough to apply to the development. Figure 6 shows the calculation and experimental results of the power consumption. The indicated power consumption W shown in figure 6 is normalized by the measured one without injection W_0. The accuracy of the calculation of the power consumption is within approximately 3%. The power consumption is getting higher as increasing the amount of the injection. This is due to the excess power to compress injected refrigerant.

Figure 7 shows the comparison of the power consumption between the HCFC-22 and the HFC-134a scroll compressors. In figure 7, the displacement of the HCFC-22 scroll compressor is 69 and 92cm^3/rev, and that of the HFC-134a scroll compressor is 189cm^3/rev. The power of consumption of those is normalized by the adiabatic power. The hermetic motor loss is not indicated in order to clarify the characteristics of the compressor easily in figure 7. The sum of the leakage, the heat, and the re-compression loss of 92cm^3/rev compressor is smaller than that of 69cm^3/rev one. Increasing the displacement, the leakage decreases because the leakage area is decrease relatively. Compared 189cm^3/rev compressor with 92cm^3/rev one, the leakage of the 189cm^3/rev is larger than that of the 92cm^3/rev. This is because that the operating compression ratio of HCFC-134a compressor is higher than that of HCFC-22 one, and the re-compression loss of HCFC-134a is larger.

As the displacement increases, the mechanical loss decreases slightly. The values of the mechanical loss are similar even if the displacement increases and even using the different refrigerant. As for the discharge pressure loss, it is getting larger due to the enlarged refrigerant flow rate by increasing the displacement.

CONCLUSIONS

The calculation program was created to predict the scroll compressor performance and the discharge gas temperature for low temperature corresponding to the liquid injection system using the alternative refrigerant.

1) The simple analysis model, in which the liquid refrigerant is assumed to evaporate immediately after injection and to be mixed with the gas refrigerant, was applied. The results of the discharge gas temperature obtained with the calculation agree very well with those from the experiments. The accuracy of the power consumption is within approximately 3%. It is sure that the scroll compressor performance and the discharge gas temperature can be predicted accurately by using the simple model. As a result, by using this simulation, the development period of new compressor has been shortened in the conventional half.

2) The characteristic of the HFC-134a scroll compressor with liquid refrigerant injection mechanism is obtained by using the simulation program. Compared between the HCFC-22 and the HFC-134a scroll compressors, the sum of the leakage, the heat, and the re-compression loss of the HFC-134a compressor is larger, but the mechanical loss is smaller than HCFC-22 one.

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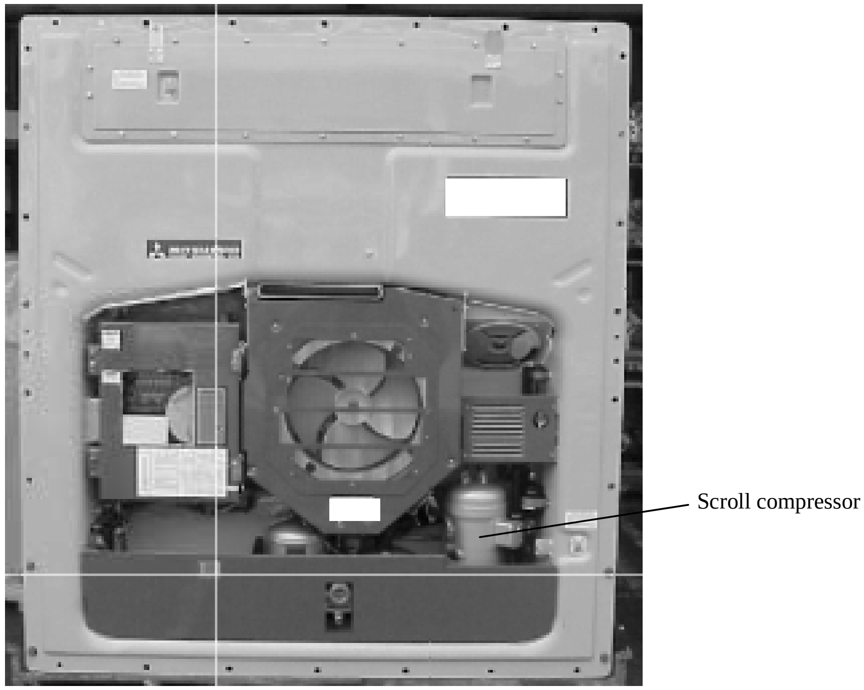


Figure 1 Refrigeration unit for cargo container with the scroll compressor for low temperature

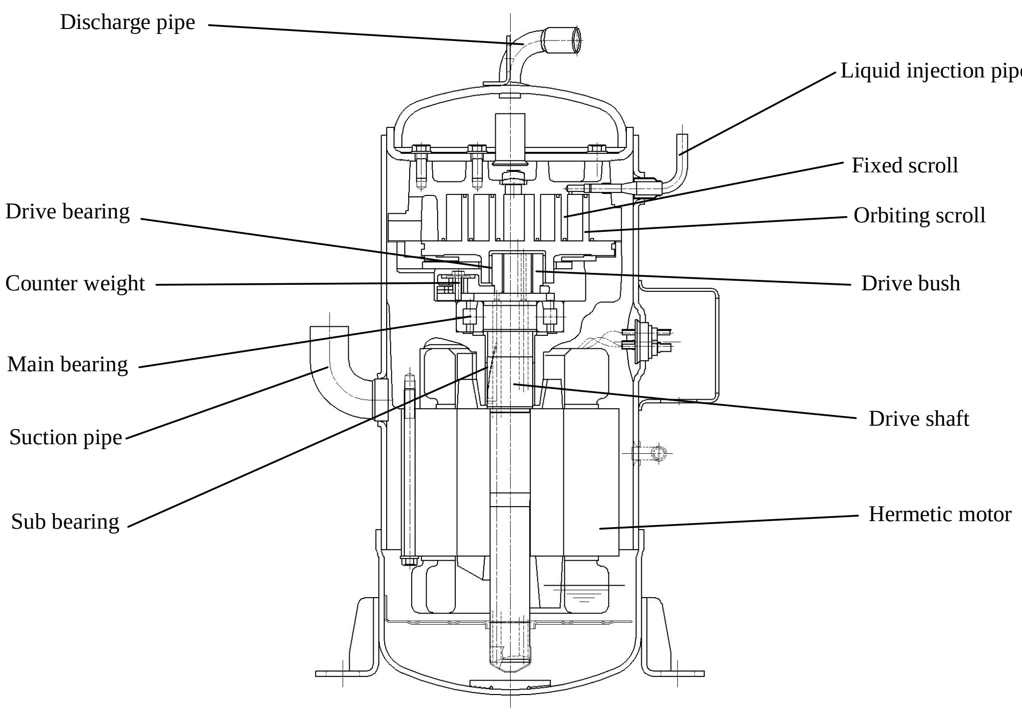


Figure 2 Scroll compressor for low temperature

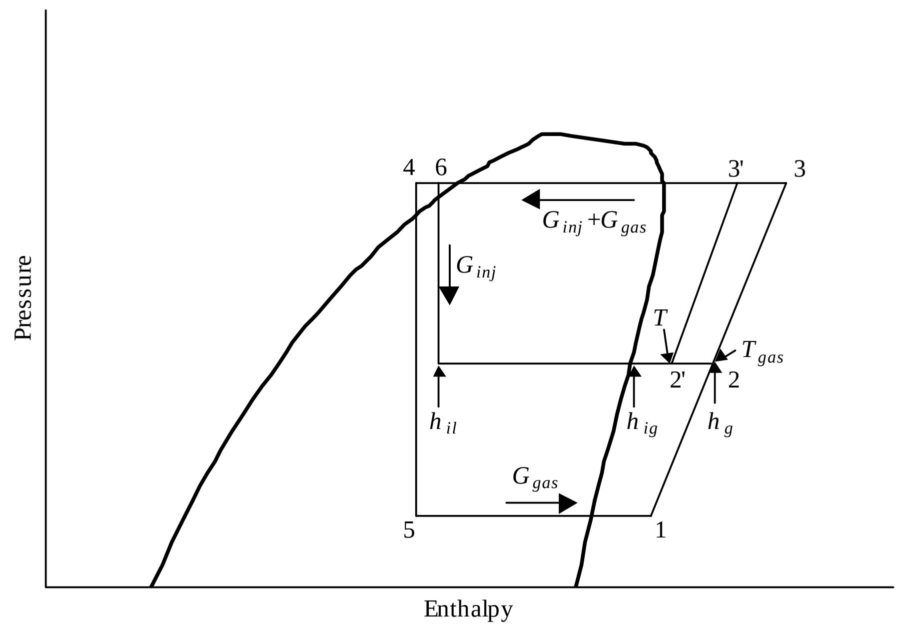
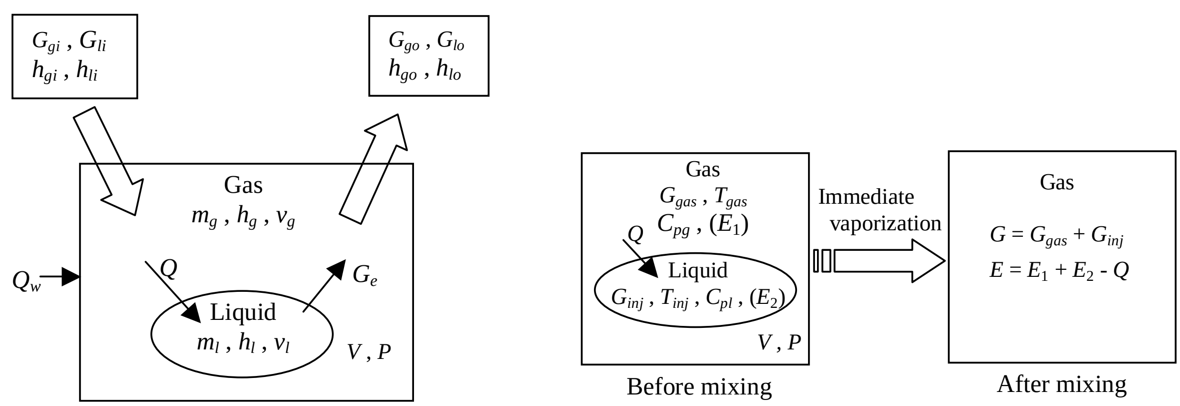


Figure 3　Refrigeration cycle with the mechanism of the liquid refrigerant injection



(a) Yanagisawa et al　　　　(b) Analysis model of this study

Figure 4　Analysis model of the liquid refrigerant injection

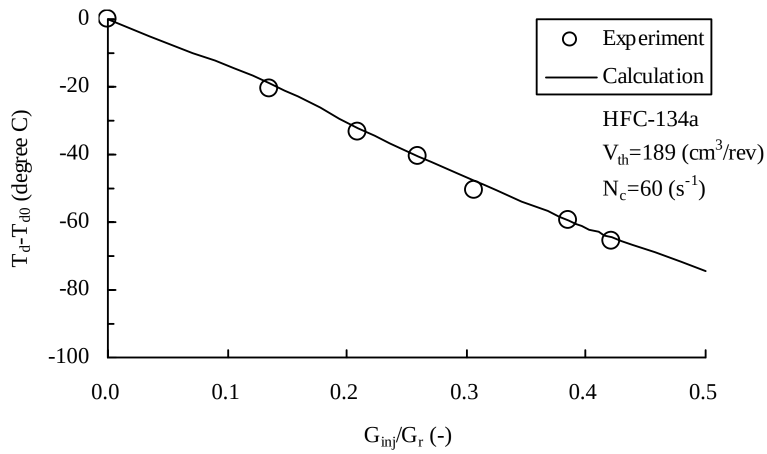


Figure 5 Discharge gas temperature decrease versus the amount of injection

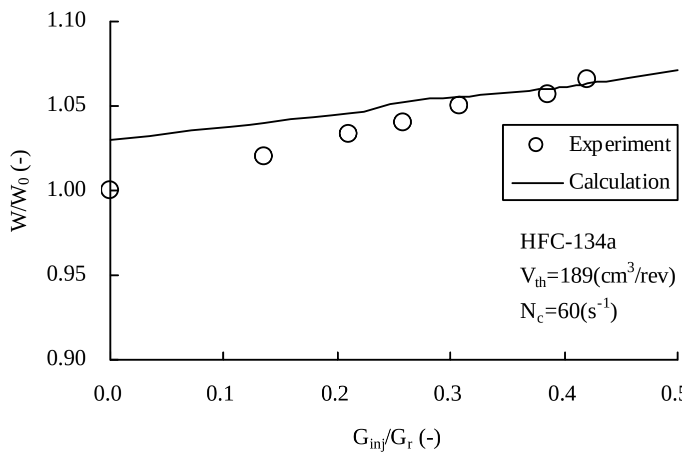


Figure 6 Power consumption ratio versus the amount of injection

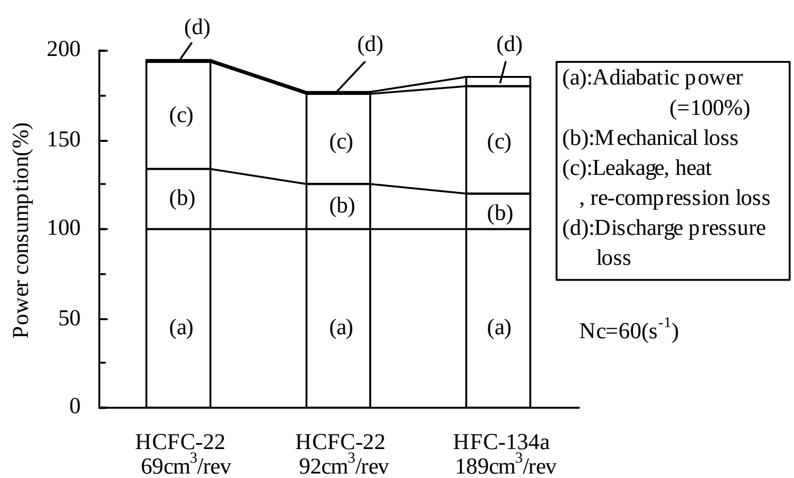


Figure 7 Comparison of the power consumption between the HCFC and the HFC scroll