Development of HCCV2001M, the World's First Large-capacity Condensing Unit equipped with two CO_2 Scroll and Rotary compressors

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To prevent global warming, refrigeration and air conditioning equipment is required to replace current refrigerants with those with low global warming potential (GWP) to achieve a reduction in GWP. Mitsubishi Heavy Industries Thermal Systems Ltd. has developed the HCCV2001M, a large-capacity 20-horsepower condensing unit following the 10-horsepower HCCV1001, both of which adopt natural refrigerant CO_2 with a GWP of 1 as an alternative to fluorocarbon refrigerants R404A (GWP3920) and R410A (GWP2090), which are the mainstream refrigerants used in commercial condensing units. This larger capacity was established by using two Scroll and Rotary compressors, which expanded the capacity range while accommodating the components in a cabinet the same size as that of the HCCV1001. As a result, the installation flexibility was ensured. This paper describes the technological issues and applied technologies of this product.

1. Introduction

In Japan, GWP reduction has been promoted by the Law Concerning the Discharge and Control of Fluorocarbons. Commercial condensing units equipped with a compressor with a rated output exceeding 1.5 kW are obliged to adopt refrigerants with a GWP of 1500 or less by 2025. As shown in **Table 1**, alternative refrigerant candidates aimed at reducing GWP include fluorocarbon refrigerants R448A (GWP of 1387) and R463A (GWP of 1494), which are mixtures of Hydro fluoroolefin (HFO) and Hydrofluorocarbon (HFC). Since these are fluorocarbon refrigerants, refrigerant leakage over a certain amount during use must be reported to the government. In addition, these refrigerants must be managed at each life stage of construction, use, maintenance, and disposal, e.g., recovery of the refrigerant during maintenance and disposal, issuance of certificates for filling and disposal, obliged regular inspection of the equipment, etc. Furthermore, these refrigerants have another disadvantage in that their GWP is as high as just under 1500. Ammonia (NH_3), a natural refrigerant, is difficult to handle in terms of maintenance and management due to its flammability and toxicity, so it is not suitable for small refrigeration equipment. On the other hand, natural refrigerant CO_2 is easy to handle because it has a high design pressure and a low GWP, and is a single-component refrigerant that is subject to fewer obligations for refrigerant management unlike fluorocarbon refrigerants. Based on these advantages, we put the HCCV1001 10-horsepower commercial condensing unit, for which a natural refrigerant CO_2 was adopted, on the market in 2017. This condensing unit has been earning a good reputation.

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Table 1 Natural refrigerant CO_2 and HFC-based mixed refrigerant

	Carbon dioxide (CO_2)	Ammonia (NH_3)	Mixed refrigerant (R448A)	Mixed refrigerant (R463A)
Global warming potential (GWP)	1	< 1	1387	1494
Flammability	Nonflammable	Slightly flammable	Nonflammable	Nonflammable
Legal refrigeration capacity (tonnage) below which qualification for operation and maintenance is unnecessary	20 tons	5 tons	20 tons	20 tons
Toxicity	Not toxic	Toxic	Not toxic	Not toxic
Safety equipment	Leak sensor	Leak sensor, detoxification equipment, seismoscope, and security equipment	Leak sensor	Leak sensor

Source of mixed refrigerant GWP values: Global warming potential (GWP) 100-year value in “IPCC Fourth Assessment Report”

Table 2 HCCV2001M specifications

Model		HCCV2001M (20 horsepower)	HCCV1001 (10 horsepower)
Application		Refrigeration	
Power supply		3-phase 200 V, 50/60 Hz	
Refrigerant used		R744 (carbon dioxide)	
Ambient operating temperature		-15°C to +43°C	
Operating temperature		-45°C to -5°C	
Legal refrigeration capacity		5.96 tons	2.98 tons
Design pressure		High pressure 14 MPaG / Low pressure 8 MPaG	
Compressor	Type	Two-stage compression Scroll and Rotary	
	Drive system	DC inverter	
	Number of compressors	2	1
External dimensions (mm)		Width 1350 x Depth 720 x Height 1690	
Product weight		470 kg	340 kg

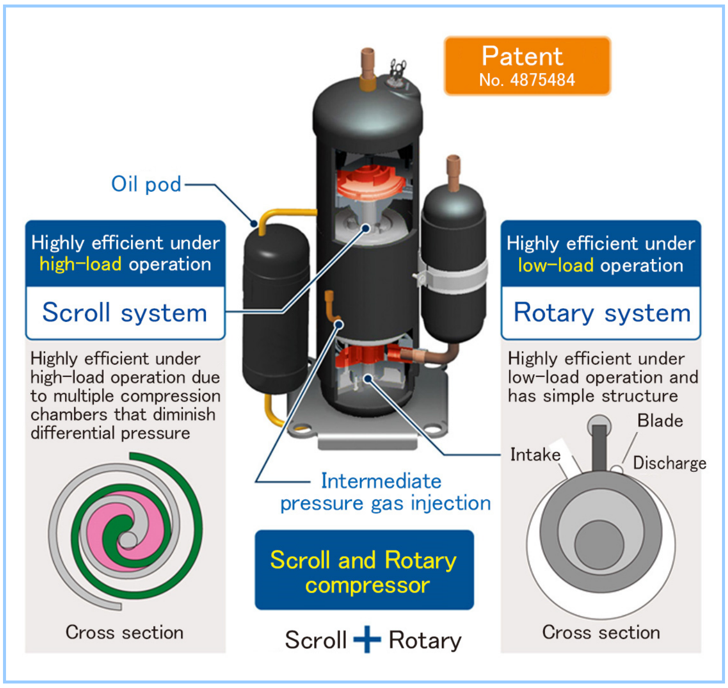

Figure 1 Scroll and Rotary compressor

As shown in **Table 2**, the newly developed HCCV2001M 20-horsepower large-capacity commercial condensing unit achieved a large capacity through the installation of two Scroll and Rotary compressors as illustrated in **Figure 1** in a cabinet with the same dimensions as the 10-horsepower HCCV1001. **Table 3** compares the developed condensing unit with a condensing unit using R22 refrigerant, which will be completely abolished in 2020 under the Montreal Protocol. The HCCV2001M was designed to reduce the external dimensions, weight, etc., in comparison to the condensing unit using R22, so that it can respond to demands for the replacement of condensing units using R22.

The HCCV2001M uses both compressor number control and compressor rotation speed control to deal with a wide range of loads. According to the load of the connected load equipment (showcases or coolers connected to the condensing unit), the compressor number control switches between single-compressor operation and two-compressor parallel operation, and the compressor rotation speed control adjusts the rotation speed of the compressors. Due to these controls, the HCCV2001M, in comparison to the HCCV1001, doubles the capacity while maintaining the same lower limit of the load that can be dealt with.

Table 3 HCCV2001M specifications and comparison with condensing unit using R22

Model		HCCV2001M (20 horsepower)	HCA150M (20 horsepower)
Application		Refrigeration	
Power supply		3-phase 200 V, 50/60 Hz	
Refrigerant used		R744 (carbon dioxide)	R22
Ambient operating temperature		-15°C to +43°C	
Operating temperature		-45°C to -5°C	
Legal refrigeration capacity		5.96 tons	6.78/8.08 tons
Design pressure		High pressure 14 MPaG / Low pressure 8 MPaG	High pressure 2.94 MPaG / Low pressure 1.27 MPaG
Compressor	Type	Two-stage compression Scrotary	Scroll
	Drive system	DC inverter	AC constant speed
	Number of compressors	2	2
External dimensions (mm)		Width 1350 x Depth 720 x Height 1690	Width 2700 x Depth 600 x Height 1800
Footprint		0.98 m^2	1.62 m^2
Product weight		470 kg	500 kg
Connecting pipe	Liquid pipe	Φ15.88	Φ19.05
	Gas pipe	Φ25.4	Φ41.28

2. Technological issues

This chapter introduces the technological issues for increasing the capacity through the installation of two Scroll and Rotary compressors.

(1) Control of excessive refrigerant for increase in capacity

To accommodate the components in the limited cabinet dimensions, the accumulator and the receiver, which contain the liquid refrigerant and adjust the amount of refrigerant in the system, had to be made smaller. Therefore, it was necessary to prevent the excessive liquid refrigerant from flowing into the compressor from the receiver.

(2) Control for securing refrigeration oil in compressor

To prevent a shortage of refrigeration oil in the compressor, in addition to in-pipe-oil return operation, two compressors were connected by an oil equalization pipe to perform oil equalization control, a proven technique used in air conditioners. In the case of a Scroll and Rotary compressor, the pressure in the oil storage area is the intermediate pressure after low-stage compression, and a differential pressure is generated between the two units by the effect of operation. Therefore, it was necessary to avoid excessive movement of the refrigeration oil through the oil equalization pipe caused by the differential pressure, while securing the refrigeration oil in each compressor through oil equalization control.

The measures against these technological issues are explained in the following chapters.

3. Control of excessive refrigerant for increase in capacity

An increase in the capacity of the system results in enlarged volume of the contained refrigerant due to the increase the volume of loads and pipes to be connected. Therefore, it is necessary to store excessive refrigerant, the amount of which changes depending on operating conditions, in the receiver. In the case of the two-stage compression gas injection cycle that we adopted, in normal operation as shown in **Figure 2** (a), the refrigerant is separated into liquid and gas in the receiver and the refrigerant gas is led to the gas injection circuit. In operation with extremely low refrigeration capacity load, the amount of refrigerant circulation decreases and excessive refrigerant may accumulate in the receiver beyond the allowable volume, causing the compressor to directly suck the liquid refrigerant from the gas injection circuit. If liquid refrigerant flows into the compressor, the refrigeration oil in the compressor becomes diluted and the viscosity decreases, resulting in the deterioration of the lubricity, which has an adverse effect on the reliability of the compressor. A general method of preventing this is to sufficiently increase the receiver capacity to increase the allowable volume. However, this method cannot meet the demand for smaller size and lighter weight.

The HCCV2001M adopts the maximum-volume receiver that can be accommodated in a machine room the same size as that of the HCCV1001 to achieve the same dimensions as the HCCV1001. It also uses a liquid level sensor that monitors the liquid level in the receiver to control excessive refrigerant as shown in Figure 2 (b). When the liquid level rises transiently and the liquid level sensor detects that the liquid level has exceeded the allowable volume, the liquid refrigerant is controlled to be temporarily released to the low-pressure side through the circuit of the internal heat exchanger (double pipe liquid-gas heat exchanger) upstream of the liquid pipe outlet of the condensing unit. This control enabled continuous operation of the compressor and secured the necessary cooling capacity. In addition, by adopting a control method that closes the injection circuit and stops the compressor when a liquid level exceeding the allowable volume is detected in low-load operation where the capacity is excessive, inflow of the liquid refrigerant into the compressor is avoided. After the compressor restarts, refrigerating capacity is ensured by the control that opens the injection circuit when the receiver liquid level decreases.

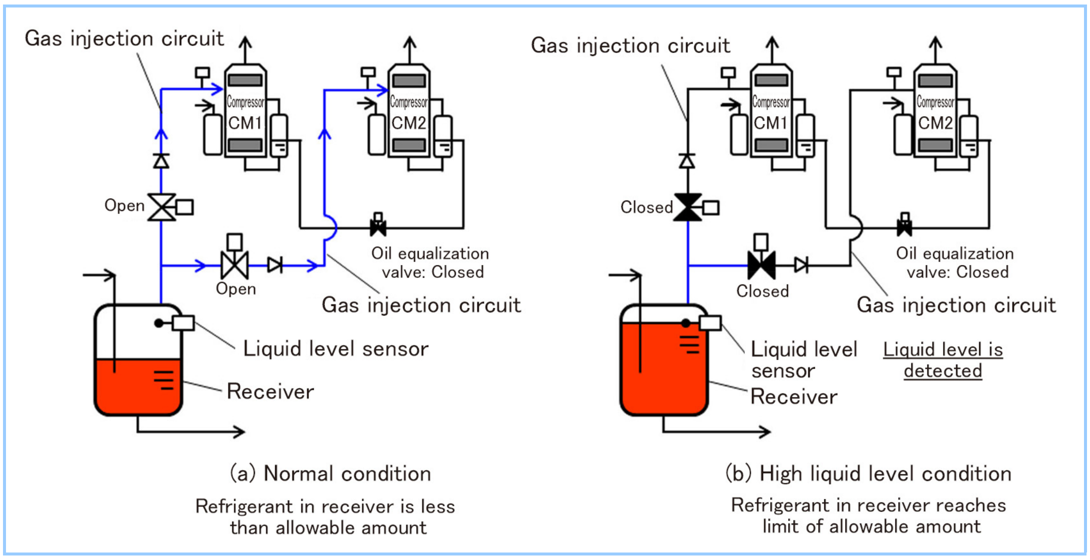

Figure 2 Control of excessive refrigerant in receiver

4. Control for securing refrigeration oil in compressor

Refrigeration oil in the compressor is secured by adopting oil return control – technology proven in air conditioners – and oil equalization control. The oil return control returns refrigeration oil in the system that has accumulated in the heat exchangers and gas pipes, which are load equipment, to the compressor. The start condition of this control is determined in consideration of the oil discharge amount from the compressor and the oil retention amount in the pipes.

Figure 3 illustrates the measured correlation between the compressor speed and the refrigeration oil circulation ratio, which indicates the ratio of oil discharged from the compressor to the refrigerant circuit that cannot be separated by the oil separator (refrigeration oil circulation amount / (refrigeration oil amount + refrigerant circulation amount)). Based on this figure, the amount of refrigeration oil discharge that varies depending on the evaporation temperature and the compressor speed is carefully estimated, and the implementation of oil return operation is determined to prevent a shortage of refrigeration oil. When returning the refrigeration oil to the compressor, the refrigeration oil can be returned together with the refrigerant in cases where the refrigerant in the pipe is a liquid, but the refrigeration oil cannot be returned at the same flow velocity as the refrigerant when the refrigerant is gaseous. This is because even compatible oil has difficulty flowing when the density and flow velocity of the refrigerant, which serves as the working fluid, are small. For this reason, in consideration of cases where the condensing unit is installed at a higher position than (or with a head difference from) the load equipment, the control that returns the refrigeration oil to the compressor by securing a refrigerant flow that can move the refrigeration oil upward (flooding flow velocity or higher) was adopted. The specific operation of the oil return control is to temporarily increase the compressor rotation speed to flow the refrigeration oil accumulated in the system and return it to the compressor to secure this flooding flow velocity. Verification of this control was performed by using a high head difference testing facility in our factory, and its validity was confirmed.

To secure the refrigeration oil, oil equalization control that eliminates the oil deviation between the two compressors was adopted. This is because when two compressors are operated in the same refrigeration cycle, the refrigeration oil deviation to one compressor occurs due to individual differences in the compressors and the system even if their operating frequencies are the same. In addition, this product employs a compressor number and capacity control that activates one compressor in some cases to enable continuous operation of the refrigerating equipment even when the load is small, which may cause refrigeration oil deviation to one compressor. Such oil deviation between the two compressors would result in a shortage of oil if continued, so the oil equalization control used for air conditioners was applied. In the case of an air conditioner, the compressors that store oil are low pressure regardless of whether each compressor is operating or stopped. Therefore, to avoid oil deviation between compressors, by connecting the two compressors with an oil equalization pipe and operating them at different rotation speeds, refrigeration oil is moved by utilizing the pressure difference between the two compressors. However, in the case of the HCCV2001M condensing unit equipped with Scroll and Rotary compressors, the oil storage area in the refrigerating equipment is intermediate pressure after low-stage compression, and the inside of the stopped compressor is low pressure during single-compressor operation. For this reason, it is necessary to avoid the refrigeration oil moving through the oil equalization pipe from the intermediate-pressure operating compressor to the low-pressure stopped compressor. With an oil equalization valve on the oil equalization pipe installed, the movement of the refrigeration oil was avoided. When the compressors are operating, the oil equalization valve is closed to avoid oil movement between the compressors. When oil equalization control is required, synchronizing control (**Figure 4** (a)) for equalizing the compressor pressures is performed, the oil equalization valve is opened, and then the oil equalization control shown in Figure 4 (b) starts.

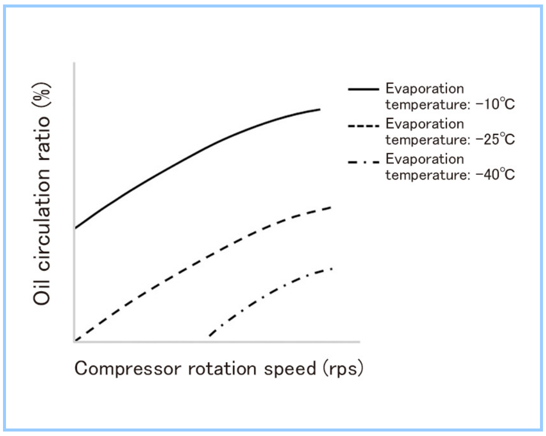

Figure 3 Oil circulation ratio

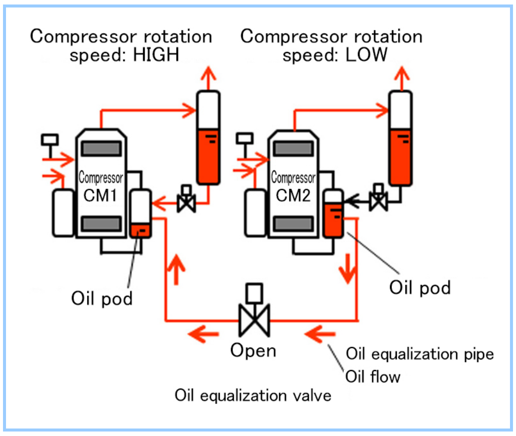

Figure 4 (b) Oil equalization control schematic diagram

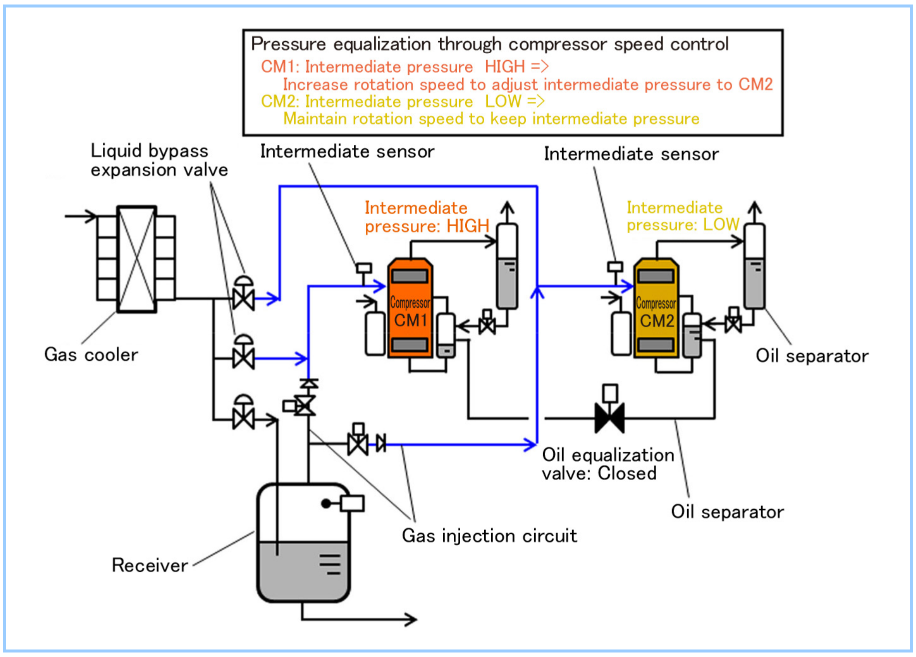

Figure 4 (a) Synchronization control schematic diagram

As a measure to further improve the reliability, an oil pod was installed to increase the storage amount of refrigeration oil and a sensor was provided to detect the refrigeration oil level. In addition, compressor failure is prevented by implementing oil return control and oil equalization control when an oil level drop is detected.

5. Securing same usage range as 10-horsepower condensing unit

The newly developed HCCV2001M large-capacity commercial 20-horsepower condensing unit is assembled in a cabinet with the same dimensions as the 10-horsepower HCCV1001, and the footprints of the two are the same. The minimum installation interval of the HCCV2001M in installation in a row is unchanged at 10 mm, so the installability with respect to the capacity has been improved (**Figure 5**). Similarly to the HCCV1001, the HCCV2001M satisfies the usage and installation conditions of condensing units using conventional fluorocarbon refrigerant, and has specifications that easily meet demands for replacing an existing unit.

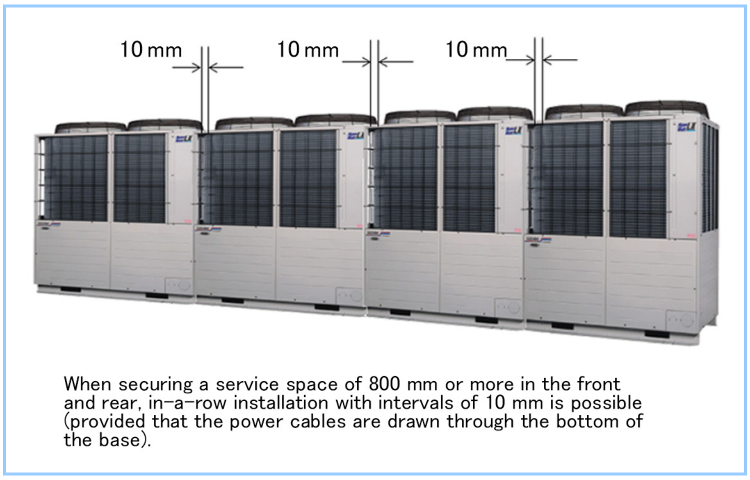

Figure 5 Installation in a row

Usage conditions

1. The evaporation temperature can be set freely from -45°C to -5°C.
2. The condensing unit can be used in the outside temperature range of -15°C to +43°C.

Installation conditions

3. The connecting pipe length between load equipment and the condensing unit can be in the range of 10 m to 100 m, and the condensing unit can be operated even under a condition where the load equipment is positioned 22 m below (**Figure 6**).

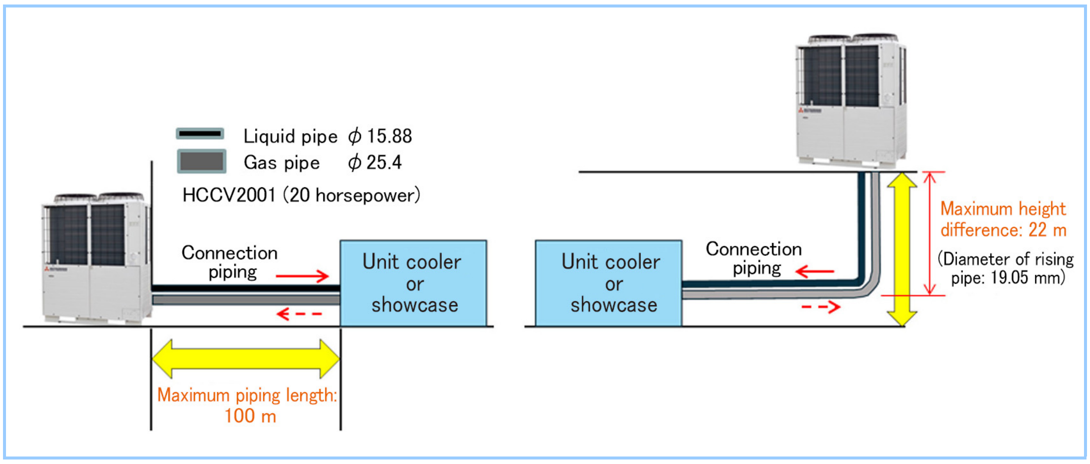

Figure 6 Installability (piping length and head difference)

6. Conclusion

The newly developed HCCV2001M large-capacity commercial condensing unit using natural refrigerant CO_2 is not only environmentally-friendly, but can also be easily handled in the same manner as units using conventional fluorocarbon refrigerant. We will contribute to global environmental conservation through the reduction of CO_2 emissions by expanding the application range of these condensing units from refrigerating warehouses and supermarkets to factory facilities.

Reference

(1) Hisao Mizuno,et al. : The application of the CO_2 Direct Expansion System for the Freezing Refrigerating Warehouse JSRAE jornal, 94 (1097), 1.3 (2019)