The development of the 9kW CO$_2$ Heat Pump water heater (3 phase 400V) for the European market

Sebastian Merino, Yasuhiro Kobori, Hideki Ito
SANYO Electric Co., Ltd, Commercial Solutions Company, 1-1-1, Sakata, Oura- Gun, Oizumi-Machi, Gunma, 370-0396, Japan

Abstract: Here in Japan the sales of the CO$_2$ heat pump water heaters “ECO CUTE” (that use CO$_2$ natural refrigerant) are increasing year by year. Moreover, the multifunction version of the ecocute has being requested from the market, so SANYO put on the market the first multifunctional (Domestic hot water and space heating) unit for cold areas. In this time SANYO adopted this technology and developed the first 9kW CO$_2$ Split-cycle unit (for household use) for the European market.

Key Words: CO$_2$ Refrigerant, Natural Refrigerant, Heat pump, Split-Cycle

1 INTRODUCTION

In recent years, the policy for environmental problems has been moved forward by the international community, and global warming problems are the most important above all. According to the assessment report of the Intergovernmental Panel of Climate Change (IPCC), even if each country practiced the actually climate change relieve deals and a continually technology development, the global warming gasses are expected to continue increase for the next dozens of years. In that case, there is a high possibility that the increase of the world temperature will exceed the increase of the 20 century (average: 0.6°C)

As a solution to this problem, here in Japan “ECO CUTE” (environmental friendly hot water supply system) has been promoted. This system received the subsidy of the Japanese government from its launching to the market in June of 2001, and 1 million of units have been sold until September of 2007.

Now that Freon (CFC, HFCFC) that was conventionally used as refrigerant for heat pumps is determined to be totally prohibited to protect the ozone layer and also HFC is regulated as a global warming gas, the natural refrigerant heat pump water supplier “ECO CUTE” use natural refrigerant CO$_2$ in its heat pump unit.

If we compare the CO$_2$ refrigerant with other natural refrigerants besides be non flammable and non toxic, it is a refrigerant adequate to maintain the unit capacity at low outdoor temperatures and to produce hot water of high temperatures. SANYO Electric Co., Ltd. has put on the Japanese market a system co-developed with Hokkaido Electric Power Co., Inc. and available to provide heating and hot water for the tap until -25°C of outdoor temperature.

In the overseas market, the European countries; advanced nations in environmental issues had a very dramatic popularization on heat pumps systems because these are very efficient energy equipments. SANYO planned the introduction to the European market of a CO$_2$ heat pump using the technology and experience obtained in the Japanese market and launched a 4.5kW unit in spring of 2005, but this time we launched a 9kW unit that make it possible to cover a bigger part of the market.

2 THE HEAT PUMP MARKET IN EUROPE

2.1 Market

The subsidies from the government are mainly promoting the markets of Germany and France. Scandinavia (Sweden, Finland, Norway) that was the core market has also continued a gradually increase and now it became a stable market. The progress in the heat pump market is shown in Graph 1
2009 was also expected to show an increase in the market, but the recession and the reduction of the subsidies brought a slowdown in the market growth.
But if we look it in a medium term we can expect the restoration of the Economy and also the first term of the Kyoto protocol is ending in 2013 and this will bring a big increase in the reduction amount duty. So it is expected the support of each country in order to reduce the Greenhouse gasses.

2.2 Market characteristics

If we classify the Heat pumps used in Europe by the type of renewable energy that they use, the capacity of the unit and the power supply type, it is as follows below.

2.2.1 Heat pump classification by type of used energy

The heat pumps in Europe can be divided in 3 types according to the type of renewable energy used
① Ground source type; pumps the heat from the ground
② Exhaust type; pumps the heat from the ventilation exhaust
③ Air to water type; pumps the heat from the outdoor air.

The ground source type dominated the conventional European market but the percentage of the air to water type has been increasing very sharply in this 5 years because its performance improvement in very low temperatures and because they are very easy to install.

Graph 2 shows the change of the heat pump market when it is classified by type of used energy from 2003 to 2008.

2.2.2 Classification by heat pump capacity

The line up for household use and professional use is from units smaller than 5kW to units bigger than 20kW. When the heat pumps are classified by its capacity, the proportion occupied in the marked is different area by area.

Graph 3 shows the Heat pump sales situation classified by the unit capacity.
The class of 7-10kW is the biggest and occupies around 60%; having a capacity of 10kW it is possible to cover the 85% of the European market. With the 9kW unit that we developed, we think that we are available to cover the 80% of the European market.

2.2.3 Classification by power supply

The 3 phase 400V power supply occupies the major part of the market, but there are also areas of single phase 230V and 3 phases 230V.
As there are 3 types of power supply it was necessary to launch a product suitable to every type of power supply. Figure 1 shows the distribution of the power supply in the European countries.

3 DEVELOPED PRODUCT

3.1 Characteristics

Based in the technology of the multifunctional CO₂ HP for the cold areas of Japan, We developed a 3 phase 400V 9kW HP as an air to water type heat pump system for space heating and hot tap water. The capacity was set to 9kW from the necessary heating load of a model house in Sweden. The used power supply is 3 phases 400V that is the most used in Europe. The CO₂ heat pump water heater system that we developed this time is composed by a 9kW Heat pump unit and a tank unit. The system is able to be used for heating and hot water supply for the tap below very hard conditions in the cold areas of Europe. The characteristics of the CO₂ system that we developed are the following:

1. It uses a Split-Cycle that makes it possible to maintain the maximum capacity of 9kW until -15 °C of outdoor temperature and 8kW until -20°C.
2. The nominal heat pump efficiency (COP) achieved more than 3 (at 7°C of outdoor temperature)
3. The heat pump was designed for cold areas so the operation of heating and hot water supply for the tap is guaranteed until-25°C of outdoor temperature.
4. The system carries an active filter for 3 phases 400V and it fulfills the European standard for harmonic current emissions (EN-61000-3-2). The system also carries a CO₂ compressor developed to obtain high output capacity. The capacity of the compressor is 3000W.
5. The maximum outlet temperature from the HP is 65°C and the HP is also available to supply this temperature until -25°C. This almost avoid the using of the auxiliary electric heater housed in the tank unit.

3.2 System outline

The system is composed by a Heat pump unit and a tank unit. Figure 2 shows the outline of the system. The water is heated in the heat pump unit and put on the tank, then this water is used to heat directly the heating terminals and to make hot water for the tap indirectly (using the hot water coil inside the tank).
The tank unit carries 2 electric heaters, one in the upper part used when the hot water consumption is too much and it cannot be totally corresponded by the heat pump unit, and another one in the bottom of the tank that is used for emergencies.

4 DEVELOPED TECHNOLOGY

The development target for the 3 phase 400V 9kW CO₂ heat pump unit was the maintenance of the capacity in low outdoor temperatures and high efficiency in order to obtain a system for all the areas of Europe including the severe cold areas of North Europe.

The following 3 Technologies were necessary to achieve the development target mentioned above.

1. Optimization of the refrigerant circuit by the improvement of the Split-Cycle circuit.
2. Development of an active filter for 3 phase 400V power supply
3. Development of a high output capacity CO₂ compressor

4.1 Optimization of the refrigerant circuit

In order to maintain the capacity in low outdoor temperatures and obtain high efficiency, the Split-Cycle circuit adopted in the multifunctional (heating and hot water supply) CO₂ heat pump system for cold areas co-developed with Hokkaido Electric Power Co., Inc. was improved.

The Split-Cycle is a refrigerant cycle developed by SANYO to maximize the performance of the circuits that uses its 2 stage compression compressor.

A portion of refrigerant after gas cooler is bypassed and adiabatically expanded to the compressor intermediate-pressure level. The remaining main refrigerant flow temperature is decreased using the resulting cooling effect from the bypassed refrigerant, thereby increasing the heat absorption from the air. Figure 3 shows the Split-Cycle refrigerant circuit and Graph 4 shows the P-h diagram.

![Figure 3. Split-Cycle refrigerant circuit](image)

![Graph 4. P-h Diagram](image)
The challenge of this development was the control of the sub-expansion valve to get the ideally opening position to obtain a stable operation avoiding the liquid compression of the refrigerant that is returning to the intermediate pressure port of the compressor. And the solution was to control the super heat equipping temperature sensors in the inlet and outlet of the internal heat exchanger. We are managing it to return always gaseous refrigerant a to the intermediate pressure port of the compressor, controlling the sub-expansion valve to maintain the same temperature difference between the inlet and outlet of the internal heat exchanger. By returning gaseous refrigerant to the intermediate pressure port, the temperature of the gas inducted to the 2nd compression stage of the compressor decrease, and this prevents that the discharge gas temperature increase too much making it possible to maintain the capacity even at low outdoor temperatures and also to obtain high efficiency. Graph 5 and 6 shows the comparison of the Split-Cycle and a conventional cycle (The conventional cycle was simulated by closing the sub expansion valve of Figure 3).

### 4.2 3 phase 400V active filter

The active filter was developed for 3 phase 400V power supply that occupies the biggest part in the market. This filter is able to supply the compressor drive power and also to control the power supply harmonics. The development target was to increase the output capacity of the compressor drive power supply during electrical high load situations to be able to maintain the heat pump capacity even in low outdoors temperatures and also be in conformity with the European power supply harmonic standards. Its circuit mode is a single-switch voltage converter mode and its control mode is a critical conduction mode, this reduce the heat radiation of the elements by a switching motion when the incoming current to the inverter is 0 to carry out high efficiency and reduce the electrical noise. The critical conduction control mode is a variable frequency control technique that controls stable the input current eliminating the rectifier loss. This mode has a superior power conversion characteristic compared with the continuance conduction mode because its rectifier loss is lower and the inductor current is not continuance. Moreover, we used the alternative input voltage and take a reference signal from the 3 phase input voltage waveform and controlled the inductor current peak to be a sine wave. This made possible to control the power supply harmonics.

### 4.3 High capacity CO₂ Compressor

The carried compressor needed to have a higher output capacity than the conventional one and the points for the development were kept compact the body in order to secure its efficiency, carry-ability, and the maintenance of the low cost. The conventional compressor type output capacity was 2200W but the new one achieved 3000W. In the other hand the weight is almost the same and also the height was 10% reduced.
Regardless the exhaust volume of the compressor was increased 33% in order to increase the output capacity, the height increase of the motor was kept under 6.6%. Moreover, the structure of the suction line of 2nd compression stage was reviewed and the conventional external line was changed for an internal suction line. This made it possible to reduce the cost of the material and reduce the size of the compressor. Figure 4 shows the compressor.

The improved points are the following.
1. The optimization of the discharge port diameter to reduce the discharge resistance and the expansion loss.
2. The optimization of the 2nd compression stage induction port form.
3. The review of the drive section form and the reduction of the machine loss. The principal change was the reduction of the bearing resistance loss by the change of the main bearing.
4. The change of the 2nd compression stage suction line from an external line to an internal one to reduce the discharge gas heat radiation loss.

These points brought an improvement of 7～10% in the efficiency

5 RESULTS BY THE INTRODUCTION OF THE CO₂ HEAT PUMP

If the popularization of environmental friendly Heat pumps advanced, it could be possible to contribute with the CO₂ reduction that each government is working on. The 3 phase 400V CO₂ heat pump system that we have developed this time made it possible to reduce approx. 20% the CO₂ exhaust amount compared with the conventional air to water heat pumps. (The calculation of the exhaust amount of CO₂ was done using the average temperature of the north, mid and south of Sweden)

6 NEXT CHALLENGE

As equipment available to reduce the global warming effect by the using of natural refrigerant, it is necessary to expand our line up meeting the needs of the market and increase the efficiency of the system to popularize internationally this air to water CO₂ heat pump

6.1 Action to expand the market

Heat pumps for commercial use are expected to become more popular in the market. The collaboration with the environment is one of the Social obligations that companies have, and also there are companies that use natural refrigerant as a kind of collaboration activity with the environment.

For the development of a commercial use unit it will be necessary to have high capacity and be able to answer to diverse needs.

So as one solution, we can mention the development of a control box for multi-connection. The point for this development is to make it possible to obtain high capacity by the multi-connection of various units and optimize the unit operation under diverse use conditions.

6.2 High efficiency

There are 2 types of approaches for the aims of high efficiency. One is the improvement of the heat pump efficiency and the other one is the improvement of the total system efficiency.
1. Heat pump improvement: It is necessary to advance the development improving the basic components; compressor, evaporator, water-refrigerant heat exchanger and the method to control them in accordance to the subsidy programs of each country.

2. System improvement: Considering the results of our monitor in the north of Sweden it is necessary to increase the availability to customize the system for each kind of use. For example, make it possible to set the unit to use the sanitary as a main function and the heating as a secondary function or the reverse.

7 CONCLUSION

The Global warming gasses reduction target after the Kyoto protocol is 20% reduction on the exhaust amount of 2020 compared with 1990 in the European Union and there are also countries that have a more severe interim reduction plan. For example Germany has a reduction plan of 40%, so the environmental friendly products that are designed according this government plan are expected to be expanded very soon in the market.

The CO₂ heat pump technology can cooperate with the earth environment improvement, so we would like to promote this technology not only to EU but also to other countries of the world.

8 REFERENCES
