Development of large capacity two stage compressor for CO_2 refrigerators

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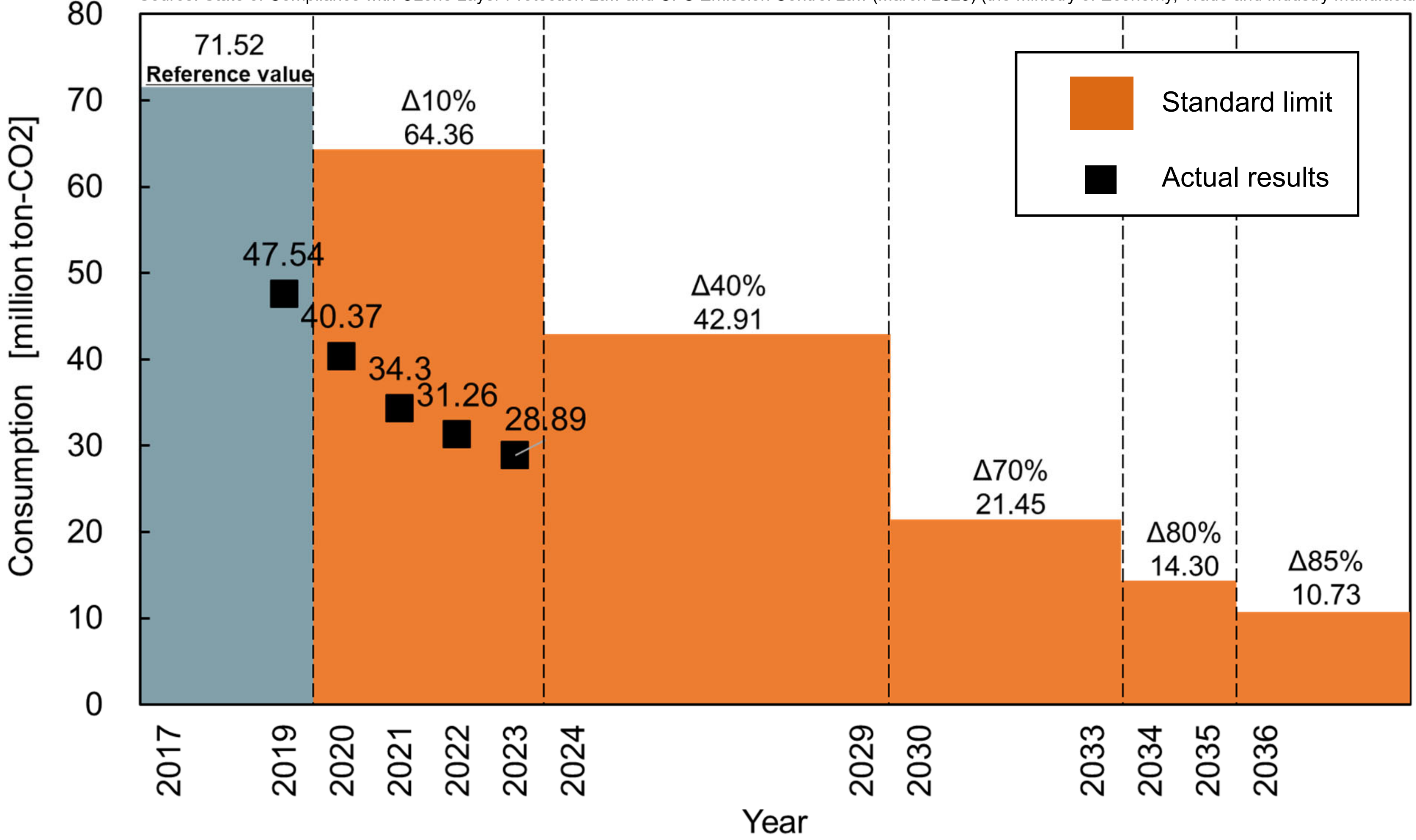
■ **Consumption limit of CFC substitutes (HFC refrigerants) under the Montreal Protocol in Japan**

Source: State of Compliance with Ozone Layer Protection Law and CFC Emission Control Law (March 2025) (the Ministry of Economy, Trade and Industry Manufacturing Industry Bureau)



- The Kigali Amendment to the Montreal Protocol requires a gradual reduction in the consumption of CFC substitutes (HFC refrigerants).
- Although the actual results are below the standard limit, **it is essential to switch to natural refrigerants to satisfy future restrictions**.

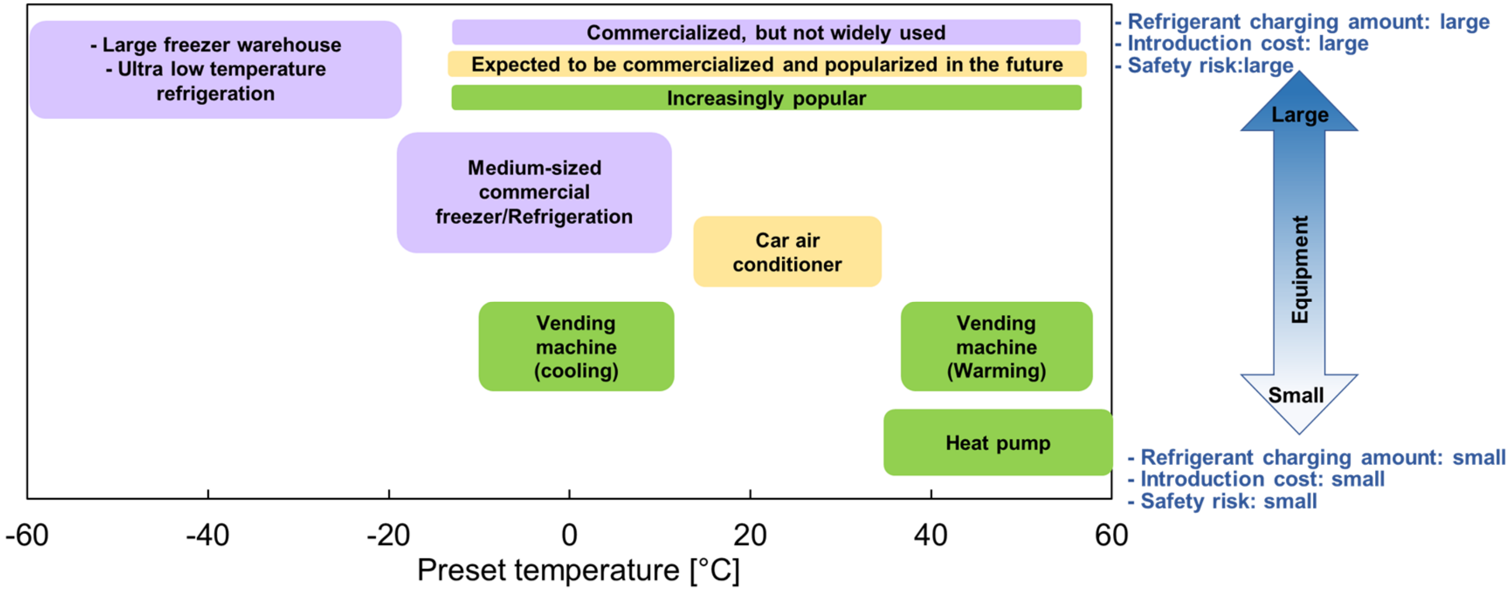
■Refrigerant Characteristics

		GWP [-]	Toxicity	Flammability	Saturation pressure at 25°C [MPaA]
Conventional refrigerant	R410A	1810	Low	No flame propogation	1.65
Natural refrigerants	Ammonia	0	High	Lower flammability	1.00
	Propane	3 or less	Low	Higher flammability	0.95
	CO_2	1	Low	No flame propogation	6.43

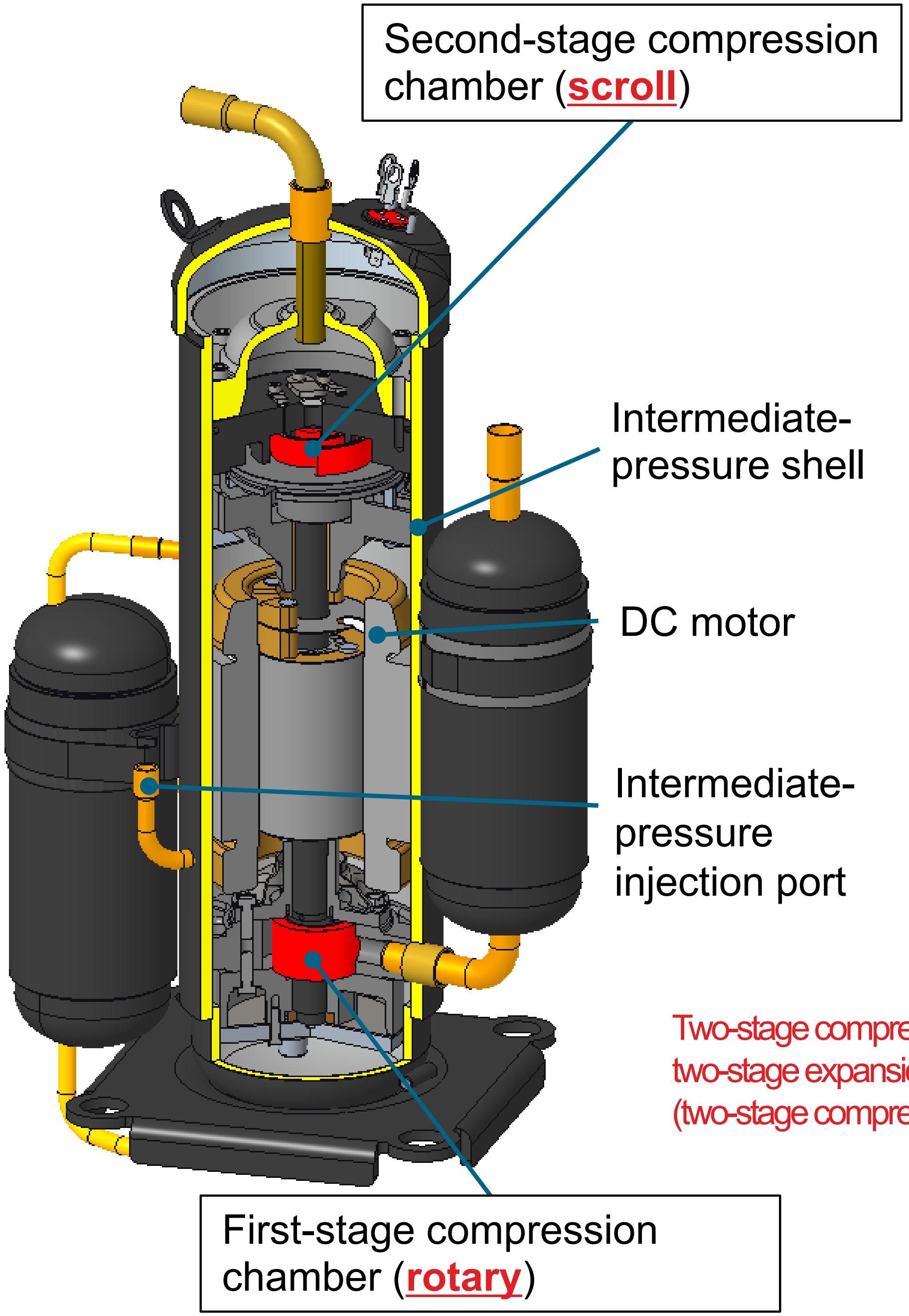
- Compared to conventional refrigerants, natural refrigerants have very low global warming potential (GWP).
- Among natural refrigerants, **CO_2 has advantages of low toxicity and no flame propogation**.
- On the other hand, **CO_2 has disadvantages of high pressure**.

■ Applications and popularization of CO_2 Refrigerants

Source: Outline of NEDO's Implementation of CFC Measures (2021) (NEDO)



Although CO_2 is mainly used for refrigeration, freezer and heat pump, product development for further popularization is desired. Our company put two-stage compressor for CO_2 refrigerant on the market in 2011.



■**Features of compressor**

<u>Two-stage compressor</u>

Pressure difference per stage is reduced, improving efficiency and reliability.

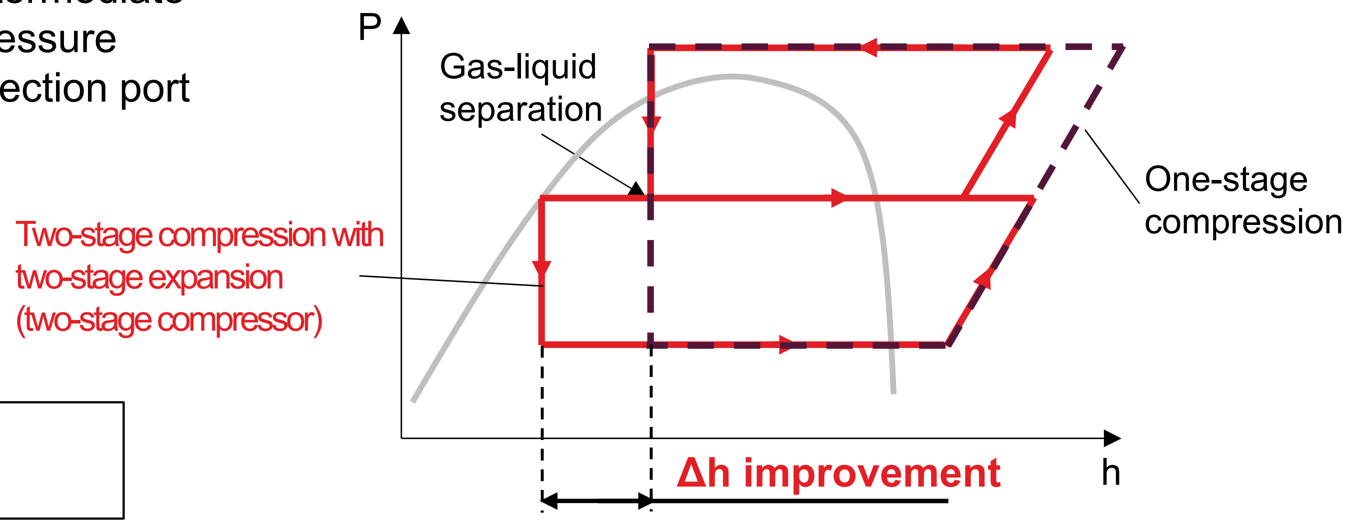
<u>Intermediate pressure injection</u>

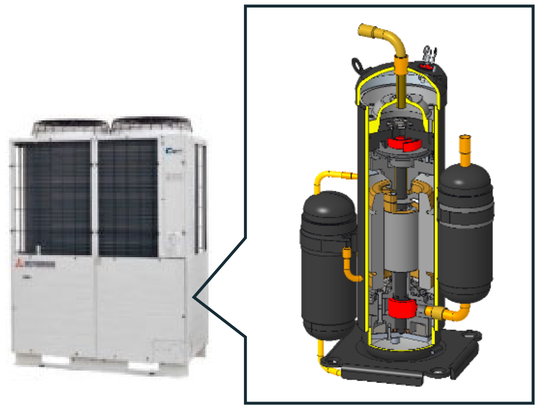
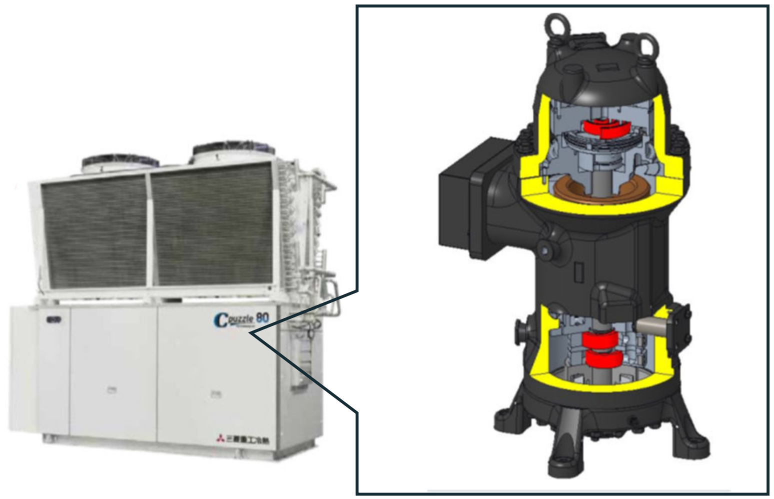
Discharge temperature can be lowered by injection between first and second stage.

■**Feature of cycle**

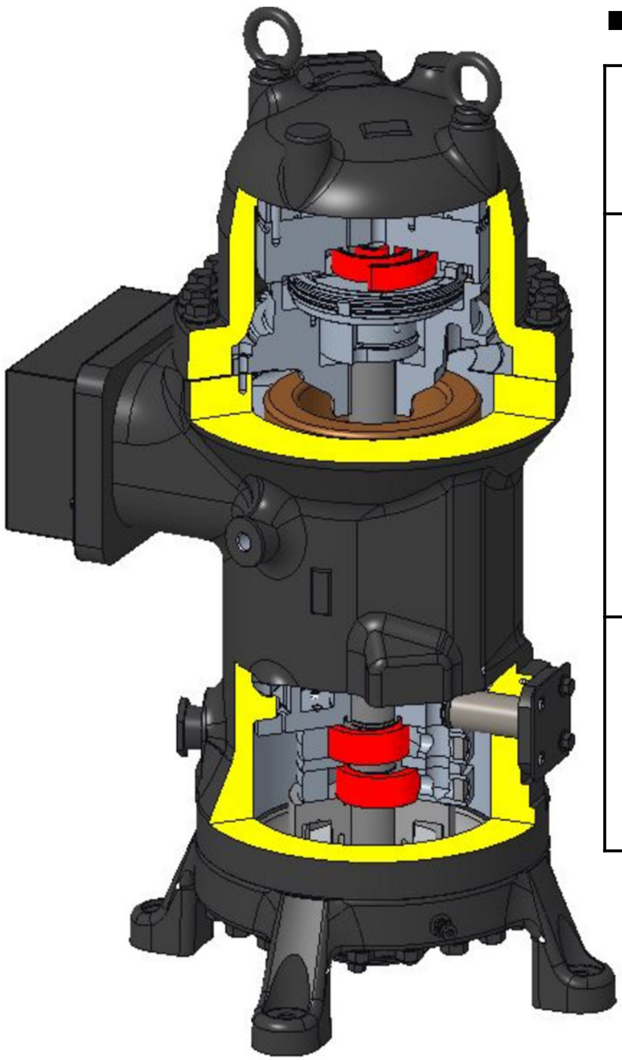
<u>Improved refrigeration capacity and system COP</u>

The enthalpy difference (Δh) in the evaporator can be improved.



Compressor	[Conventional compressor] 10 HP two-stage compressor				**[Developed compressor]** **40 HP large capacity two-stage compressor**
Purpose	Hot water supply	Freezing and refrigeration			**Freezing and refrigeration**
Nominal output [HP]	10	10	20	40	**80**
Appearance of unit Appearance of compressor					
Number of compressors per unit	1		2	4	**2**

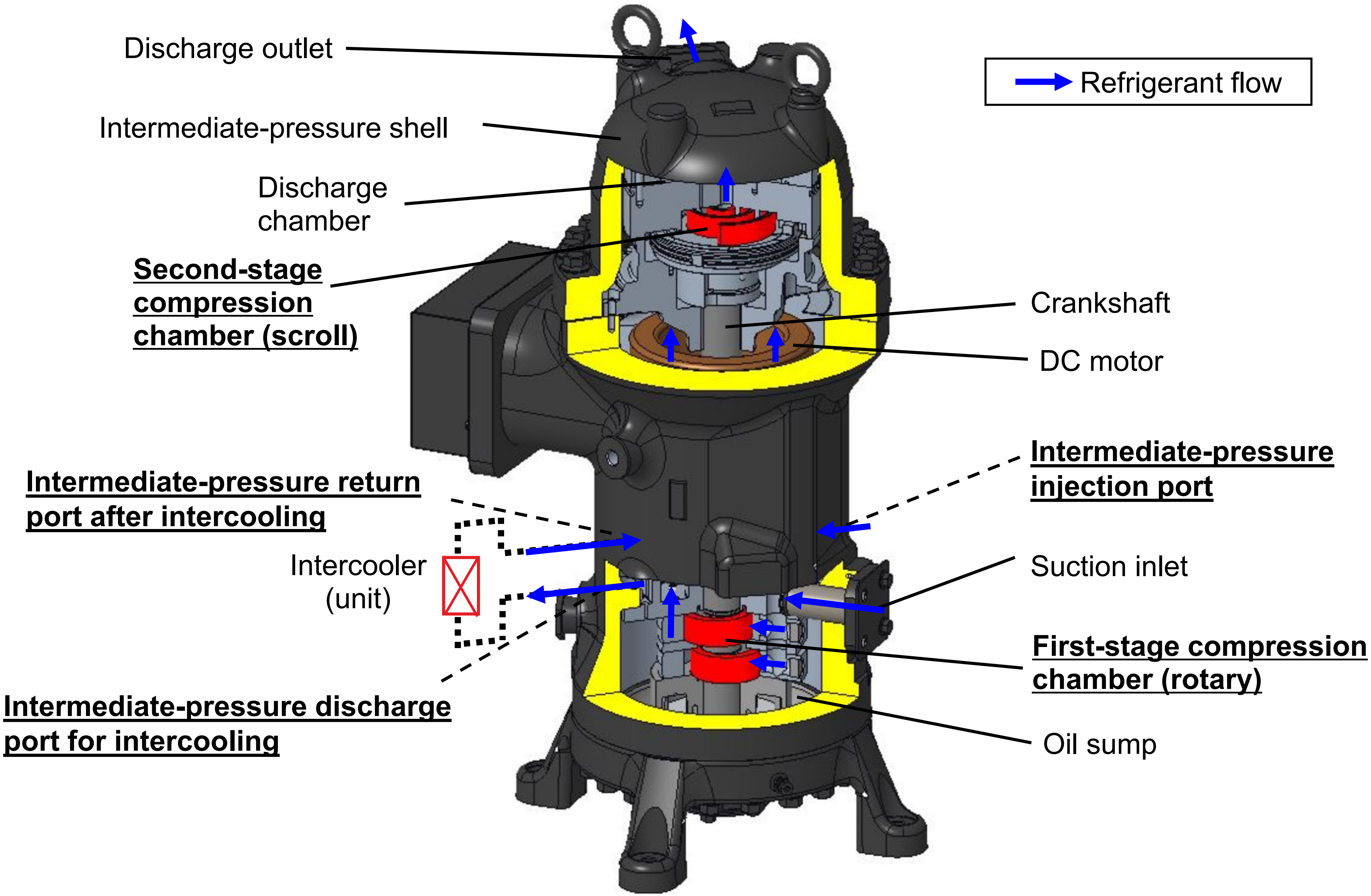
We have put 10 to 40 HP CO_2 commecial condensing unit on the market.
On the other hand, large capacity refrigerators and freezers are required by market.
Therefore, we have developed **40 HP large capacity two-stage compressor** for 80 HP condensing unit.



■**Basic specifications**

		[Conventional compressor] 10 HP two-stage compressor	**[Developed compressor] 40 HP Large capacity two-stage Compressor**
Compressor mechanism	First-stage compression	Single rotary	**Twin rotary**
	Second-stage compression	Scroll	←
	Oil supply pump	Rotary pump	**Trocoid pump**
	Bearing	Journal bearing	←
For system COP improvements	Displacement ratio	Set to handle both hot water supply and freezing/refrigeration	**Optimized for freezing/refrigeration**
	Intercooling	No	**Yes**

In addition to increasing the displacement compared to conventional compressor, a new structure (such as an intercooling compatible structure) was also added.


Discharge outlet
Intermediate-pressure shell
Discharge chamber
Second-stage compression chamber (scroll)
Refrigerant flow
Crankshaft
DC motor
Intermediate-pressure return port after intercooling
Intermediate-pressure injection port
Intercooler (unit)
Suction inlet
First-stage compression chamber (rotary)
Intermediate-pressure discharge port for intercooling
Oil sump

3. Addressing Key Issues

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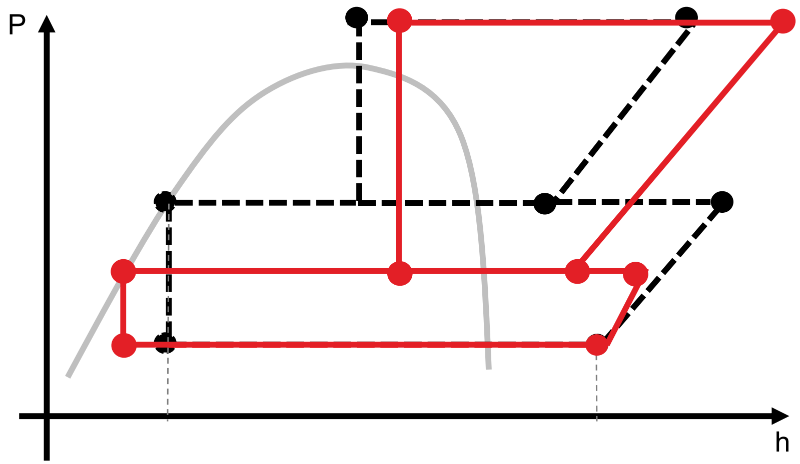
Items	Key Issues		Responses
	Items	Details	
Performance	Improvement of system COP	Because the application was different from that of the conventional compressor, it was necessary to change displacement ratio.	Displacement ratio was optimized to improve the system COP under refrigeration and freezing conditions, which are frequent conditions.
	Improvemt of compressor efficiency	There was a concern about a decrease in efficiency due to increased pressure loss associated with the increase in flow rate.	Machanical loss was reduced by reducing the rated speed by increasing displacement.
Reliability	Ensuring oil film thickness of moving parts	There was a concern about insufficient oil film thickness in the moving parts due to the increase in compressive load associated with the larger capacity.	Viscosity of oil supplied to bearing was measured and reflected in the design.

3. Addressing Key Issues Improvement of System COP

The qualitative effect of displaecement ratio on the system COP is shown below.
(displacement ratio = displacement of second-stage (V_2) / displacement of first-stage (V_1))

1. Condition of high displacement ratio (V_2/V_1)
(= low intermediate pressure)



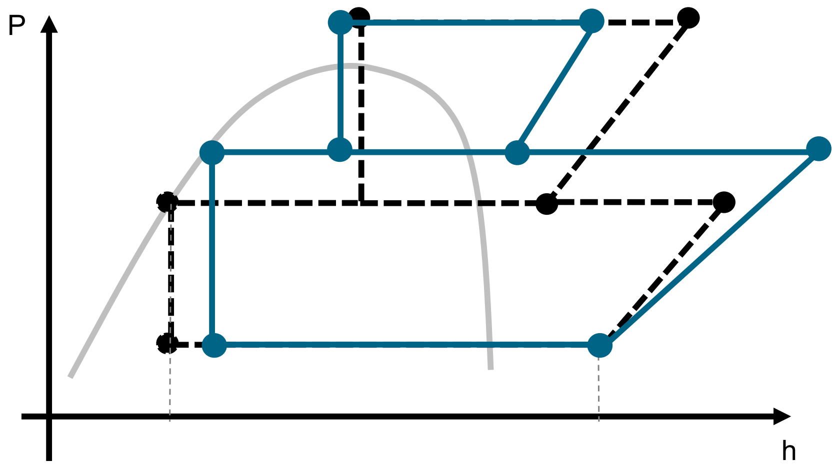
Positive effect on COP

- First-stage efficiency improvement by reducing the pressure difference in the first-stage
- Evaporator enthalpy difference increase

Negative effect on COP

- Second-stage efficiency reduction by increasing the pressure difference in the second-stage

2. Condition of small displacement ratio (V_2/V_1)
(= high intermediate pressure)



Positive effect on COP

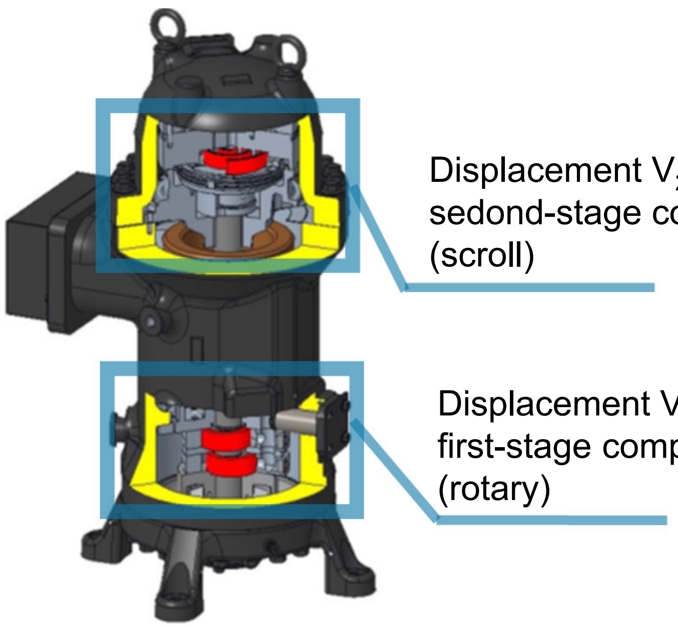
- Second-stage efficiency improvement by reducing the pressure difference in the second-stage

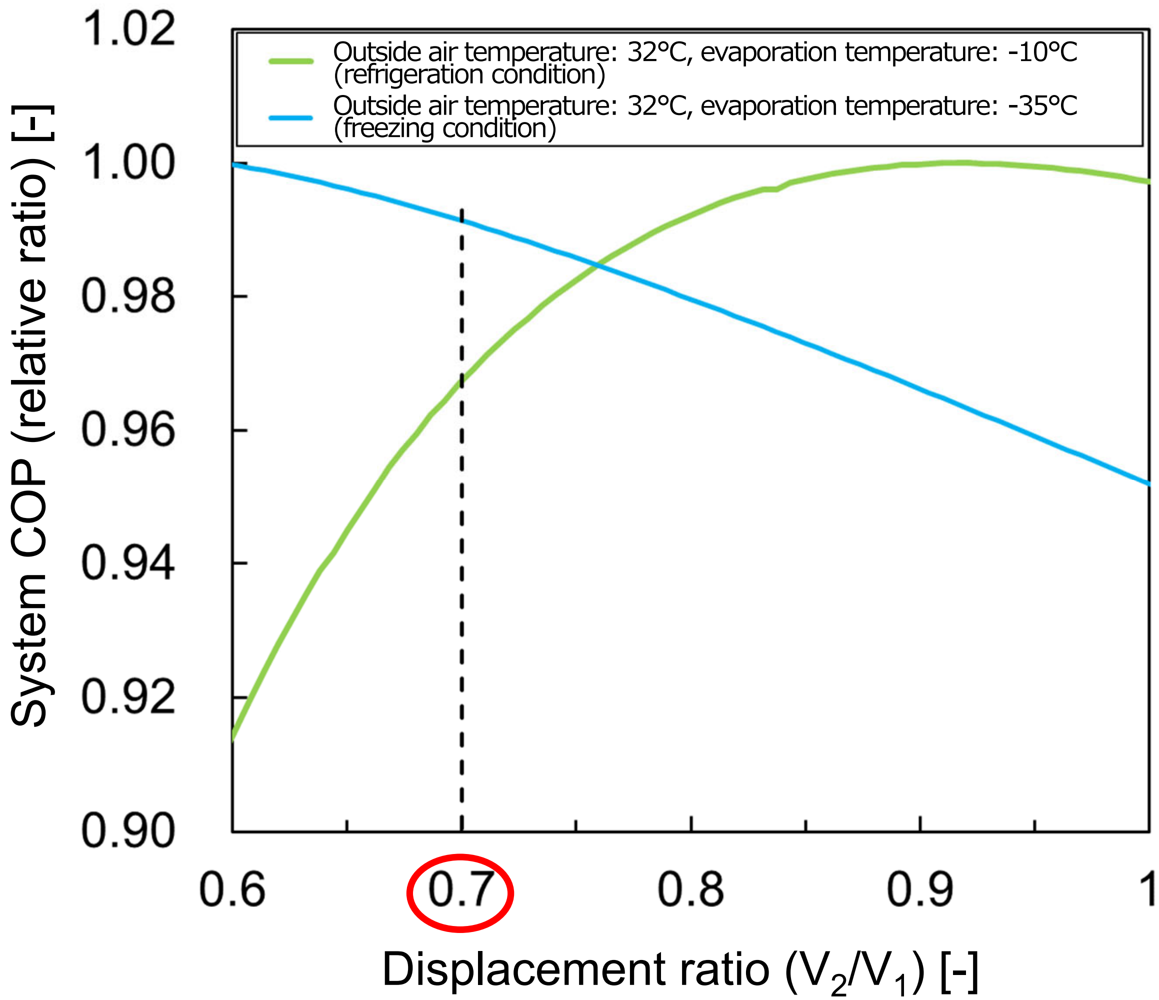
Negative effect on COP

- First stage efficiency reduction by increasing the pressure difference in the first-stage
- Evaporator enthalpy reduction

The system COP has an optimum value depending on displacement ratio (= intermediate pressure).

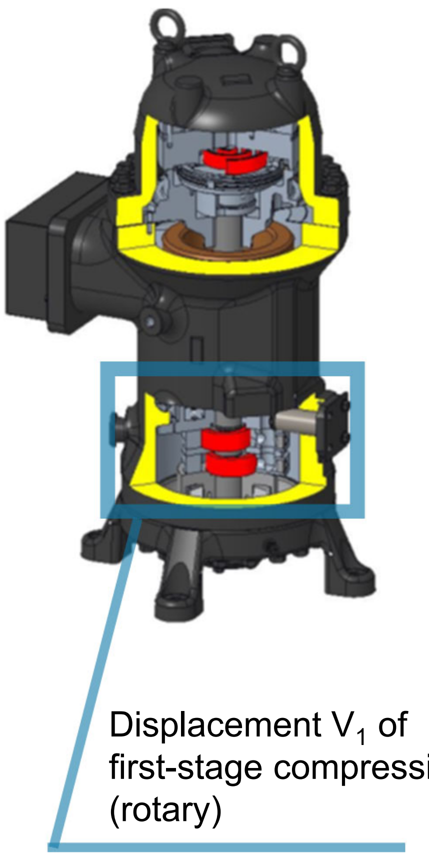
The relationship of system COP to displacement ratio under refrigeration and freezing conditions was calculated.

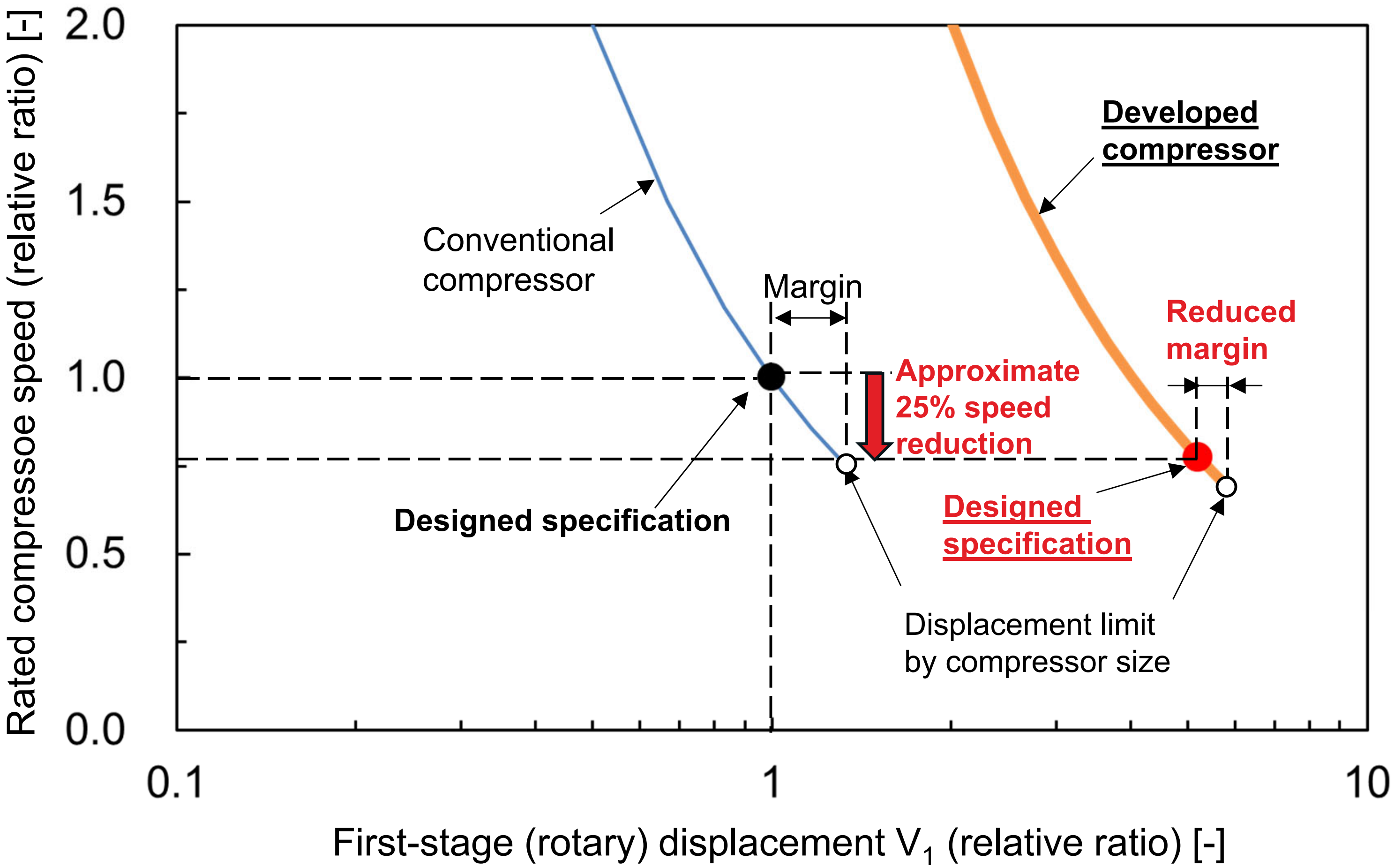




The optimum displacement ratio is different between refrigeration and freezing conditions. Considering the system COP of both conditions, the displacement ratio was determined to be **V_2/V_1 = 0.7**.

The relationship between displacement and rotational speed was calculated while keeping the rated capacity (∝ displacement × rotational speed) constant.

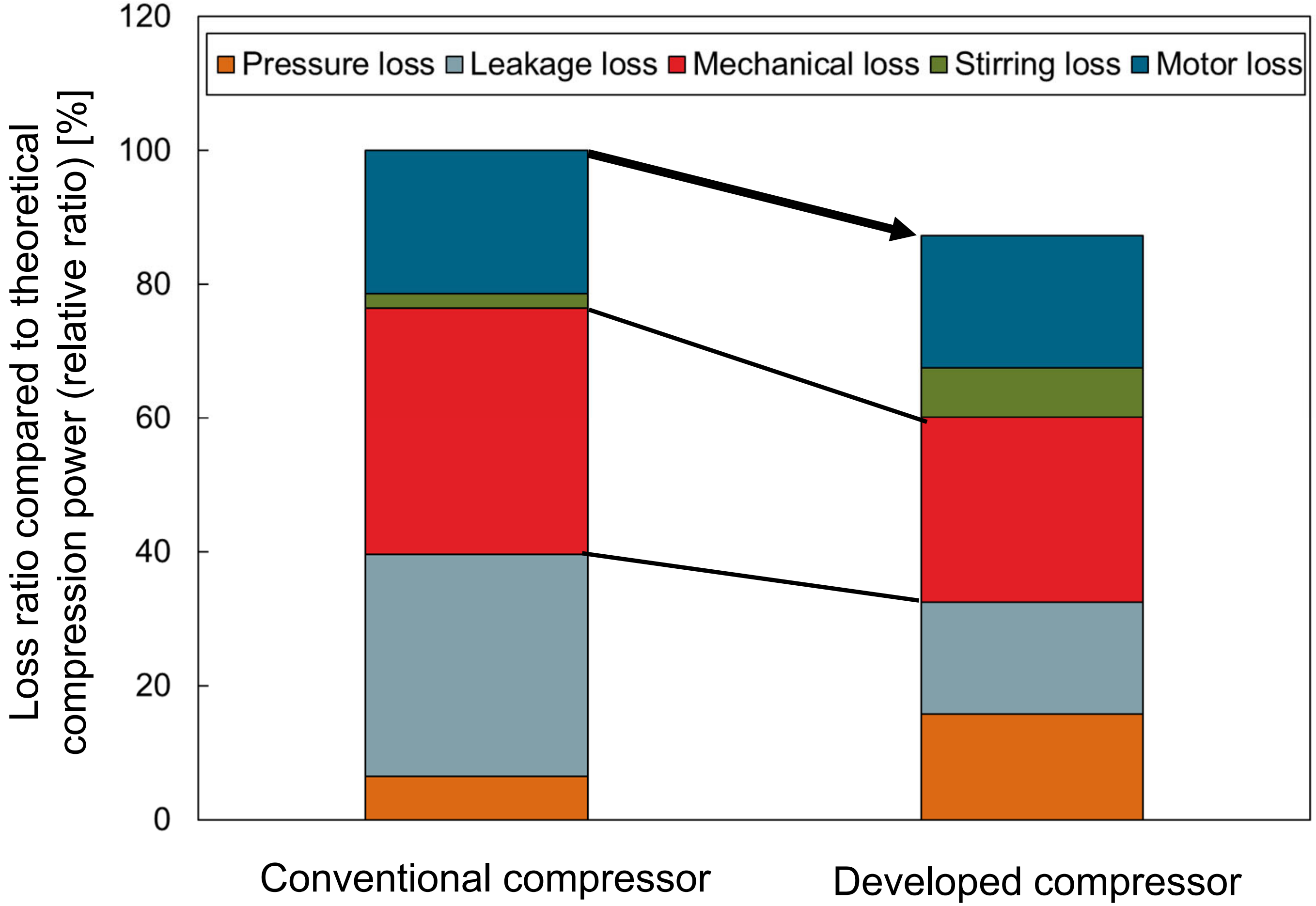




<u>Compressor speed could be set approximately 25% lower than the conventional compressor</u> by reducing the margin of displacement limit by compressor size.

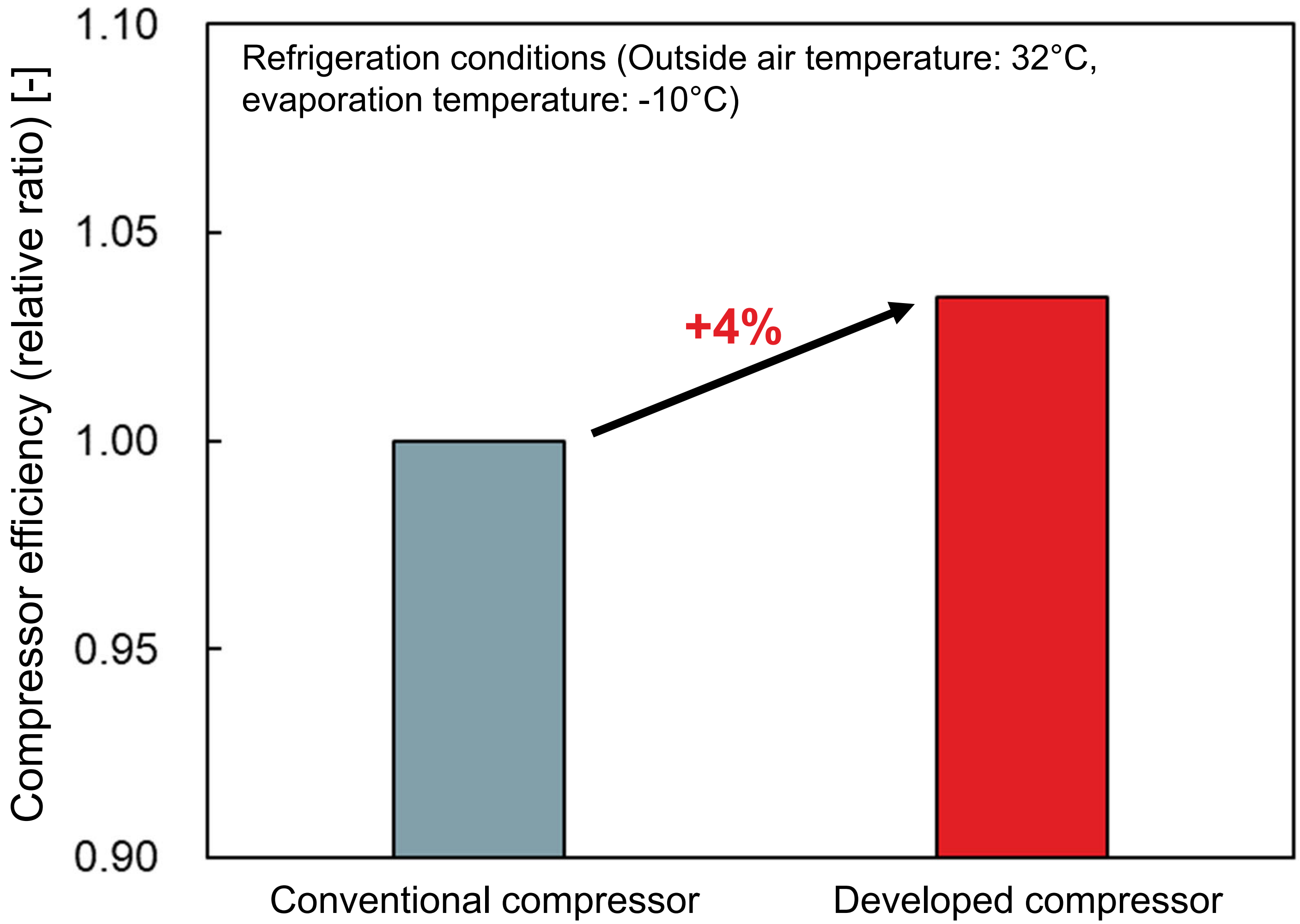
■ Result of loss calculation

The developed compressor was designed with the displacement ratio and the displacement of first-stage determined as described above. Each loss ratio comperaed to theoretical compression power under the rated condition was calculate.



Through the reduction of mechanical loss and other factors, it was confirmed that losses could be reduced compared to conventional compressor.

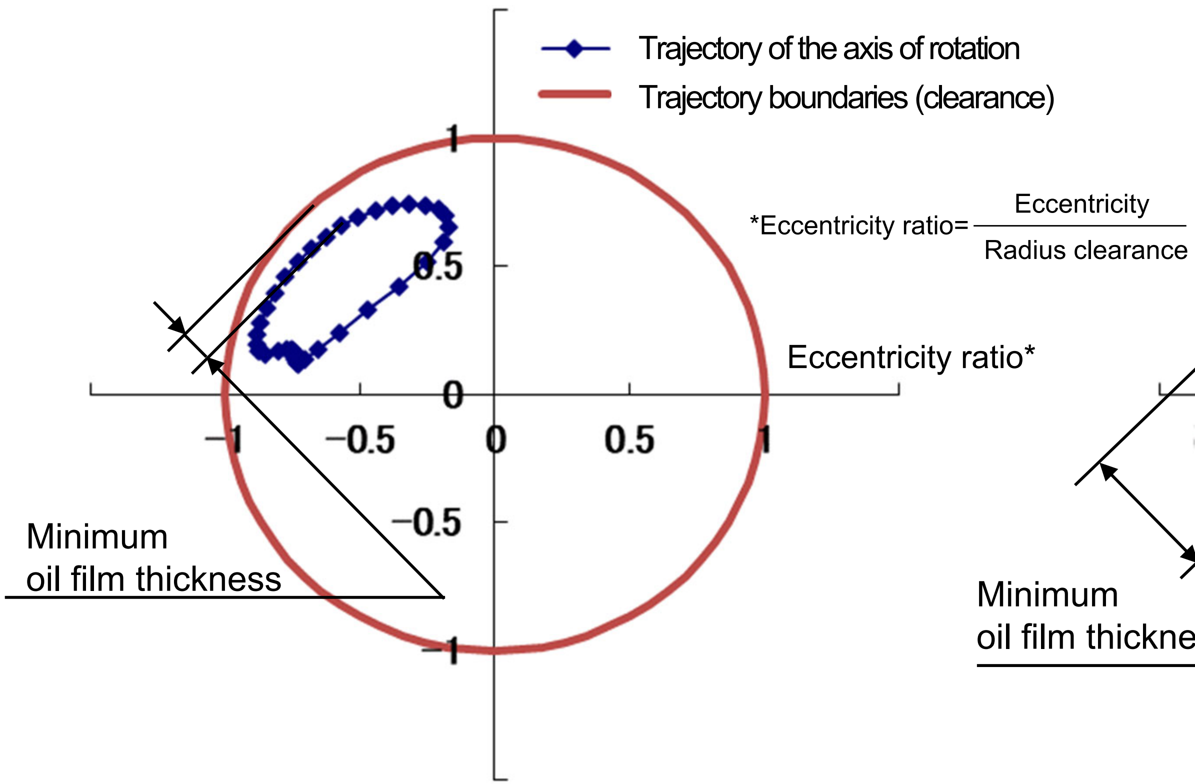
■ **Measurement results of compressor efficiency (overall adiabatic efficiency)**



<u>It was confirmed through measurements that the compressor efficiency (overall adiabatic efficiency) improved by 4% compared to conventional compressor</u>.

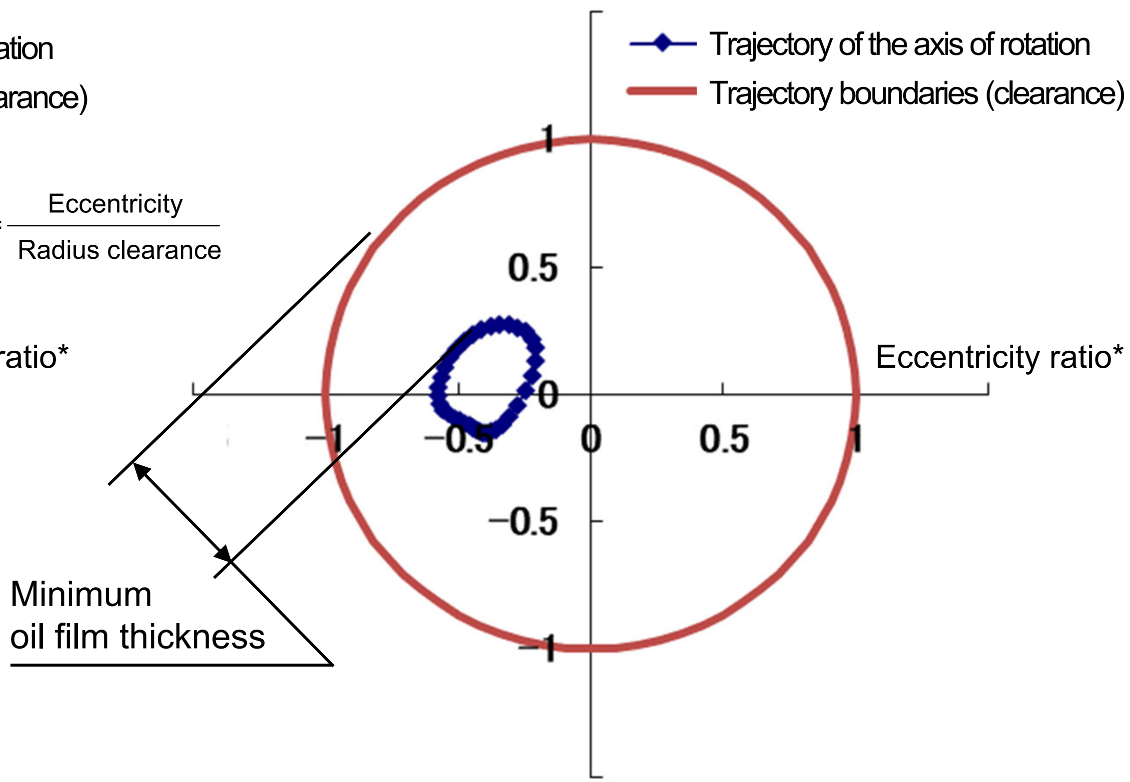
The trajectory of the axis center in the rotary bearing was calculated, and the minimum oil film thickness was calculated.

■ **Low viscosity conditions**



Minimum oil film thickness: small

■ **High viscosity conditions**

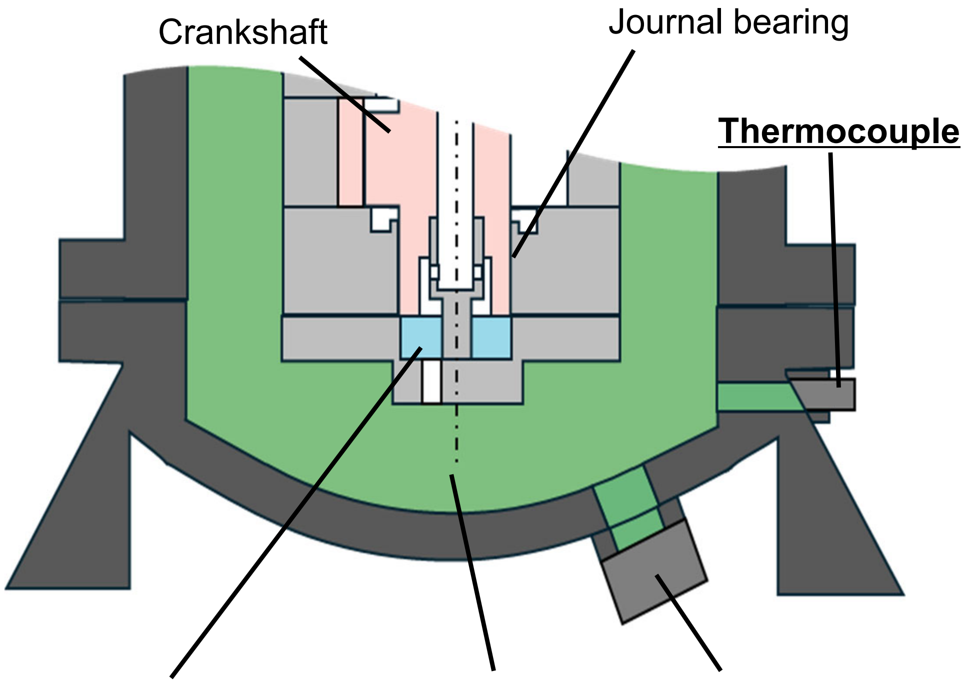


Minimum oil film thickness: large

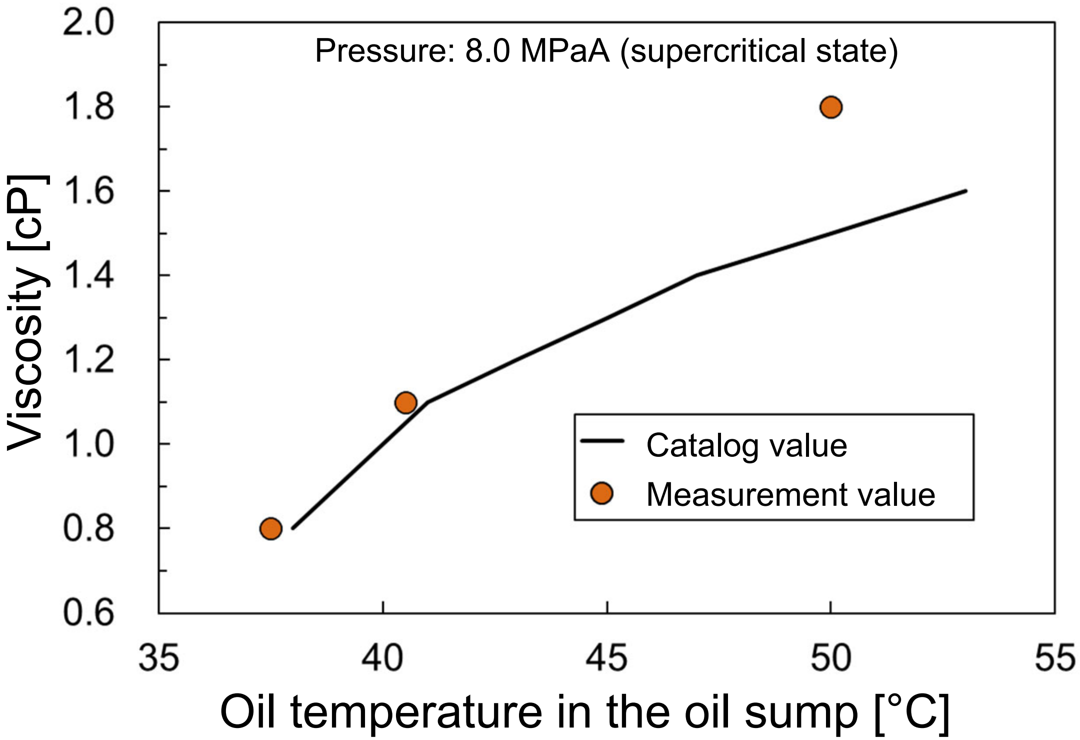
Despite the significant impact of viscosity on the lubrication (oil film thickness), there is a lack of viscosity data, particularly in the supercritical state, it is crucial to obtain experimental measurements of viscosity.

By installing a viscometer and a thermocouple at the bottom of the compressor, the temperature and viscosity of the oil sump were measured.

■ Measurement points for viscosity and temperature



■ Viscosity measurement results



At around 50°C oil temperature, the difference between the measured values and the catalog values was confirmed.

→ **By conducting bearing design based on the measured viscosity data, the reliability of the compressor was ensured**.

- A large-capacity CO_2 two-stage compressor, in which capacity (nominal output) was expanded to 40 HP from the conventional 10, was newly developed.

- The displacement ratio between the first and second stages was set to optimize the system COP under both refrigeration and freezing conditions.

- Mechanical loss could be reduced by maximizing displacement and decreasing rotation speed, which improved compressor efficiency by 4.0% from the conventional compressor.

- Since available data on viscosity of supercritical lubricant oil is scarce, lubricant oil viscosity was measured and the results were used in bearing design, resulting in a compressor with high reliability.

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