

CO₂ Vending Machines

By Sanyo Electric Co., Ltd.

Abstract

This paper describes CO₂ compressors and systems for light commercial refrigeration applications such as vending machines. The natural refrigerant CO₂ (R-744) has the potential to replace HFC-based applications, as it has no Ozone Depletion Potential (ODP) and a negligible Global Warming Potential (GWP) of just 1. Furthermore, as CO₂ features better efficiency for heating, Heat Pump Water Heaters (HPWH) using CO₂ refrigerant have been sold in Japan since 2001. The main challenge to apply CO₂ for refrigeration applications was its lower theoretical efficiency and the fact that CO₂ systems operate at 3 to 5 times higher working pressure than the conventional HCFC and HFC-based systems. Sanyo's rotary 2-stage compressor developed for HPWH was applied to refrigeration applications with suction line heat exchangers and intercoolers to address the lower efficiency. As a result, lower indirect emissions were attained as well as lower direct emissions with no ODP and negligible GWP.

1. Background

In the vending machine industry, HCFC refrigerants have already been phased out and replaced by HFCs, such as R134a, R407C and R404A. Although these refrigerants have no Ozone Depletion Potential (ODP), they have a high Global Warming Potential (GWP), of more than 1000. As refrigerant leakage happens throughout the life cycle of the equipment, the use of these refrigerants is having a negative impact on global warming. Natural refrigerants are thus preferred as the post-HFC refrigerant. Among them, carbon dioxide (CO₂) can be considered as one of the best solutions due to its properties, as shown on Table 1.

Table 1: Refrigerant Characteristics

Type	Refrigerant	ODP	GWP	Flammability	Toxicity
HCFC	R22	0.055	1700	No	No
HFCs	R134a	0	1300	No	No
	R407C	0	1530	No	No
	R404A	0	3260	No	No
Natural Refrigerants	CO ₂	0	1	No	No
	HC	0	3	YES	No
	NH ₃	0	~ 0	No	YES

2. Development of Alternative

Sanyo has produced CO₂ compressors since 2001, originally developed for Heat Pump Water Heaters (HPWH), where CO₂ refrigerant has the efficiency advantage.

Sanyo CO₂ compressors have the unique feature of a rotary 2-stage compression mechanism, with internal intermediate pressure structure, to address the higher working pressure of CO₂ refrigerant. CO₂ operates under 3 to 5 times higher working pressure than conventional refrigerants, which in turn makes the pressure difference larger.

The 2-stage compression mechanism divides the compression load into 2 compressions. This mechanism reduces the leakage at the seal so that high compression efficiency can be attained. In

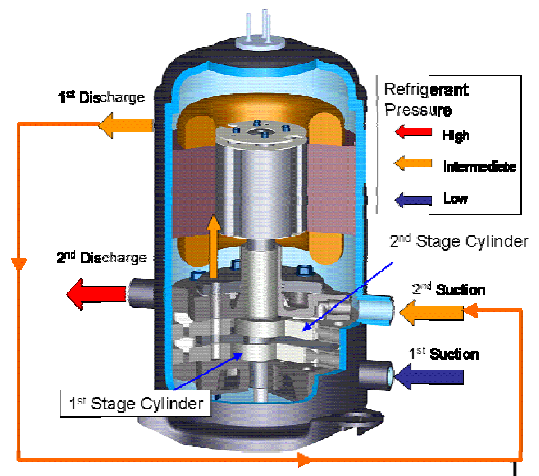


Figure. 1 CO₂ Compressor Refrigerant Flow

addition, two pistons located at opposite directions off-set and reduce the vibration made by each compression. The refrigerant compressed at the 1st stage cylinder is discharged to the shell so the shell pressure is kept at intermediate pressure. The intermediate pressure refrigerant is then taken into the 2nd stage cylinder and compressed to the final discharge pressure, as shown on Figure 1.

Internal intermediate pressure structure enables the shell wall thickness to be 35% thinner than that of typical internal high pressure structure, while keeping the high reliability of the compressor shell. In addition, the higher density of CO₂ refrigerant, compared to conventional refrigerants, enables the reduction in piston size. Further, the combination of internal intermediate pressure structure and the higher density of CO₂ allow for the reduction in the weight of the compressor.

3. Bringing the Alternative to Market

3-1 System Performance Improvement

Although the high working pressure issue was addressed by the 2-stage compression mechanism with internal intermediate pressure structure, the lower efficiency for the refrigeration applications also needed to be addressed. The solution was the combination of suction line heat exchanger (SLHX) and intercooler (IC) as shown on Figures 2 and 3 (SLHX : 5→6 / 8→1, IC : 2→3).

A suction line heat exchanger (SLHX) can be located after the evaporator on the low pressure side, and after the gas cooler on the high pressure side. As the high side pressure operates above critical point, and the high pressure refrigerant does not condensate, the high side heat exchanger is called “gas cooler”. SLHX increases the cooling effect on the evaporator. However, adding a SLHX also increases the discharge temperature due to the higher suction temperature. Higher discharge temperature becomes more critical at the high load condition for the reliability of the refrigeration system.

The adoption of an intercooler (IC) can solve this issue. An IC can be located between the 1st discharge and the 2nd suction. By cooling the intermediate pressure refrigerant after the 1st stage discharge, the final discharge temperature can be reduced. An IC can be applied only for 2-stage compression mechanism. Isentropic efficiency improvement from intermediate to high pressure can be also expected since the isentropic curve is steeper with lower enthalpy.

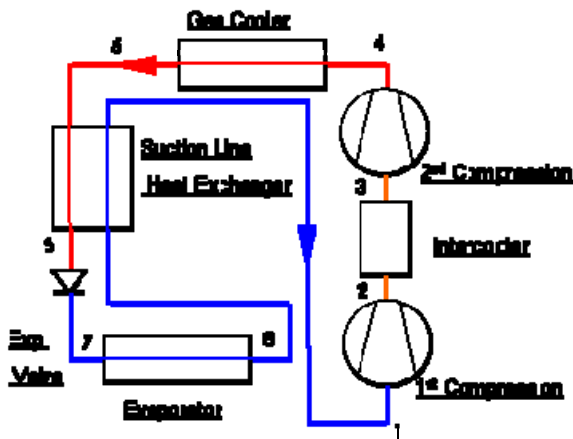


Figure 2 CO₂ refrigeration cycle

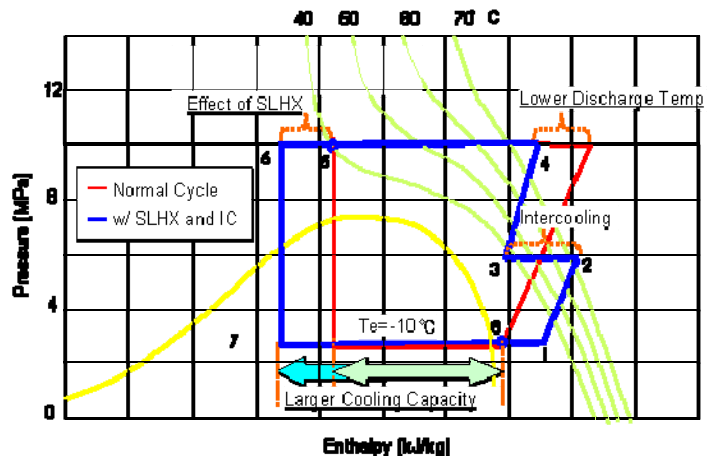


Figure 3 P-h Diagram of CO₂ cycle with SLHX and IC

3-2 Replacement from Existing Refrigeration System

In order to compare the CO₂ refrigeration system with an existing HFC-based one, a first field test was conducted from February 2004 in Australia. The CO₂ refrigeration system was optimized to keep the same pull down performance, cooling fans, light and physical sizes of the installation room as the produced by a R134a-based vending machine system. Power consumption of each system was measured in the field by the data

acquisition system. Results show that 17% lower energy consumption by the CO₂ system consumes 17% less energy compared to the R134a system during the summer season.

4. Impacts of Switch to Alternative

After the initial research and development described above, CO₂ refrigeration technology started to be applied to the commercial refrigeration market as a feasible alternative. Updates on recent activity and technology are given below, including the latest model for the largest and most successful application of CO₂ refrigerant so far all over the world, Heat Pump Water Heaters (HPWH).

4-1 Japanese Vending Machine Market

CO₂ and Hydrocarbons (HC) vending machines are already being sold in the Japanese market. Almost all major beverage companies in Japan have started to purchase vending machine using natural refrigerants. This transition started in 2005, and sales of CO₂ vending machines are increasing every year. The cumulative quantity of total CO₂ vending machines in the market is over 30,000. In some cases, the label shown on Figure 4 is presented on the front side of the vending machine, in order to let the consumer recognize that the vending machine uses environmental friendly technology. The label shows “Environmental Friendly Non-Freon Vending Machine, cooled by Natural Refrigerant (CO₂)”.



Figure 4 Natural Refrigerant Label

4-2 Acceleration by The Coca-Cola Company world wide

Outside Japan, CO₂ for light commercial refrigeration use has been introduced by the strong leadership of The Coca-Cola Company. More than 8,500 CO₂ compressors for The Coca-Cola Company’s machines have been installed to date. Some of the machines include a module refrigeration system called “Cassette,” which allows for the easy replacement of refrigerant—ideal for technicians without expertise in the servicing/maintenance of refrigeration equipment containing natural refrigerants. As CO₂ system requires a special tooling for servicing, the cassette concept is a good solution. At the upcoming Olympic games this summer in Beijing, 5,000 CO₂ Cassettes will be installed.

4-3 Hot and Cold Vending Machine

An example of the latest technology developed with CO₂ is the Heat Pump Vending Machine (HPVM). A unique model for the Japanese market is the “Hot and Cold” vending machine type, that provides both hot and cold beverages in one machine. While typical machines have an electrical heater for hot drinks, the HPVM heats those with a CO₂ heat pump cycle. HPVM achieves up to 40% better energy efficiency (lower consumption) than typical electrical heater system.

4-4 Heat Pump Water Heater

Heat Pump Water Heater (HPWH) in Japan, under the name of EcoCute, is the biggest and most successful market for CO₂ refrigerant all over the world. The market volume of HPWH in Japan is rapidly growing every year, and reached over 1 million units in 2007. One of the reasons for this success story is the strong collaboration between government, electric power companies and manufacturers, together with lower running cost of CO₂ HPWH compared to conventional water heaters. Its annual market volume in Japan is expected to grow by more than 500,000 units in 2008.

4-5 Future Overview

Sanyo has manufactured CO₂ compressors not only for HPWH but also for light commercial refrigeration systems. Sanyo’s unique 2-stage compression mechanism and wide lineup offers the potential to introduce CO₂ technology to other applications such as open-front showcase and ice cream showcase. Under the corporate vision, “Think GAIA”, Sanyo positions itself as the leading provider of Environment and Energy related Products and Services, and CO₂ technology will be a part of benefits that Sanyo provides.

The latest example from Sanyo’s CO₂ products is the new HPWH that applies a unique cycle option called “Split Cycle”. As shown on Figures 6 and 7, “Split Cycle” applies an Internal Heat Exchanger by splitting the refrigerant flow. That cycle option is applicable thanks to a 2-stage compressor. CO₂ HPWH with “Split Cycle” has a larger heating capacity and better efficiency, especially at cold regions, where the evaporating pressure becomes lower

and the pressure difference becomes larger. Sanyo is proud to launch this product in Northern Europe this spring.

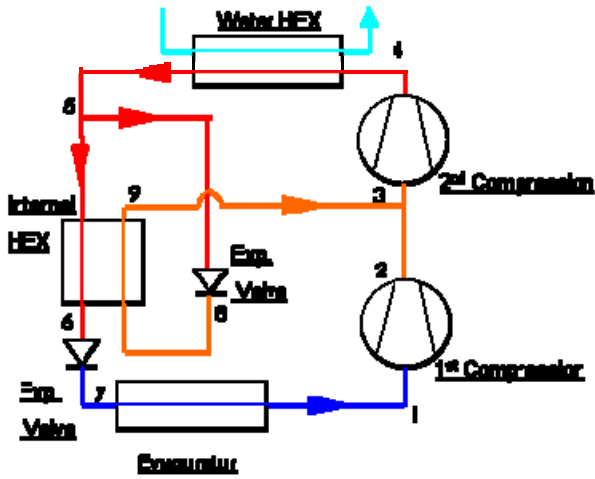


Figure 6 Split Cycle for HPWH

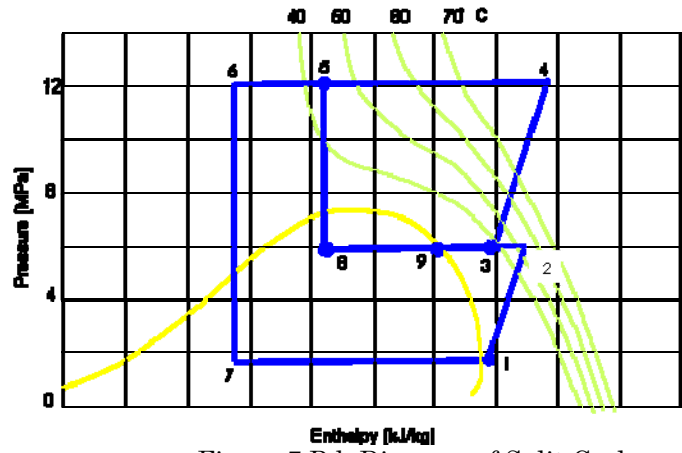


Figure 7 P-h Diagram of Split Cycle

For more information, contact:

Daiki Shiomi
 Sanyo Compressor Chicago CRM
 Tel: 630 694 8241
 dshiomi@attglobal.net