Development of the "Q-Ton" CO_2-Refrigerant Heat Pump for Industrial Water-Heater Systems for Use at Outside Air Temperatures Down to –25°C

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Traditionally, water and room heaters have mainly been powered by oil and gas burners. This trend is currently shifting toward heat-pump systems to achieve reduced carbon dioxide (CO_2) emissions which are thought to be a cause of global warming. In particular, heat pump water-heater systems with CO_2-refrigerant, which have a global warming potential (GWP) of 1, are already in wide domestic use in mild-climate areas, and are also seeing increased industrial use, owing to their ability to furnish a high-temperature water supply by exploiting their refrigerant characteristics.

In cold-climate areas, the reduced heating power and energy efficiency at low outside air temperatures leads to increased initial and operating costs, due to the increased number of installations required. This results in slow prevailing speeds for industrial systems in the cold-climate Hokkaido and Tohoku areas. Mitsubishi Heavy Industries, Ltd. (MHI), has developed an industrial water heater based on the "Q-ton ESA30" CO_2-refrigerant heat pump (hereinafter referred to as "Q-ton"), with a heating capacity of 30 kW, to solve these problems and contribute to the reduction of CO_2 emission. The new system adopts an innovative two-stage scroll-rotary (GSR) compressor for significantly improved heating capacity at cold outside air temperatures.

1. Features

(1) The world's first two-stage GSR compressor

"Q-ton" adopts the newly developed two-stage GSR compressor, which exhibits significantly improved performance at cold outside air temperatures. The GSR compressor is shown in **Figure 1**. It has two compression stages. The low stage has a rotary compressor mechanism that provides good compression efficiency at low-pressure ratios, while the high stage has a scroll compressor that provides good compression efficiency at high-pressure ratios. The inside of the housing is designed for medium pressure. This configuration offers the following advantages. The two-stage compression reduces the leak-loss during the compression stroke, and provides high compression efficiency. Refrigerant gas injection into the medium-pressure housing between the two compression stages enables increased refrigerant recirculation on the heating side (gas cooler), and increases the heating capacity.

(2) Refrigeration cycle based on gas injection into the GSR compressor at medium pressures

Figure 2 shows a refrigeration cycle using the GSR compressor. The two-stage compression allows the use of optimum medium pressure and control of the quantity of gas injected. The refrigerant is separated into liquid and gas after expansion, under optimum medium-pressure conditions, and gas-cooler refrigerant recirculation and heating capacity are increased in comparison to a single-stage compression cycle with direct gas inhalation into the compressor. The decreased amount of recirculated liquid refrigerant that flows into the vaporizer reduces the electric consumption in the compressor and increases the energy efficiency.

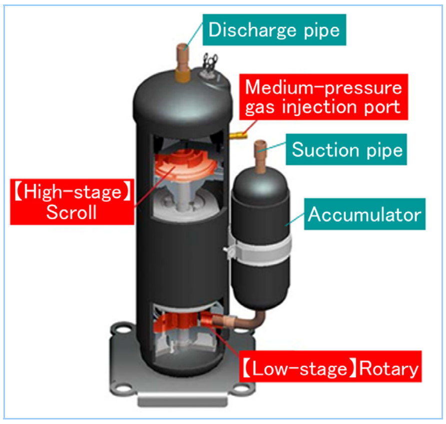

Figure 1 Two-stage GSR compressor

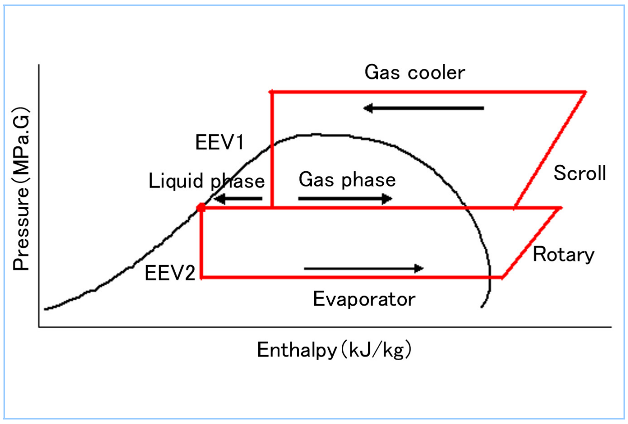

Figure 2 Refrigerant cycle – Mollier diagram

(3) Heating capacity and energy-saving characteristics of “Q-ton” compatible with low outside air temperatures

The heating capacity and energy efficiency (COP: coefficient of performance or heating power electricity consumption) of “Q-ton” are compared to those of other manufactured systems at various outside air temperatures in **Figures 3** and **4**.

Figure 3 shows the heating capacity at various outside air temperatures. The heating capacity in moderate seasons is assumed to be 100%. The heating capacity rate is the heating capacity at various outside air temperatures compared to the capacity at a moderate temperature. Inverter driven water heaters from other manufacturers exhibit capacity deterioration at an outside air temperature of 0°C, while “Q-ton” retains its full heating capacity at outside air temperatures down to –7°C. The other heaters exhibit capacity degradation of 70% or less at an outside air temperature of –15°C, whereas “Q-ton” retains a capacity of 70% or more at outside air temperatures down to –20°C.

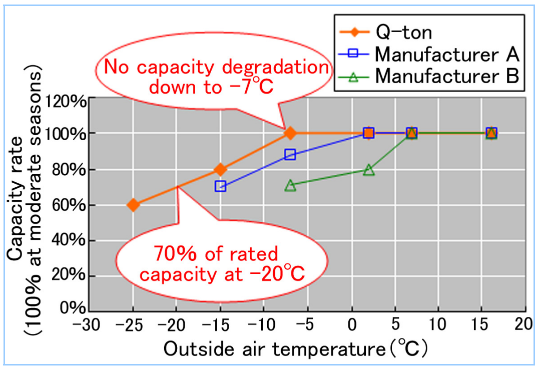

Figure 3 Heating capacity relative to outside air temperature

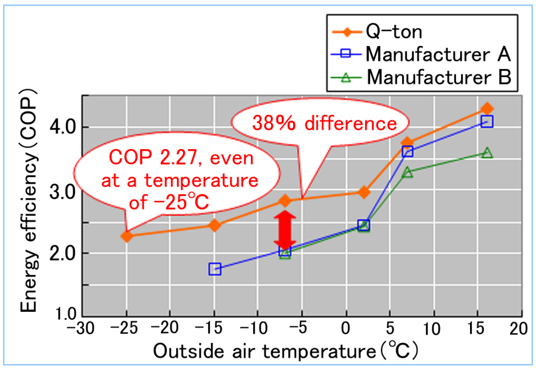

Figure 4 Energy efficiency relative to outside air temperatures

Figure 4 shows the COP variation with respect to the outside air temperature. All of the heaters have reduced COP at lower temperatures. “Q-ton” has the smallest COP reduction (COP = 2.27) at an outside air temperature of –25°C. Heaters from other manufacturers have COP values of 2.0 or less, while the COP of “Q-ton” is 38% higher. Assuming a 33% electricity generation efficiency at the terminal, this translates into a primary energy conversion efficiency of approximately 92%, which is better than that of a boiler.

Field tests were conducted using the new system as a substitute heater for a boiler in three cold-climate areas (Hokkaido, Iwate, and Toyama), beginning in December, 2010. The heating capacity, energy-saving performance, and reliability in a cold climate (including anti-freezing measures used for water pipes and drain water, defrosting and snow-removal of the outside heat exchanger, and the range of the refrigeration cycle and electrical equipment operation) were verified.

The reductions in operating cost and CO_2 emissions are listed in **Table 1**.

Table 1 Field tests

Cold climate area	Premises	Conven-tional fuel	Data acquisition period	Operating cost (compared to a conventional system)	CO_2 emissions (compared to a conventional system)
Hokkaido	Kitchen, restroom	Fuel oil	Dec. 2010 to Jan.2011	50%	65%
Iwate	Factory health facility	Kerosene	Jan. 2011 to March2011	43%	59%
Toyama	Boiler feed-water heating	Fuel oil	Jan. 2011 to Feb.2011	54%	53%

Figure 5 Touch-panel remote controller

The electricity fees were calculated from the power consumption at each site, and the fuel costs were calculated from the conversion of heating energy to the conventional boilers. The electricity consumption includes the energy consumed by the anti-freezing heater for the water pipes in the system. The operating costs were reduced to 43% to 54%, and CO_2 emissions to 53% to 63%, compared to the existing heater. Since we were able to observe improvement in running cost and CO_2 emissions in colder seasons, it is expected to result in a much higher COP during moderate and summer seasons when the outside air temperature is higher. Therefore, the operating costs and CO_2 emissions are expected to be reduced to approximately one third of those of the current system over a whole year.

In Hokkaido, the outside air temperature is occasionally below -20°C. It was verified that a hot water temperature of 90°C (as a planned heating capacity) can be readily obtained under these conditions via heat pump operation.

(4) Touch-panel remote controller allows finely adjusted operation for energy savings

In an industrial water heater based on a CO_2-refrigerant heat pump, for improved energy-saving performance, it is necessary to control the heat source to achieve heat-storage operation compatible with onsite hot water requirements. The main remote controller (**Figure 5**) provides a peak-cut timer, a weekly timer, a setting function for stored hot water temperatures, a transition chart showing stored hot water quantities, and an on-screen user manual based on customer requirements. Also, a single remote controller can control a unit with a heating capacity of 30 kW and up to 16 coupled units (a total of 480 kW) for better operability.

(5) Unvented or open vent tank selection according to customer requirements

Unvented or open vent tanks can be applied per customer request, and for easy replacement of existing heaters. The heat source unit is compatible with both tanks, facilitating wide market applicability.

2. Specifications

Table 2 lists the “Q-ton” specifications.

Table 2 “Q-ton” specifications

Specification			“Q-ton” ESA30
Moderate season heating capacity* Outside air temp. 16DB/12WB Water in at 17°C, out at 65°C	Heating capacity	kW	30
	Electricity consumption	kW	6.98
	COP	—	4.3
Winter season heating capacity* Outside air temp. 7DB/6WB Water in at 9°C, out at 65°C	Heating capacity	kW	30
	Electricity consumption	kW	8.0
	COP	—	3.75
Dimensions	H×W×D	mm	1,690×1,350×720
Weight		kg	365
Refrigerant			R744(CO_2)
Operating temperature range	Outside air	$^{\circ}$C	−25 to 43
	Water inlet	$^{\circ}$C	5 to 63
	Water outlet	$^{\circ}$C	60 to 90

* The measuring conditions for heating capacity, electricity consumption, and COP were compliant with JRA4060 of the Japan Refrigeration and Air Conditioning Industry Association performance for industrial heat-pump water heaters