Technology for Applying Heat Pumps to Beverage Vending Machines

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ABSTRACT

Beverage vending machines, widely used for their convenience, are required to improve their energy efficiency. Fuji Electric has developed a technology for beverage vending machines to expand the use of heat pumps between internal compartments and improve energy efficiency. An electronic expansion valve is used to precisely control the amount of refrigerant expansion to maintain the target evaporation. This load adjustment operation based on the evaporation temperature allows the adjustable operating range of the heat pumps to be expanded. PID control keeps the condensation temperature to match the target value. This technology was able to run vending machines only on heat pumps between internal compartments, thereby saving approximately 4% of energy.

1. Introduction

Beverage vending machines are highly convenient products that readily provide beverages at ready-to-drink temperatures 24 hours a day. There are approximately 2.25 million vending machines in use in Japan. Since beverage vending machines consume energy, they were designated as special equipment in the Act on the Rational Use of Energy (Energy Conservation Act) in 2002 and are required to achieve a higher level of energy efficiency. Fuji Electric has been involved in the development of various technologies, including heat pumps. In this paper, we will describe a heat pump application technology for beverage vending machines that sell both canned and bottled beverages.

2. Heating and Cooling Mechanisms in Beverage Vending Machines

2.1 Internal structure and operation of beverage vending machines

Figure 1 shows the internal structure of a beverage vending machine. A typical beverage vending machine has three product storage chambers (left, middle, and right) inside the storage compartment and a machine room outside the storage compartment. In terms of product storage racks, in addition to the standard racks, which mainly hold small-capacity canned beverages of 350 ml or less, plastic bottle racks are used to hold large-capacity beverages in 500 ml plastic bottles. There are also a wide variety of width and depth dimensions for beverage vending machines, depending on the type of product to be stored.

Beverage vending machines have built-in heat pumps to cool and heat drinks. Each storage chamber can be divided into a cooling chamber or heating chamber depending on the type of product. In typical vending machines, the left and middle chambers serve as both cooling and heating chambers, while the right chamber is dedicated to cooling.

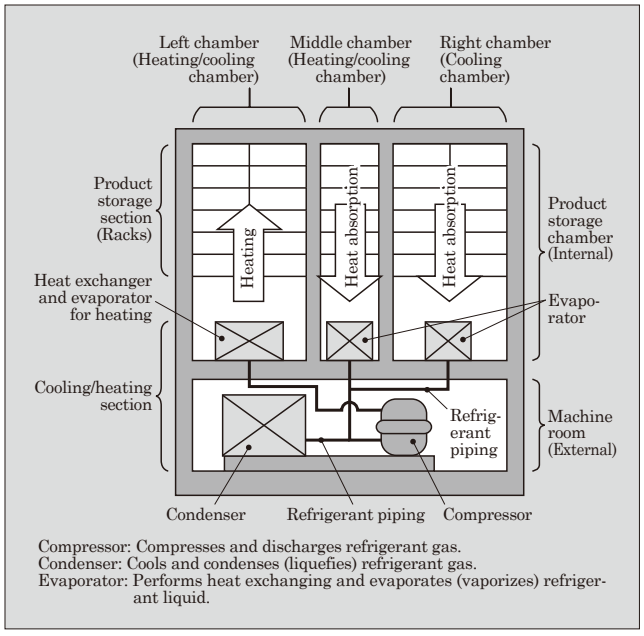

Fig.1 Internal structure of a beverage vending machine

Table 1 shows the different uses (operation modes) of the cooling and heating chambers for beverage vending machines. There are four operation modes, and most of the time, during the summer season, all three chambers are operated in the CCC mode for cooling. During other seasons, cooling and heating operations are switched depending on sales trends and other factors, but in actual operation, the HCC mode shown in Fig. 2 is used for most of the year. Therefore, a reduc-

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Table 1 Operation modes of beverage vending machines

Operation mode*	Left chamber (Heating/cooling chamber)	Middle chamber (Heating/cooling chamber)	Right chamber (Cooling chamber)	Main operating seasons
CCC	Cooling	Cooling	Cooling	Summer
HCC	Heating	Cooling	Cooling	Spring and Autumn
CHC	Cooling	Heating	Cooling	Spring and Autumn
HHC	Heating	Heating	Cooling	Winter

*C: Cold; H: Hot

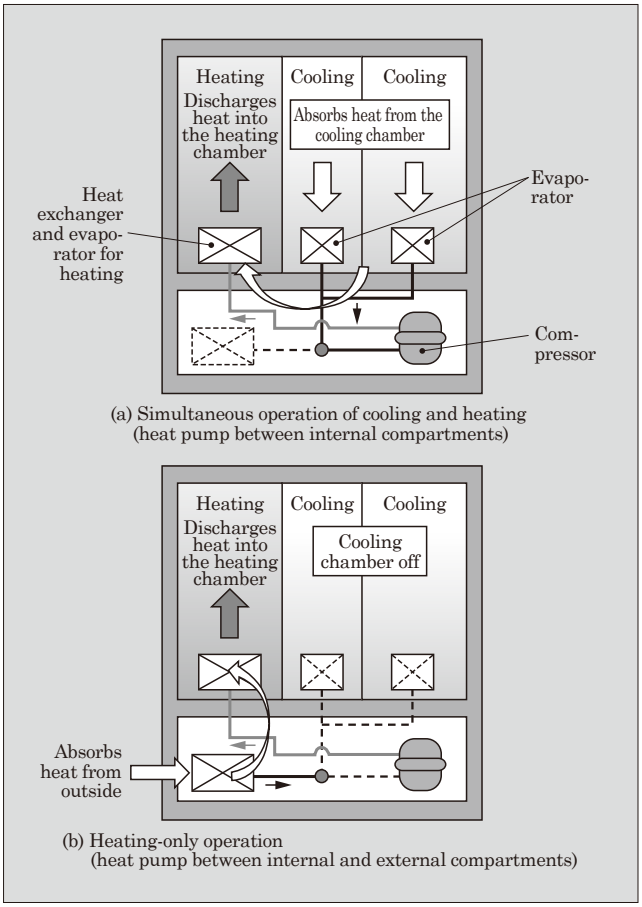

Fig.2 Heat pump mechanism of beverage vending machines (HCC operation mode)

tion in power consumption in this operation mode can be expected to have a significant energy-saving effect.

2.2 Heating and cooling mechanisms of heat pumps

Heat pumps are called heat transfer pumps and are used, for example, in residential air conditioners for cooling and heating. In the case of heating, air conditioners are used to heat indoor rooms by collecting heat from the outdoor air with very little electrical energy. In the case of cooling, air conditioners are used to cool indoor rooms by collecting heat from the indoor air and releasing hot air outside. In contrast to air conditioners, which switch between cooling and heating, beverage vending machines simultaneously perform cooling and heating by drawing heat from cooling chambers so that it can be used in the heating chamber.

Products in the heating and cooling chambers are required to be kept within an appropriate temperature range. In principle, heat pumps cannot perform cooling and heating separately. Therefore, they need to cool the cooling chambers and heat the heating chambers in sync. In conventional beverage vending machines, the heat pump between internal compartments [see Fig. 2(a)] is controlled primarily for the cooling chamber and secondarily for the heating chamber. For example, if the ambient temperature is 15°C, the temperature difference between the cooling chamber temperature of 5°C and the heating chamber temperature of 55°C will be 10 K and 40 K respectively. Since the load for heating is higher, an insufficient amount of heat will be provided to the heating chamber. To compensate for this, an external heat pump [see Fig. 2(b)] is installed between internal and external compartments to draw heat from the air outside the chamber. Figure 3 shows the operation of the heat pump. When the temperature in the cooling chamber rises to the set temperature, the heat pump between internal compartments begins operating, cooling the cooling chamber and heating the heating chamber. When the temperature in the cooling chamber drops to the set temperature, the heat pump between internal compartments stops. At this point, however, the heating of the heating chamber is insufficient. Therefore, the heat pump between internal and external compartments is immediately started to continue heating the heating chamber. When the temperature in the heating chamber reaches the set temperature, the heat pump between internal and external compartments stops. After this, the process is repeated when the

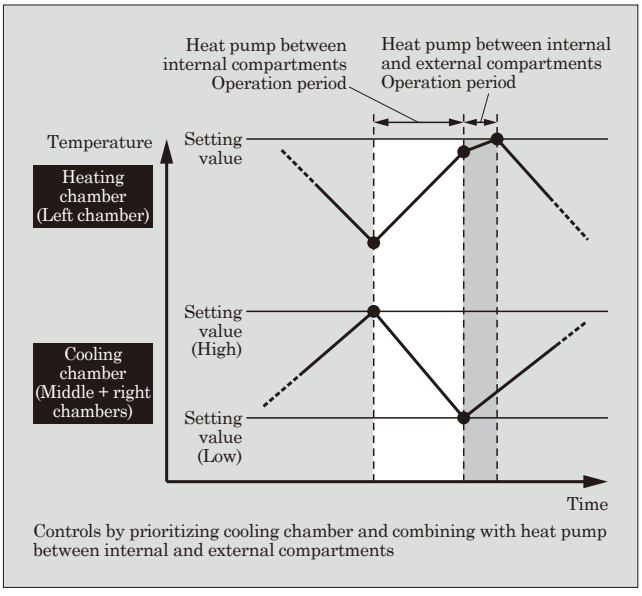

Fig.3 Operational behavior of a heat pump (conventional machine)

temperature in the cooling chamber rises again.

The heat pump between internal and external compartments is used only for heating by drawing heat from outside the chamber. It is less efficient than the heat pump between internal compartments that performs heating and cooling at the same time. In order to save energy, it is necessary to reduce the usage of the heat pump between internal and external compartments.

3. Improving the Operating Efficiency of Heat Pumps

To solve the issues described in Section 2.2, we developed a technology that performs heating and cooling using only the heat pump between internal compartments, eliminating the need of the low-efficient operation of the heat pump between internal and external compartments.

3.1 Balancing heating and cooling capacity by controlling evaporation temperature

Conventional heat pumps between internal compartments have insufficient heating capacity relative to cooling capacity. However, by changing the temperature at which the refrigerant in the evaporator evaporates (evaporation temperature), it is possible to change the ratio of cooling capacity to heating capacity. Figure 4 shows the relationship between the refrigerant evaporation temperature and the ratio of cooling capacity to heating capacity in our newly developed vending machine. The ratio of heating capacity to cooling capacity increases as the evaporation temperature increases. By controlling the evaporation temperature by changing the flow rate of refrigerant at the expansion valve, cooling can be delayed and the heat pump can be controlled so that the temperatures in the cooling and heating chambers reach their respective setting values at the same time. Conventional machines can only operate at a pre-set evaporation temperature, but our newly developed machine can expand the operating range of the heat pump between internal components by adjusting its capacity based on the evaporation temperature as needed.

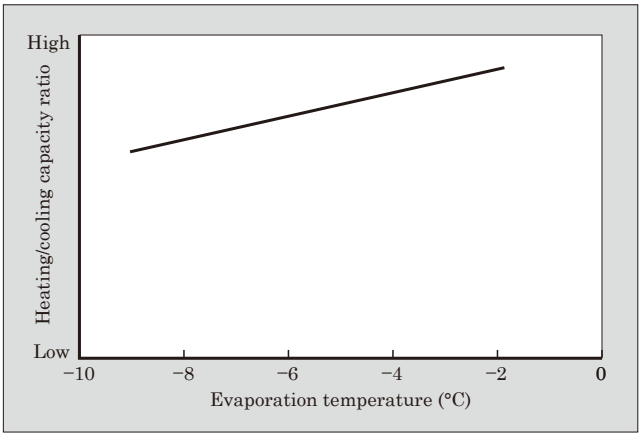

Fig.4 Relationship between the refrigerant evaporation temperature and heating/cooling capacity ratio in our newly developed vending machine

3.2 Improving heating efficiency by controlling condensation temperature

The temperature at which the refrigerant condenses in the condenser (i.e., the condensation temperature) involves conditions that maximize the heating efficiency of the heat pump. By controlling the speed of the compressor, this condensation temperature can be maintained to maximize heating efficiency. By controlling the compressor speed with an inverter using proportional-integral-differential (PID) control, the condensation temperature of the heat exchanger in the heating chamber can be maintained at the target value. Figure 5 shows the block diagram for PID control.

3.3 Effect

Figure 6 shows the operational behavior of the heat pump with the control described in Section 3.1 applied. In this case, the heat pump is controlled primarily

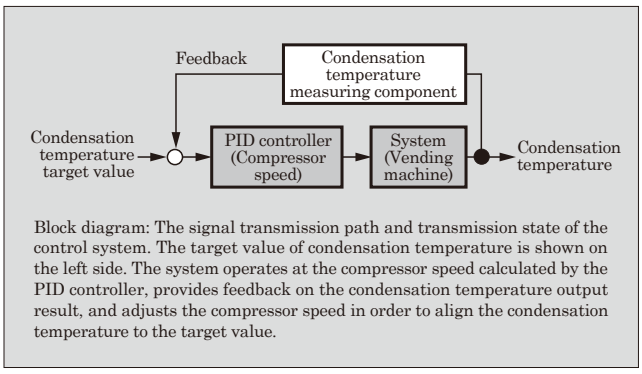

Fig.5 Block diagram for PID control

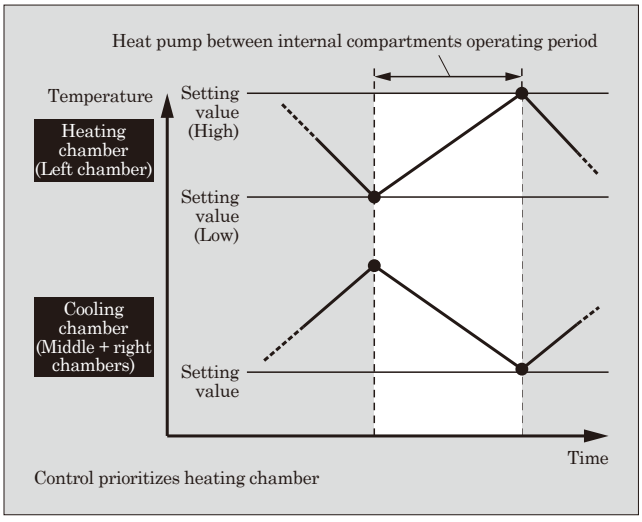

Fig.6 Operational behavior of heat pump (newly developed machine)

for the heating chamber and secondarily for the cooling chamber. When the temperature in the heating chamber drops to the set temperature, the heat pump between internal compartments starts operating to begin heating the heating chamber and cooling the cooling chamber. When the temperature in the heating chamber rises to the set temperature, the heat pump between internal compartments stops. By controlling the evaporation temperature of the refrigerant in the evaporator, the temperatures in the heating and cooling chambers can reach their respective setting values at the same time.

Figure 7 shows the transition of condensation temperature during heat pump operation. Our newly developed machine operates at the target condensation temperature by using PID control. The target condensation temperature is the minimum temperature required to heat the applicable products.

Figure 8 shows the transition of energy efficiency from the start to the end of heat pump operation. Our newly developed machine has an approximately 18% higher ratio of heating capacity to cooling capacity

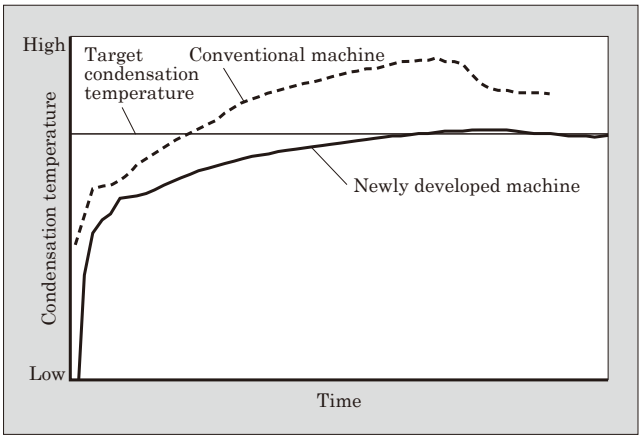

Fig.7 Transition of condensation temperature during heat pump operation

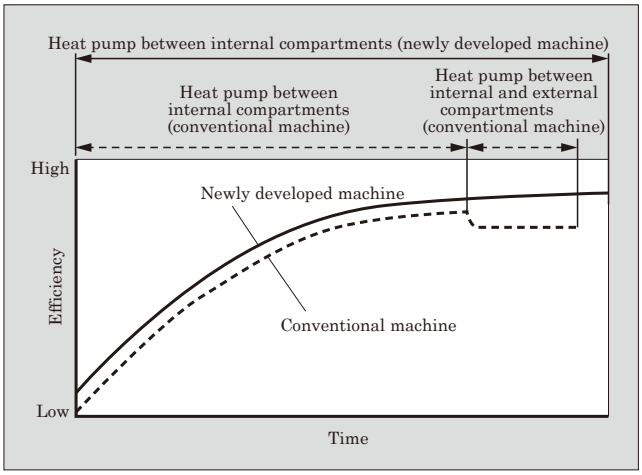

Fig.8 Energy efficiency during heat pump operation

than a conventional machine, and is more energy efficient than a conventional machine from start to finish. The effect of using only the heat pump between internal compartments instead of combining it with a heat pump between internal and external compartments is significant, achieving a 4% energy savings in the example shown in Fig. 8.

4. Postscript

In this paper, we described a heat pump application technology for beverage vending machines. This research has enabled us to expand the operation and improve the efficiency of heat pumps between internal compartments. In the future, there will continue to be a need for optimal energy-saving operation suited to the installation environments of beverage vending machines. We will continue to promote technological development aimed at improving the circuit technology of heat pumps and increasing the sophistication and precision of control to achieve to higher efficiency.

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