# "C-puzzle" High-Efficiency Condensing Unit Employing $CO_2$ as Natural Refrigerant for Freezing and Refrigeration

Mitsubishi Heavy Industries
Thermal Systems, Ltd.

Various measures against global warming have been undertaken in the industrial world. Concerning commercial condensing units, it is necessary to promote the adoption of refrigerants with low global warming potential (GWP). Mitsubishi Heavy Industries Thermal Systems, Ltd. has developed the "C-puzzle," which is a high-efficiency condensing unit for freezing and refrigeration using the natural refrigerant $CO_2$ with a GWP of 1. In this condensing unit, the refrigerant flows in the medium-pressure range, allowing the reduction of the piping design pressure, the setting of a wide range of evaporating temperatures, a wide range of ambient operating temperatures and the installation of the unit with a long pipe. The features and specifications of this product are described below.

## 1. Features of the product

(1) Adoption of natural refrigerant $CO_2$

Since the Kigali Amendment to the Montreal Protocol in October 2016, each country has made efforts to reduce HFC refrigerants to address global warming. Japan has set the goal of a 26% reduction in greenhouse gas emissions in FY2030 compared to in FY2013. In Japan, the Fluorocarbons Emission Control Law has come into effect, and the target value of GWP for the refrigerants used in the specified products and the year by which the target should be achieved have been set to promote the adoption of low-GWP refrigerants such as natural refrigerant. This law stipulates that the GWP of the refrigerant used in a commercial condensing unit with a compressor output of over 1.5 kW should be 1,500 or less by 2025. Alternatives to the current mainstream refrigerants, R404A (GWP3943) and R410A (GWP1924), which are HFC (Hydro-Fluoro-Carbon) refrigerants, have been sought. The candidate refrigerant is R448A (GWP1337), which is an HFO (Hydro-Fluoro-Olefin) and HFC mixed fluorocarbon refrigerant, which is the most promising natural refrigerant with a GWP of 1 or less. For a product using a fluorocarbon mixed refrigerant, care must be exercised in the handling of the refrigerant in the stages of installation, use, maintenance and disposal, such as leakage during use and the collection of refrigerant at the time of disposal. Furthermore, ammonia $NH_3$ also requires consideration in terms of toxicity and maintenance/control. Therefore, among natural refrigerants, $CO_2$ has the best quality (**Table 1**).

**Table 1 Comparison of natural refrigerants, carbon dioxide ($CO_2$) and ammonia ($NH_3$), and mixed refrigerant (R448A)**

| | Carbon dioxide ($CO_2$) | Ammonia ($NH_3$) | Mixed refrigerant (R448A) |
|---|---|---|---|
| Global warming potential (GWP) | 1 | <1 | 1337 |
| Combustibility | Non-combustible | Slightly combustible | Non-combustible |
| Toxicity | Without | With | Without |
| Qualification for operation/maintenance | Not required for less than the legal refrigeration capacity of 20 tons (Note) | Not required for less than the legal refrigeration capacity of 5 tons | Not required for less than the legal refrigeration capacity of 20 tons |
| Safety equipment | Leakage sensor | Leakage sensor, detoxifying equipment, seismoscope, safety tools | Leakage sensor |

Note: "Document no.5 Smartization of High Pressure Gas",11th High Pressure Gas Subcommittee, Security Subcommittee, Industrial Structure Council (March 23, 2017)

(2) Feeding of the refrigerant at medium pressure

Since $CO_2$ refrigerant has a higher operating pressure compared to HFC refrigerant, higher design pressures are required not only for the condensing unit, but also for the loading apparatus such as a showcase or unit cooler as well as the connecting pipe.

Therefore, this product adopts the gas injection cycle, which allows the medium-pressure refrigerant after one-stage expansion to be fed to a loading apparatus such as a showcase or unit cooler. This enables the design pressure of the connecting pipe and the loading apparatus to be medium pressure, not high pressure, facilitates the piping installation, reduces the costs, and improves the reliability against leakage of the refrigerant (**Figure 1**).

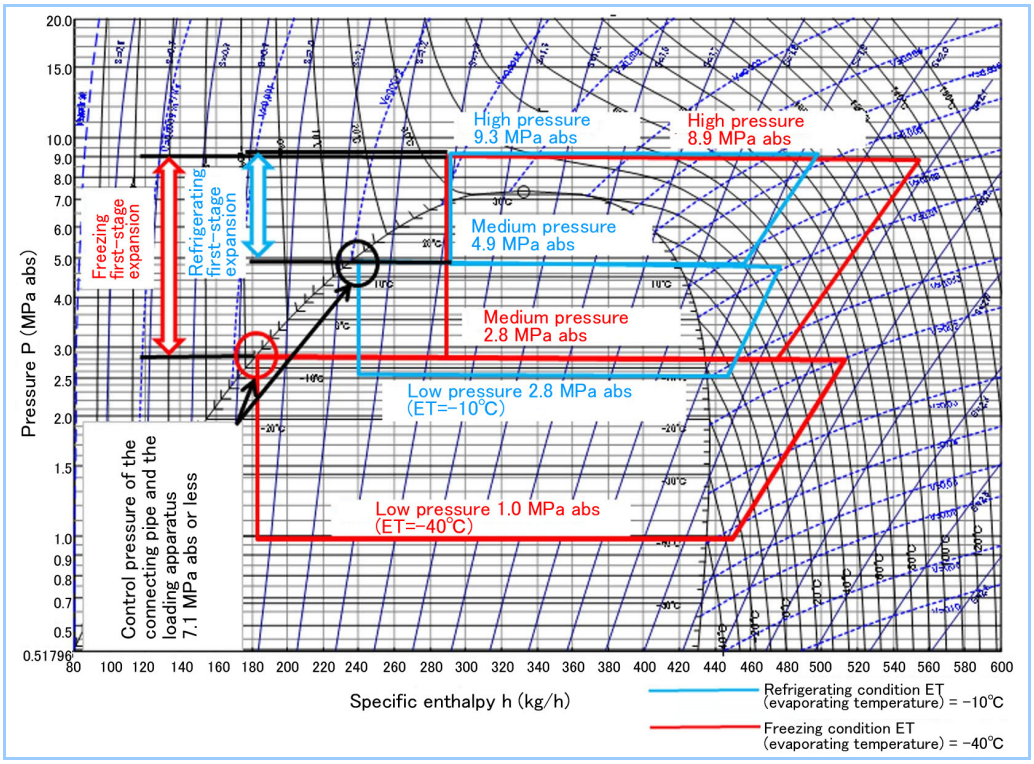


**Figure 1 Operating cycle under the freezing condition and the refrigerating condition**

(3) A wide range of evaporating temperatures (any temperature between -45°C and -5°C can be set)

When the condensing unit operates at the evaporating temperature of -45°C, the low-pressure density is drastically reduced, as is the circulating volume of the refrigerant. As a result, the temperature of the motor coil of the compressor that is cooled by the refrigerant rises. In particular, when the ambient temperature is high at 43°C, the problem comes to the forefront because the load on the compressor is increased. Furthermore, when the pressure difference between the high pressure and the low pressure becomes large, the discharge gas temperature increases, and therefore the mechanical compression parts also need to be cooled. As a measure against such an increase in temperature, a method of injecting the liquid refrigerant from the gas injection pipe is adopted, in which the compressor is installed at the front side of the motor (bottom of the compressor) relative to the flow of the refrigerant, so that the motor is cooled more positively (**Figure 2**).

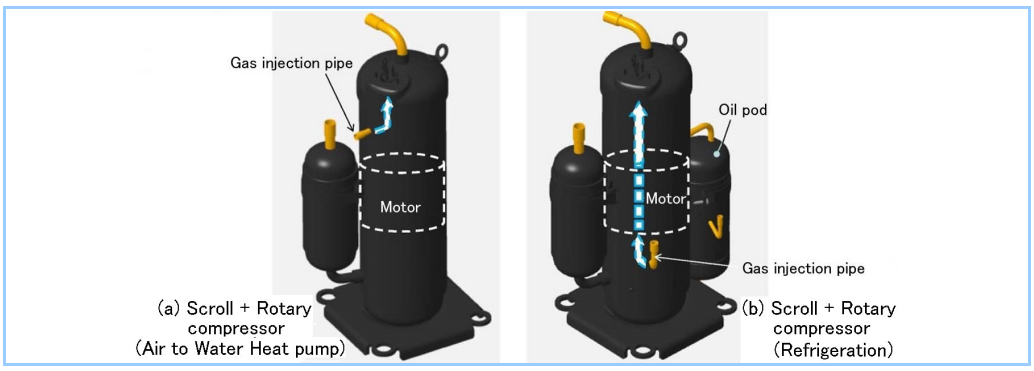


**Figure 2 Scroll+Rotary compressors for Air to Water Heat pump and for Refrigeration**

(4) Use at a wide range of ambient temperatures (from -15°C to 43°C)

When the ambient temperature decreases to -15°C, the high pressure decreases and the refrigerant stays in the gas cooler, and apparently, a shortage of refrigerant occurs, resulting in the degradation of performance. To prevent this problem, the speed of the gas cooler fan is controlled so that the high pressure is maintained, and the motorized valve installed between the high pressure and the medium pressure is operated so that the refrigerant from the gas cooler is positively discharged to the medium-pressure receiver, to prevent the refrigerant from staying in the gas cooler. When the ambient temperature increases to 43°C, the temperature at the gas cooler outlet remarkably increases. Therefore, the allocation of paths of the gas cooler (the number of divisions of heat transfer pipes and their arrangement) is set so that the air flow and the refrigerant flow are opposed, thereby securing the heat radiation characteristics. Furthermore, the inlets and outlets of adjacent circuits are located in an assembled manner to avoid heat transfer, thereby increasing the heat radiation performance (**Figure 3**).

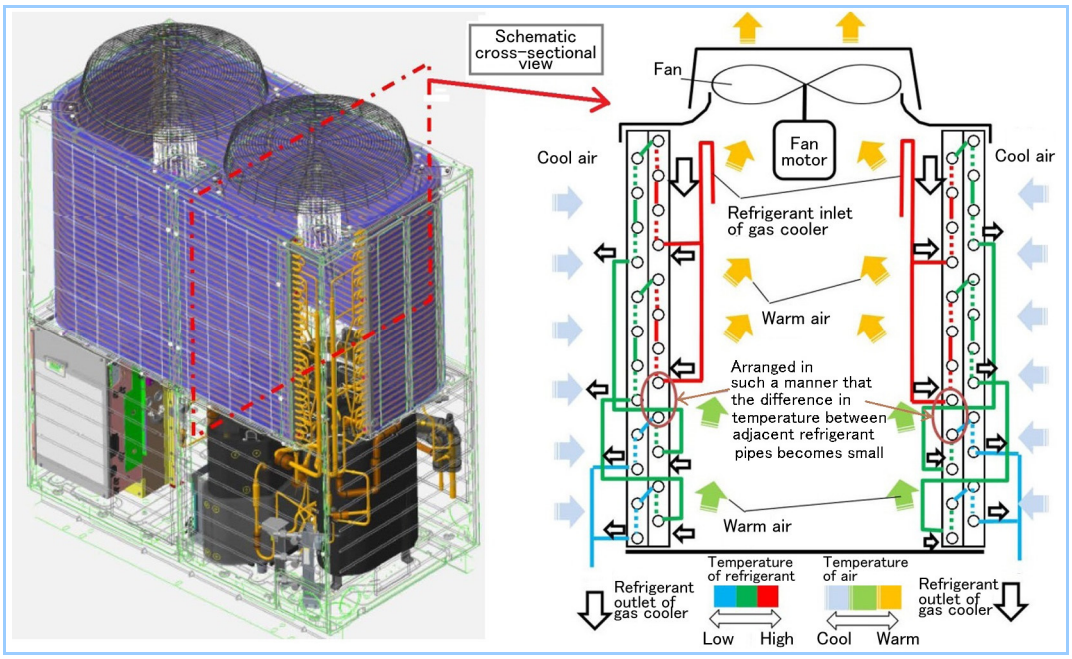


**Figure 3 Specifications of the "C-puzzle" 10-horsepower-type HCCV1001 gas cooler (allocation of paths)**

(5) Securing installation flexibility

Condensing units are installed in various places. Therefore, even if a long pipe is used to connect to the loading apparatus such as a unit cooler or a showcase, the condensing unit must be able to operate. In this case, the problems are the degradation of performance due to insufficient sub-cooling and the compressor running out of oil. To prevent the former, a sub-cooling coil is installed to optimize the sub-cooling control, thereby enabling the supply of refrigerant in a stable liquid phase to the loading apparatus. To prevent the latter, the number of revolutions of the compressor is controlled so that oil does not stay in the pipe, and the oil staying in the gas pipe and the unit cooler is returned to the compressor. These measures enable the installation with the maximum piping length being 100m and the maximum difference in height between the condensing unit and the loading apparatus being 22m (**Figure 4**).

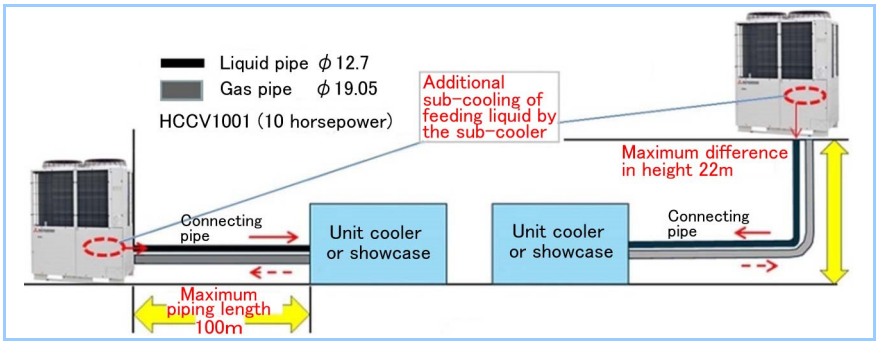


**Figure 4 Installation (Piping length and head difference)**

In addition, the air flow around the gas cooler is analyzed to optimize the flow of wind so that air warmed by the gas cooler is prevented from being drawn in, and multiple units can be continuously installed side by side, contributing to the saving in space (**Figure 5**).

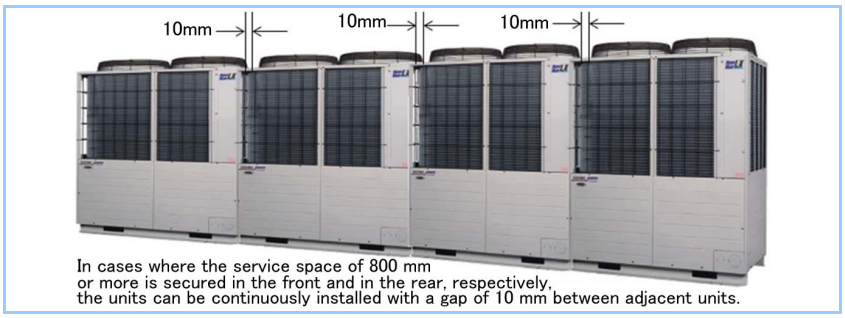


**Figure 5 Continuous installation**

(6) Advantages of introduction

With this product, the annual cost for electricity under both refrigerating and freezing conditions can be reduced by 16% compared to the conventional unit (using R22 refrigerant) and the environmental load is decreased (**Figure 6**). In addition, the report about the estimated leak amount which was required for HFC refrigerant is not required for $CO_2$ refrigerant.

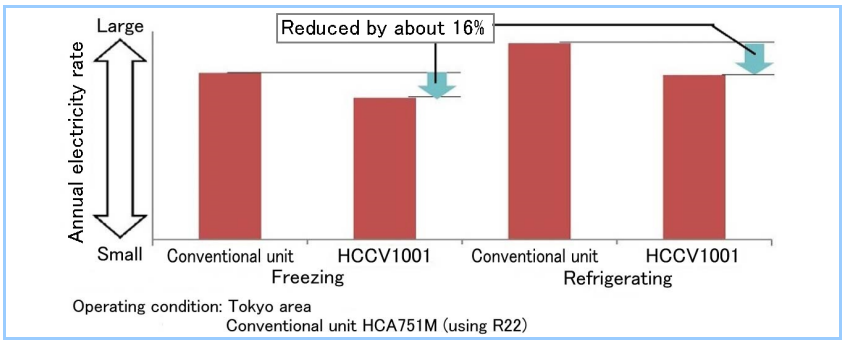


**Figure 6 Comparison of the annual quantity of electricity between the conventional unit (using R22 (10 horsepower)) and the HCCV1001**

## 2. Specifications of the product

**Table 2** shows the specifications of the "C-puzzle" 10-horsepower-type HCCV1001 that is already on the market.

**Table 2 Specifications of HCCV1001**

| | | |
|---|---|---|
| Model | | HCCV1001 (10 horsepower) |
| Application | | Refrigerating/freezing |
| Power | | 3 phase 200V 50/60Hz |
| Refrigerant used | | R744 (carbon dioxide) |
| Ambient operating temperature | | -15°C to 43°C |
| Operating temperature range | | -45°C to -5°C |
| Legal refrigeration capacity | | 2.98 tons |
| Design pressure | | High pressure: 14 MPaG, Low pressure: 8 MPaG |
| Compressor | Method | Two-stage compression Scroll+Rotary |
| | Drive system | DC invertor |
| | Number of units | 1 |
| Outside dimension | | Width 1350×Depth 720×Height 1690 mm |
| Product weight | | 340 kg |

## 3. Future development

The newly-developed "C-puzzle" commercial condensing unit that uses $CO_2$ as a natural refrigerant is environmentally friendly, and can also be handled as easily as the conventional unit using HFC refrigerant. In April 2017, we started the production and sale of a 10-horsepower-type condensing unit, and we plan to develop a 20-horsepower series which has a larger capacity. We will expand the application of these products not only to refrigerated warehouses and supermarkets, but also to plant facilities, thereby reducing $CO_2$ emissions and contributing to the conservation of the global environmental.