Vending Machine That Can Sell –5°C Beverages

OSAWA, Katsuyuki*

ABSTRACT

Asahi Soft Drinks Co., Ltd. and Fuji Electric have jointly developed a subfreezing beverage vending machine. Opening the beverage container triggers the contents to turn into a sherbet-like state. This unexpected event is caused by the supercooling phenomenon, that is, the liquid starts freezing as the internal pressure is altered by the container being opened. To consistently reproduce this event, we adopted the hot gas defrosting method, which does not affect beverage temperature. The vending machine has three zones, sub-freezing temperature zone, preliminary cooling zone, and replenished product cooling zone and allows the change of the maximum number of beverages to be sold per day. This structure enables the machine to stably supply sherbet-like subfreezing beverages.

1. Introduction

A beverage that starts freezing into a sherbet-like state when its container is opened. Such a product has become a popular topic because it creates a cool, refreshing feeling. A sub-freezing beverage vending machine jointly developed by Asahi Soft Drinks Co., Ltd. and Fuji Electric applies the supercooling phenomenon, in which “liquid starts freezing as its internal pressure is altered by the container being opened.” In order to reproduce this supercooling phenomenon consistently, the beverage must be carefully cooled into an appropriate temperature zone. By taking advantage of the fact that a vending machine can create such an environment, we can produce the effect of not only selling products but also encouraging consumption, by offering consumers the fun of watching a beverage start freezing in front of their eyes and experiencing a snow-cone-like texture that fills the mouth. This can be one example that could change the assumed values of vending machines.

2. Development Background

Due to discounts at supermarkets and the emergence of coffee chains and convenience stores in recent years, sales through vending machines are tending to decrease. Therefore, just the convenience of getting a product anytime, anywhere does not work anymore. Vending machine operators are therefore trying to increase their sales by offering attractive products with a unique selling point of vending machines, by setting various temperature zones in accordance with the preference of consumers with regard to beverage drinking temperatures.

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

Fig.1 Exterior appearance of sub-freezing beverage vending machine

Under such circumstances, Fuji Electric has developed a vending machine that can cool a carbonated beverage to −5 °C, which is the temperature immediately before freezing (see Fig. 1). Its product concept is “contributing to the growth of customer business by offering products with novel surprise, fun and taste to consumers to increase the appeal of vending machines and by improving the value of product brand to increase the sales per machine.”

3. Development Target and Challenges

Figure 2 shows the structure of a typical vending machine. A vending machine has three compartments for storing beverage products (left, center and right compartments). The operation modes of these compartments can be switched to cooling or heating individually depending on the season. In order to cool beverages into a normal temperature zone (+5 °C),

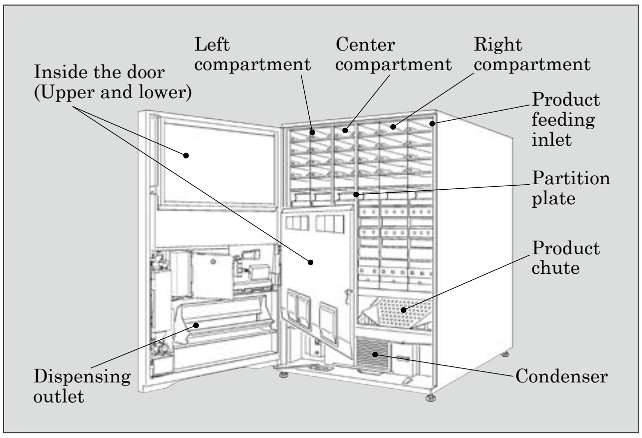

Fig.2 Structure of vending machine

conventional machines internally circulate cold air that has passed through an evaporator maintained at a specific temperature. When the inner temperature becomes too low, the cooling unit is turned off. The unit repeats on/off operation to keep the inner temperature constant. As a measure to reduce cooling load and minimize power consumption, the circulating cold air is concentrated into the lower part of the storage where the next to be sold products are stored.

In order to allow consumers to enjoy sherbet-like beverages, we have to make this developed machine constantly keep the beverages cooled into a temperature zone in which opening the container triggers the supercooling phenomenon (−5 °C). That means, the machine needs to send the necessary amount of cold air that is colder than that of conventional machines to the required area. Assuming the machine would be used in summer when sherbet-like beverages are preferred in particular, there is another request from an operator to leave consumers the option of selecting beverages in a normal temperature zone while providing sherbet-like beverages efficiently by setting conditions for cooling all compartments.

Meeting these requests meant we had to solve the following challenges:

(a) Controlling the inner temperature by properly lowering the evaporator temperature and adjusting the combination of operating time and air volume.
(b) Avoiding a rise in the temperature of the products by removing frost (defrosting) that increases due to the lower evaporator temperature.
(c) Avoiding a temperature rise during product replenishment.

In order to achieve a cooling performance that can cool replenished products to a uniform temperature and create a supercooling state, it is necessary to prevent invading heat from the outside and cooling loss. For that purpose, we checked factors related to each element one by one and tried to optimize the entire system.

The factors related to each element are as follows:

(a) Cooling performance: Evaporation temperature, installation environment, and piping circuit
(b) Uniform product temperature: Airflow temperature, airflow velocity, operating rate, and duct height
(c) Product load: Capacity, and number of products, sales
(d) Invading heat: Heat insulating material, gaskets, and airflow velocity
(e) Cooling loss: Defrosting, operating rate, and environmental factors

4. Features

4.1 Defrosting system

Conventional vending machines have adopted a fan defrosting method. It melts the frost that has formed on the evaporator gradually by circulating air inside the machine while the cooling unit stops operating. This operation is repeated periodically to prevent excessive frost from clogging the airflow passage in the evaporator, which results in preventing a rise in the temperature of the products. Unfortunately, using this method on the developed machine will increase the amount of frost because of the lower evaporator temperature. As a result, defrosting must be repeated more frequently. Moreover, the inner temperature is set to lower than that of conventional machines by about 10 K, which means it takes longer to melt the same amount of frost. Since cooling stops during defrosting, a longer defrosting time results in a rise in the temperature of the products. The lower target inner temperature causes a larger temperature difference between the inside and outside compared with conventional machines. This is another factor that makes the gap between the product temperature and target temperature larger.

In order to cool beverages into the sub-freezing temperature zone, it is necessary to eliminate such a loss during defrosting. For the developed machine, therefore, we use a heat pump circuit(1) to enhance the energy-saving ability of the heating chamber of the vending machine. This allows it to lead the high-temperature and high-pressure refrigerant into the evaporator and finish defrosting within a much shorter time, resulting in preventing a rise in the temperature of the products.

As Fig. 3 shows, there are four operation modes as listed below:

(a) Pattern 1: Cooling (cold, sub-freezing)
(b) Pattern 2: Heating (hot)
(c) Pattern 3: Fan defrosting
(d) Pattern 4: Hot gas defrosting

During the cooling operation, shown as Pattern 1, a high-temperature and high-pressure refrigerant is sent to the condenser. After heat dissipation and adiabatic expansion, the low-pressure refrigerant is

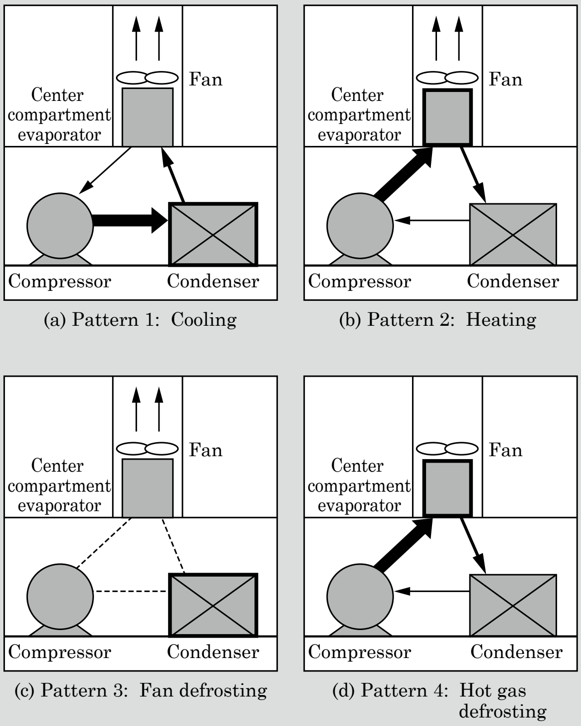

Fig.3 Refrigerant passage in each operation mode

Table 1 Comparison of defrosting methods

Item	Conventional machine	Developed machine
Defrosting method	Fan defrosting	Hot gas defrosting
Operation	No cooling + Fan operation	Heating + No fan operation
Principle	Gradual defrosting by invading heat and airflow	Quick defrosting by supplying hot refrigerant in reverse flow
Defrosting time	120 minutes (about 15 minutes in conventional temperature zone)	5 minutes
Maximum product temperature	Approximately 2 °C	−3 °C or lower

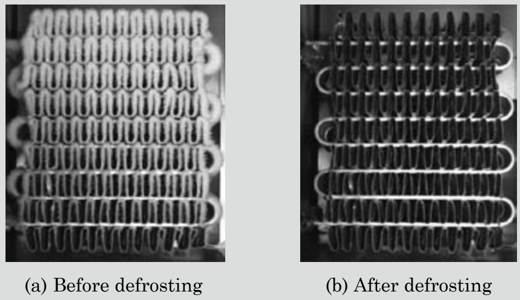

Fig.4 Evaporator before and after hot-gas defrosting of developed machine

sent to the evaporator for heat absorption (cooling). The heating operation of Pattern 2 does the opposite. The high-temperature and high-pressure refrigerant is led to the evaporator to dissipate heat and send hot air inside the machine. In either operation, the fan mounted inside the evaporator operates to send the airflow that has exchanged heat in the evaporator (cold or hot airflow) to cool or heat the products to the target temperature. When defrosting operation is considered here, in the conventional temperature zone, the fan defrosting method described earlier is used for defrosting in the state shown in Pattern 3. In this pattern, the fan is operated while the compressor stops. The frost is melted by the lukewarm airflow that is gradually heated by invading heat.

On the other hand, the state of Pattern 4 is used in the temperature zone of the developed machine. The high-temperature and high-pressure refrigerant is directly led to the evaporator as described above. It heats the evaporator directly from the piping side to melt the frost. Since this method does not send airflow to melt the frost, the fan can be stopped. As a result, it does not send warm air around the products and can prevent a wasteful rise in the temperature of the products. Table 1 shows a comparison of defrosting methods between the conventional and developed machines.

When compared in the temperature zone of the developed machine, the defrosting time of about 120 minutes required by the fan defrosting method can be reduced to about 5 minutes by the hot-gas defrosting method. This can prevent the situation where the products go out of the temperature zone required for triggering the supercooling phenomenon during defrosting. Once the product temperature rises, the sales opportunity will be lost until the temperature returns into the supercooling range. We selected this method as an efficient one especially in the temperature zone of the developed machine. Figure 4 shows an example of the evaporator state, before and after the hot-gas defrosting of the developed machine.

4.2 Zone operation system

Product replenishment is one of the causes of a thermal loss that prevents the machine from cooling into the sub-freezing temperature zone. In addition to the load of hot outside air entering when the machine door is opened, there is a load of reducing the capacity of heat held by the replenished products themselves that are almost as warm as the outside temperature into the sub-freezing temperature zone. Cooling the products into that sub-freezing temperature zone before selling was therefore a big challenge for the developed machine. To solve the challenge, Fuji Electric focused on the amount of replenished products and replenishment position and performed three-temperature zone management linked to the operation (zone operation system, see Fig. 5). The products are replenished from the top of the vending machine. They are stored vertically inside and sold

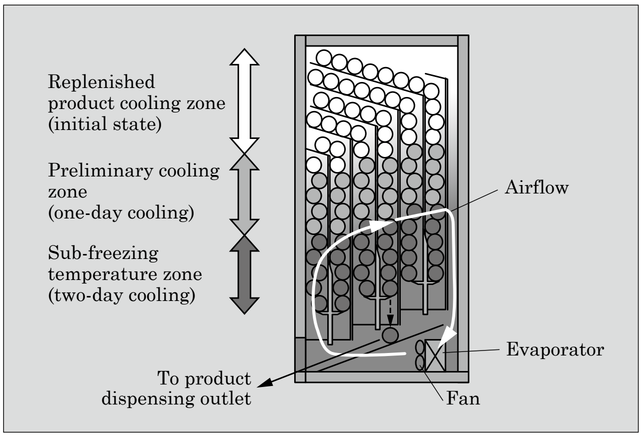

Fig.5 Zone operation system

in the order from the one at the bottom (first-in, first-out system). Consequently, the products replenished earlier move gradually downward inside the machine. This ensures a long cooling time until the product is finally sold from the bottom. Note, however, that the amount of products that can be stocked inside is limited. Moreover, the amount of stored products varies depending on the positions of the product storage racks in the depth direction (front to rear). Simply replenishing the products results in varying standby times from replenishment to being sold. As a countermeasure, controlling the amount and timing of product replenishment makes it possible to secure the necessary cooling time. The temperature zones are set individually for the three compartmental divisions provided horizontally (left, center and right). As a result, the product storage racks in the same compartment are kept in the same temperature zone regardless of their position. The target product discussed in this paper is sold through the use of all center compartments so that the control described above can be done throughout the center compartment.

With the developed machine, the number of beverages sold per day approximately corresponds to one-third of all the beverages stocked inside. This means that the beverages will be sold in about three days from replenishment. Therefore, we divided the inside into three zones: sub-freezing temperature zone (products to be sold next), preliminary cooling zone and replenished product cooling zone. We managed the zones in accordance with the maximum number of beverages that can be sold per day for each rack based on the maximum storable number that varies depending on the position in the depth direction (front to rear). As a result, we can ensure at least two days as the cooling time for replenished products and stably supply beverages that turn into a sherbet-like state.

4.3 Heat insulation structure and temperature control

In order to lower the product temperature to −5 °C, it is necessary to set the evaporator temperature lower than those of conventional machines so that colder cooling airflow will be applied to the products. Vending machines control the circulation of the refrigerant according to the operating environment of the cooling unit by using the temperature sensor mounted in the evaporator of the cooling unit to properly control the temperature of the evaporator. The developed machine sets this setting temperature lower to adjust the evaporator temperature. On the other hand, although continuous sending of airflow settles the temperature to a certain level, the stabilized temperature varies depending on the temperature of the surrounding environment. We control the on/off operation of the cooling unit based on the temperature detected by the temperature sensor mounted at the bottom of the product storage rack. This makes it possible to keep the inner temperature constant and accommodate variable factors. The developed machine controls the final product temperature according to the target based on this setting temperature set to around −5 °C. Figure 6 shows the changes in the product temperature, inner temperature and evaporation temperature over time.

Figure 7 shows a cross-sectional view of the inside of the center compartment during cooling operation. In the structure of such a beverage vending machine, the airflow and inner temperature distribution are correlated. As Fig. 7(a) shows, the products are cooled faster in the rack position that directly receives the air blown immediately out from the cooling unit (on the product dispensing outlet side). Conversely, during the cooling unit is off, the position that receives stronger air blow undergoes a temperature rise more easily due to the invading heat from the outside, as shown in Fig. 7(b). The products in the rack position that does not receive direct airflow from the cooling unit (on the rear side) are cooled slower but are relatively less affected by invading heat. As Fig. 7(c) shows, conventional machines suppress invading heat as much as possible to maintain the target temperature by stopping the airflow also while the cooling unit stops.

The developed machine, however, requires a lower target temperature, which results in a larger temperature difference from the outside air and higher influence of invading heat compared with conventional

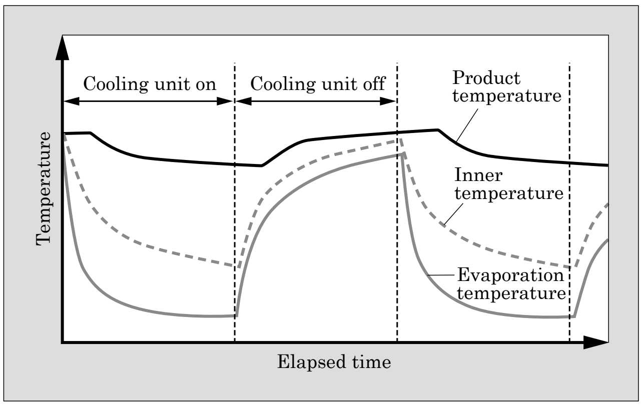

Fig.6 Change in temperatures over time

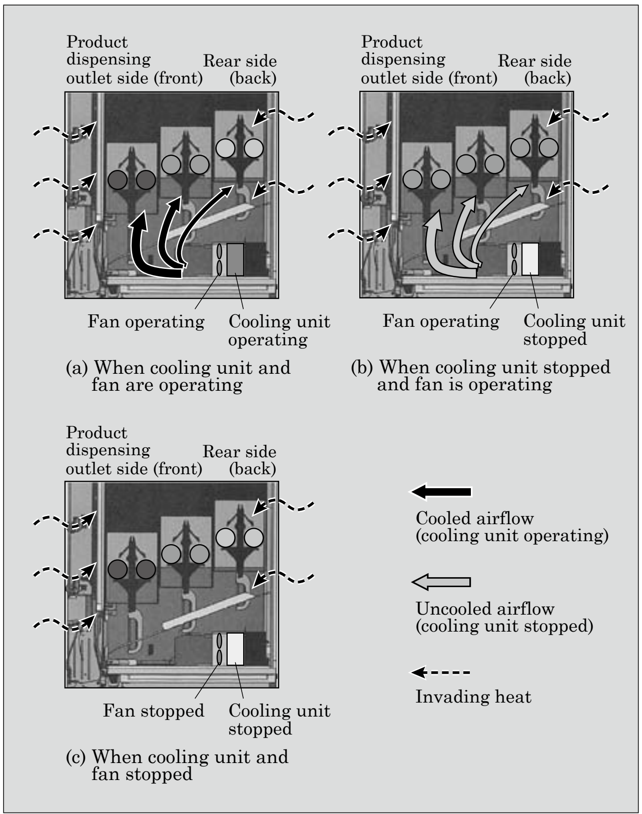

Fig.7 Cross-sectional view of inside of center compartment during cooling operation

machines. If the airflow is stopped while the cooling unit stops, the attained temperature of the products is prone to fluctuation depending on the position in the depth (front to rear) direction inside the machine. This is because the products on the dispensing outlet side (front) that receive direct airflow are cooled faster by cold air and the temperature of those on the rear side (back) that do not receive direct airflow more easily rises when the cooling unit stops. To solve this problem, we reinforced the heat insulation wall and made the airflow continuously even while the cooling unit stops. This reduced the fluctuation in the product temperatures in the depth direction and kept them within the temperature zone required for triggering the supercooling phenomenon. By limiting the target to the center compartment when cooling the three compartments, we could make the temperature difference between the center compartment and the right and left compartments smaller and further suppress invading heat. Furthermore, the front and rear sides use vacuum insulating material to reinforce the heat insulation. The reinforced insulation allowed us to design the cold air inlet port at a higher position to increase the range of low temperature, which provided some margin for the zone operation system described above.

5. Postscript

This paper described a vending machine that can sell beverages stored at −5 °C. This machine adopts the hot-gas defrosting method, which uses the condensation heat of a refrigerant and does not affect product temperature. It enables temperature management by dividing the inside of a vending machine into three zones to ensure a product temperature in the subfreezing temperature zone at the time of sale.

Fuji Electric will further provide new products based on these new technologies to stimulate the vending machine market as well as to contribute to increasing beverage sales.

References

(1) Ishida, S. ZERO Heating Power Vending Machine “Hybrid ZERO”. FUJI ELECTRIC REVIEW. 2015, vol.61, no.3, p.163-167.

Fuji Electric

Innovating Energy Technology