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Performance Evaluation of Swing and Scroll Compressors Using Low GWP Refrigerant

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ABSTRACTS

In recent years, there has been much discussion on how to respond to climate change within an international framework. The "Kigali Accord" of the Montreal Protocol, for example, implements phase-down regulations for CFC and HCFC refrigerants from the perspective of global warming and greenhouse gas emission control. In particular, GWP regulations are being discussed in Europe ahead of other countries. For example, if GWP is regulated below 150, HFO refrigerants R1234yf and R454C are candidates as low-GWP refrigerants. HFO mixed refrigerant, which is a mixture of HFC and HFO, is also a candidate, and propane and CO2 are candidates as natural refrigerants. In this paper, we report the effect of R1234yf refrigerant on the performance of a swing and scroll compressor with R32 refrigerant. R1234yf refrigerant has the largest impact on compressor performance due to its low mass density.

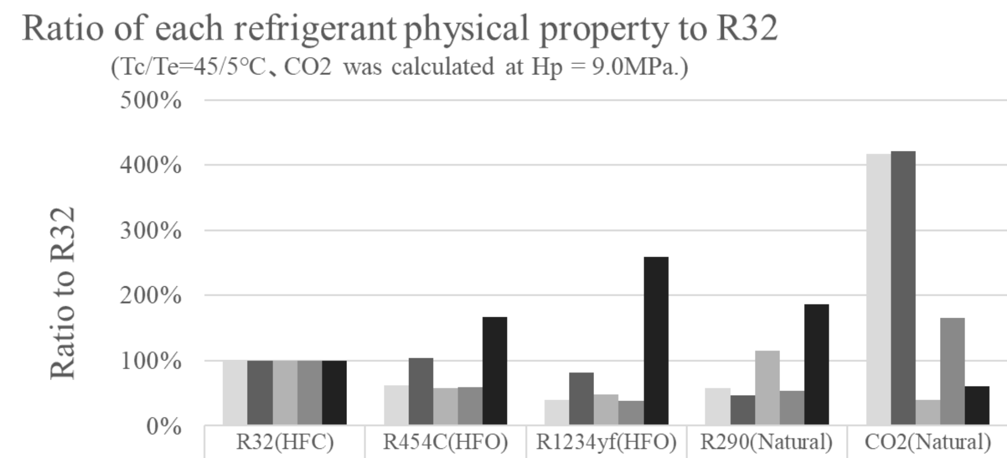
1. INTRODUCTION

The Kigali Agreement of the Montreal Protocol and other international frameworks have been discussing the measures to be taken regarding climate change. Within that framework, phase-down regulations for CFC and HCFC refrigerants have been implemented from the perspective of protecting the ozone layer. In addition, from the viewpoint of global warming prevention, HFC reduction plans are currently being proposed by Europe and North America in the framework of the Protocol. In addition, each region is also working on the revision of regulations related to HFCs.
If the regulations require a GWP of 150 or less, candidates for low-GWP refrigerants include R1234yf and R454C, which are HFO refrigerants; HFO mixed refrigerants, which are mixtures of HFC and HFO; and propane and CO2 as natural refrigerants. However, low-GWP refrigerants other than CO2 have lower pressures than R32. Therefore, they are expected to affect refrigeration capacity and compressor efficiency. In this paper, we evaluated the performance of swing and scroll compressors using R32 refrigerant when HFO refrigerant is applied.

2. REFRIGERANT PROPERTIES

The characteristics of low-GWP refrigerants are shown in Figure 1. The following HFO refrigerants are candidates for low-GWP refrigerants: R32 as the current refrigerant with GWP $\leq$ 750, R454C as the most efficient refrigerant with GWP $\leq$ 150, R1234yf with GWP $\leq$ 10, and R290 and CO2 as natural refrigerants.
In this study, R1234yf refrigerant was selected for evaluation. Among the low GWP candidate refrigerants, excluding R290 and CO2, which are natural refrigerants, R1234yf refrigerant has the smallest enthalpy difference to R32

refrigerant. Due to the smaller enthalpy difference, R1234yf refrigerant requires a higher running speed or a larger suction volume to achieve the same capacity as R32.



	R32(HFC)	R454C(HFO)	R1234yf(HFO)	R290(Natural)	CO2(Natural)
Suction pressure [MPa]	100%	62%	39%	58%	417%
Inhalation density [kg/m3]	100%	105%	81%	47%	422%
Difference in specific enthalpy equivalent to ability [kJ/kg]	100%	57%	48%	115%	39%
Capacity per unit inhalation volume [kJ/m3]	100%	60%	39%	54%	166%
Inhalation volume per unit inhalation volume [cc/J]	100%	167%	259%	186%	60%

Figure 1: Ratio of each refrigerant physical property to R32

3. PERFORMANCE EVALUATION

3.1 Test Equipment and Test Compressors

The calorimeter used in the performance evaluation is shown in Figure 2. Refrigerant is discharged from the compressor at high temperature and high pressure, and cooled in the condenser. The refrigerant cooled in the condenser is further cooled by a subcooler, then flows through an expansion valve to a low pressure and low temperature. It then flows through an evaporator and is sucked into the compressor.

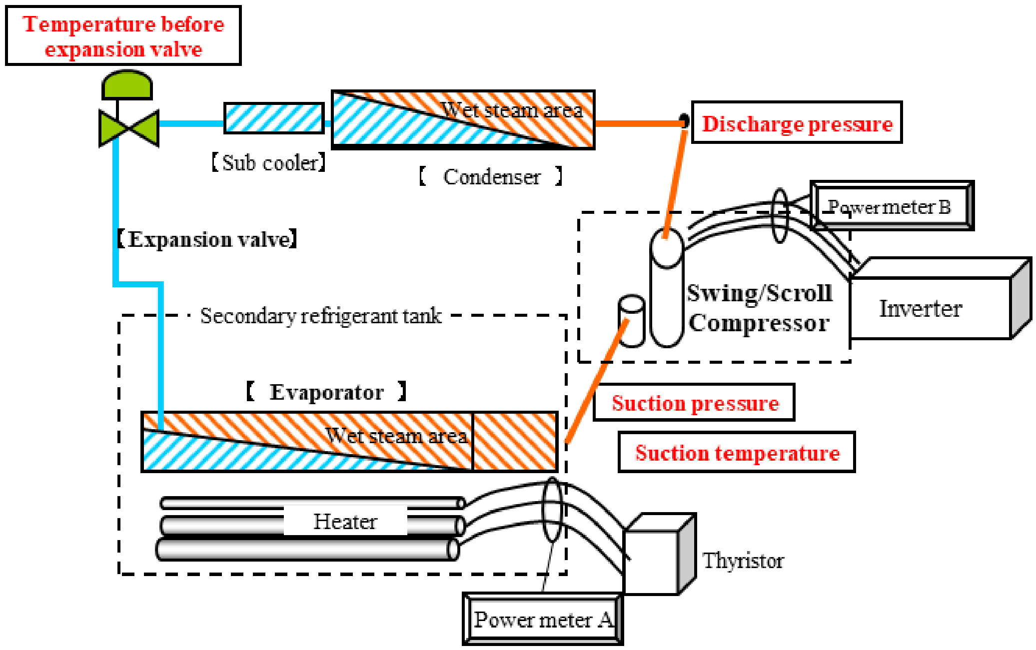


Figure 2: Test equipment: Calorimeter

In this performance evaluation, a swing compressor with 42cc suction volume and a scroll compressor with 57cc suction volume, both compatible with R32, were selected in order to clarify whether there is any performance impact when HFO refrigerant is applied. R32 and R1234yf refrigerants were used, and the evaluation was conducted with condensation temperature Tc/evaporation temperature Te = 45/5°C.

3.2 Performance Measurement Results

The measured refrigeration capacity and compressor efficiency of swing and scroll compressors using R32 and R1234yf refrigerant are shown in Figure 3. The horizontal axis shows the rotation speed and the vertical axis shows the ratio to R32.

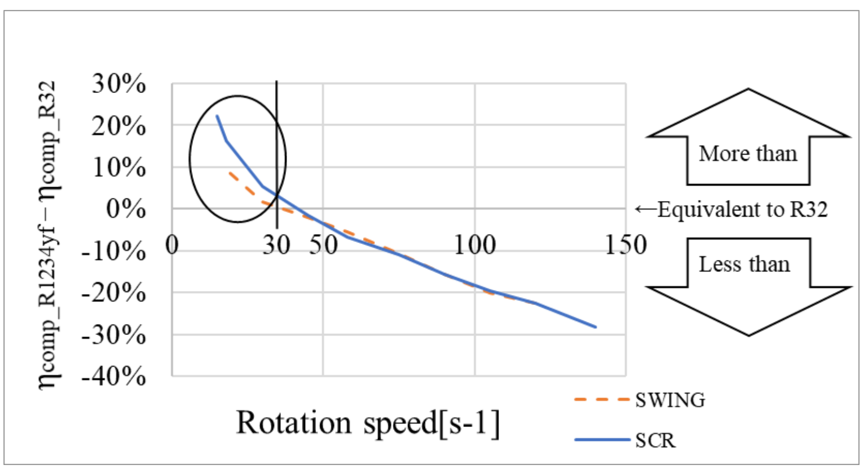


Figure 3: Compressor efficiency for R32 refrigerant

Comparing compressor efficiency, R1234yf refrigerant improves compared to R32 in both swing and scroll compressors at low RPMs below 30s-1. Also, compressor efficiency decreases at higher RPMs than 30s-1. One factor that increases efficiency on the low RPM side is the effect of leakage. R1234yf refrigerant has 39% lower pressure than R32 refrigerant, resulting in a smaller pressure difference and a smaller effect of leakage.

Next, the efficiency of the figure is examined. Internal pressure diagrams for R32 and R1234yf refrigerant at 90s-1 rpm are shown in Figures 4 and 5. The vertical axis shows the ratio of discharge pressure Pc to inlet pressure Ps, and the horizontal axis shows the crank angle. Compression loss was calculated from the difference between the theoretical and measured values to obtain the over-compression loss. Comparing the internal pressure diagram of R32 and R1234yf refrigerant, the over-compression is greater for R1234yf than for R32 in both swing and scroll compressors. This leads to the lower efficiency shown in the diagram. This is thought to be due to the characteristics of R1234yf refrigerant, which has a lower pressure than R32, resulting in a relatively larger pressure drop effect. This indicates the need to expand the flow path, including the discharge port and discharge valve.

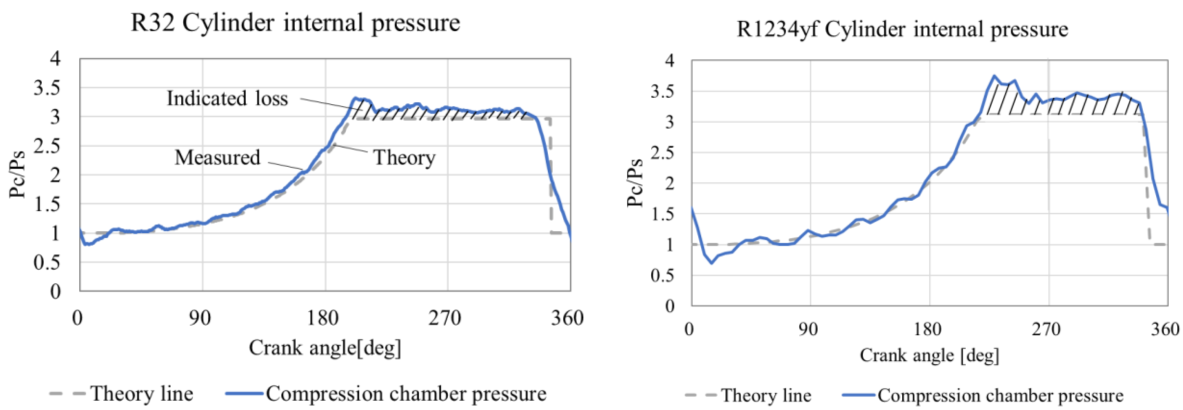


Figure 4: Internal pressure diagram of swing compressor

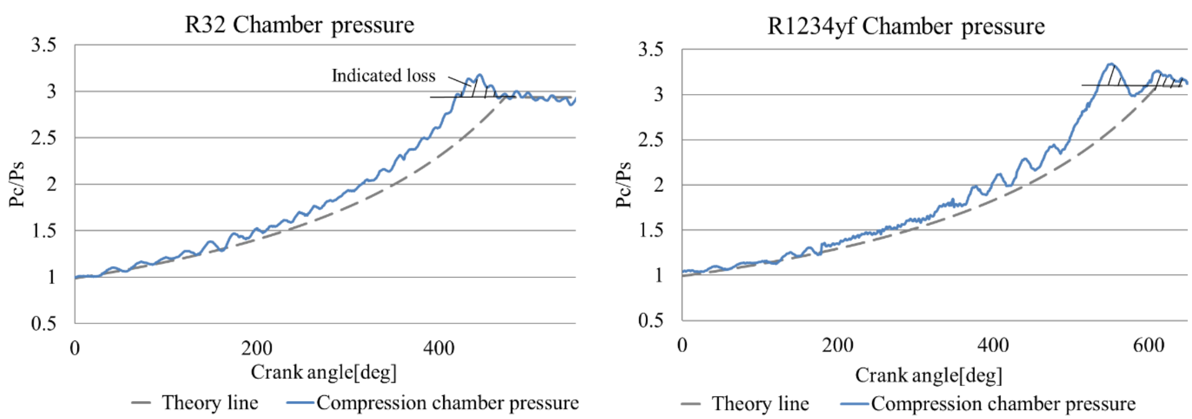


Figure 5: Internal pressure diagram of scroll compressor

In addition, the volumetric, Indicated, motor, compressor, and mechanical efficiencies of R1234yf refrigerant relative to R32 refrigerant at 90s-1 RPM are shown in Tables 1 and 2. The volumetric, compressor, and Indicated efficiencies are measured values, the motor efficiency is assumed to be equivalent, and the mechanical efficiency is a calculated value calculated backward from the above efficiencies. For both swing and scroll compressors, the mechanical efficiency is significantly lower than the other efficiencies. This is thought to be due to the drop-in evaluation for the R32 refrigerant-compatible compressor, which has excessive allowable bearing loads for the R1234yf, which has a smaller pressure than the R32 refrigerant, resulting in increased mechanical losses. Each efficiency was calculated using the following formula (1), (2), (3), and (4).

$$\eta_v = Q_c/Q_{th} \tag{1}$$

$$\boldsymbol{\eta_c} = COP_c/COP_{th} \tag{2}$$

$$\eta_i = W_c - W_{th} \tag{3}$$

$$\eta_m = (\eta_v \cdot \eta_i \cdot \eta_p)/\eta_c \tag{4}$$

$\boldsymbol{\eta_v}$: Volumetric efficiency [-]
$\boldsymbol{\eta_c}$: Compressor efficiency [-]
$\boldsymbol{\eta_i}$: Indicated efficiency [-]
$\boldsymbol{\eta_m}$: Mechanical efficiency [-]
$\boldsymbol{\eta_p}$: motor efficiency [-]
$\boldsymbol{Q_c}$: Actual measured freezing capacity [kW]
$\boldsymbol{Q_{th}}$: Theoretical freezing capacity [kW]
$\boldsymbol{COP_c}$: Actual measured COP [-]
$\boldsymbol{COP_{th}}$: Theoretical COP [-]
$\boldsymbol{W_c}$: Actual measured indicated work [J]
$\boldsymbol{W_{th}}$: Theoretical indicated work [J]

Table 1: Each efficiency of R1234yf with respect to R32 of swing/scroll compressor in 90s-1, Tc/Te=45/5℃

Compressor model	Swing	Scroll
Rotation speed	90s-1	90s-1
Volumetric efficiency	3.4%	-2.2%
Indicated efficiency	-4.8%	-7.2%
Motor efficiency	0.0%	0.0%
Compressor efficiency	-10.0%	-16.8%
Mechanical efficiency	-9.1%	-8.4%

4. CONCLUSION

In this study, we selected R1234yf refrigerant, which is an HFO refrigerant and has the highest capacity with GWP≤10, and conducted drop-in evaluation of R1234yf refrigerant using R32 refrigerant-compatible swing and scroll compressors. R1234yf refrigerant has a lower pressure at the same temperature compared to R32 refrigerant. Therefore, R1234yf refrigerant has a smaller refrigeration capacity due to the smaller enthalpy difference. Comparing R32 and R1234yf refrigerant in terms of compressor efficiency, R1234yf refrigerant is more efficient than R32 refrigerant at low RPM and less efficient than R32 refrigerant at high RPM. The reason for the higher efficiency at low RPM is that R1234yf has a smaller pressure differential, which reduces the effect of leakage in the low RPM range. The reason for the lower efficiency at high RPM is that the drop-in test of R1234yf refrigerant was conducted in a compressor optimally designed for R32 refrigerant. The discharge port and discharge valve were also optimally designed for R32 refrigerant, resulting in increased over-compression. The reason for the decrease in mechanical efficiency is that the compressor used has an optimal bearing design for R32 refrigerant. The allowable bearing load is excessive for R1234yf, which has a smaller pressure differential, resulting in increased frictional losses and lower mechanical efficiency. The evaluation results indicate that a compressor that uses R1234yf refrigerant and is compatible with R32 must have a higher RPM or a larger suction volume in order to achieve the same refrigeration capacity as R32 refrigerant. However, the efficiency decline due to over-compression at high RPM and the decline in mechanical efficiency due to shaft design are issues to be addressed. Therefore, expanding the suction volume and enlarging the flow path rather than increasing the speed can reduce the decline in compressor efficiency compared to higher speeds.

5. REFEREMCES

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