Cold Storage Container "Chilled Type D-BOX"

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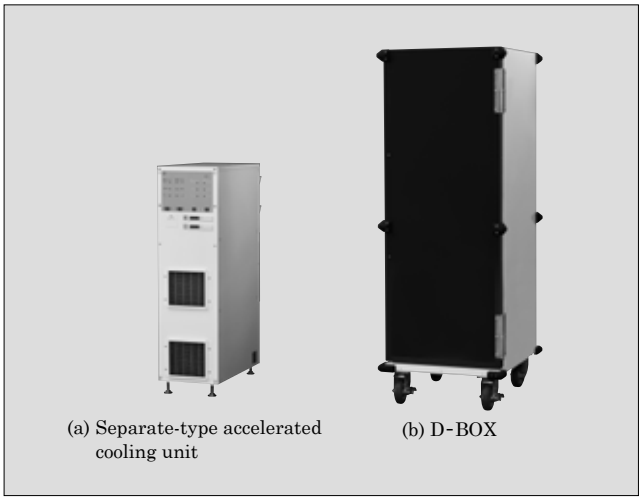
ABSTRACT

In recent years, there has been increasing awareness concerning the need for food safety and security, and as a result, the food distribution industry has become more strictly required to manage the temperature of food products throughout all of the stages of the supply chain. Fuji Electric has developed the Cold Storage Container "Chilled Type D-BOX" to reduce the cost of distribution processes and completely meet the needs of managing the temperature of food products. The Chilled Type D-BOX is capable of keeping food products in the chilling temperature range for 5 hours without a power supply, even in environments with an ambient temperature of 32 °C. Furthermore, it can freeze the cold storage materials in 4 units simultaneously in 3 hours.

1. Introduction

In recent years, there has been increasing awareness concerning the need for food safety and security, and as a result, the food distribution industry has become more strictly required to manage the temperature of food products throughout all of the stages of the supply chain.

To meet the need to reduce initial and running costs while ensuring food safety and security with an integrated distribution system that thoroughly controls temperature, Fuji Electric has developed "Chilled Type D-BOX," a product that consists of a standalone-type accelerated cooling unit and "D-BOX" cold storage containers (see Fig. 1).



(a) Separate-type accelerated cooling unit (b) D-BOX

Fig.1 "Chilled Type D-BOX"

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2. Development Background

To ensure both the safety and quality of food during the food distribution process, products are transported in several types of trucks (such as chilled and refrigerated trucks) to keep each item at its ideal temperature. However, chronic driver shortages, difficulty ensuring vehicles and problems facing the industry such as dramatic fuel cost increases due to the inexpensive yen require that quick measures be taken.

In response, Fuji Electric continues to develop its "D-BOX Series" with 3 temperature ranges (frozen: −20 °C or lower; chilled: −5 °C to +5 °C; normal: 10 °C to 20 °C). This equipment seamlessly controls products at constant or low temperatures to maintain freshness and makes it possible to transport products in trucks kept at normal temperature, thus reducing initial distribution costs and bringing customers a revolution in how products are distributed. Among these, Chilled Type D-BOX makes it possible to store fresh food and other products in cold storage and maintain freshness.

3. Development Goals and Challenges

3.1 Overview of "Chilled Type D-BOX"

Chilled Type D-BOX is composed of a standalone-type accelerated cooling unit equipped with 2 refrigeration devices, and D-BOX cold storage containers that are characterized by their ability to keep food products cool for a long period of time without any power supply. Figure 2 demonstrates an implementation example.

Prior to implementing Chilled Type D-BOX, product temperatures were controlled for each of the following processes when transporting products in the chilled temperature range.

(a) Products are kept cool by loading them on pal-

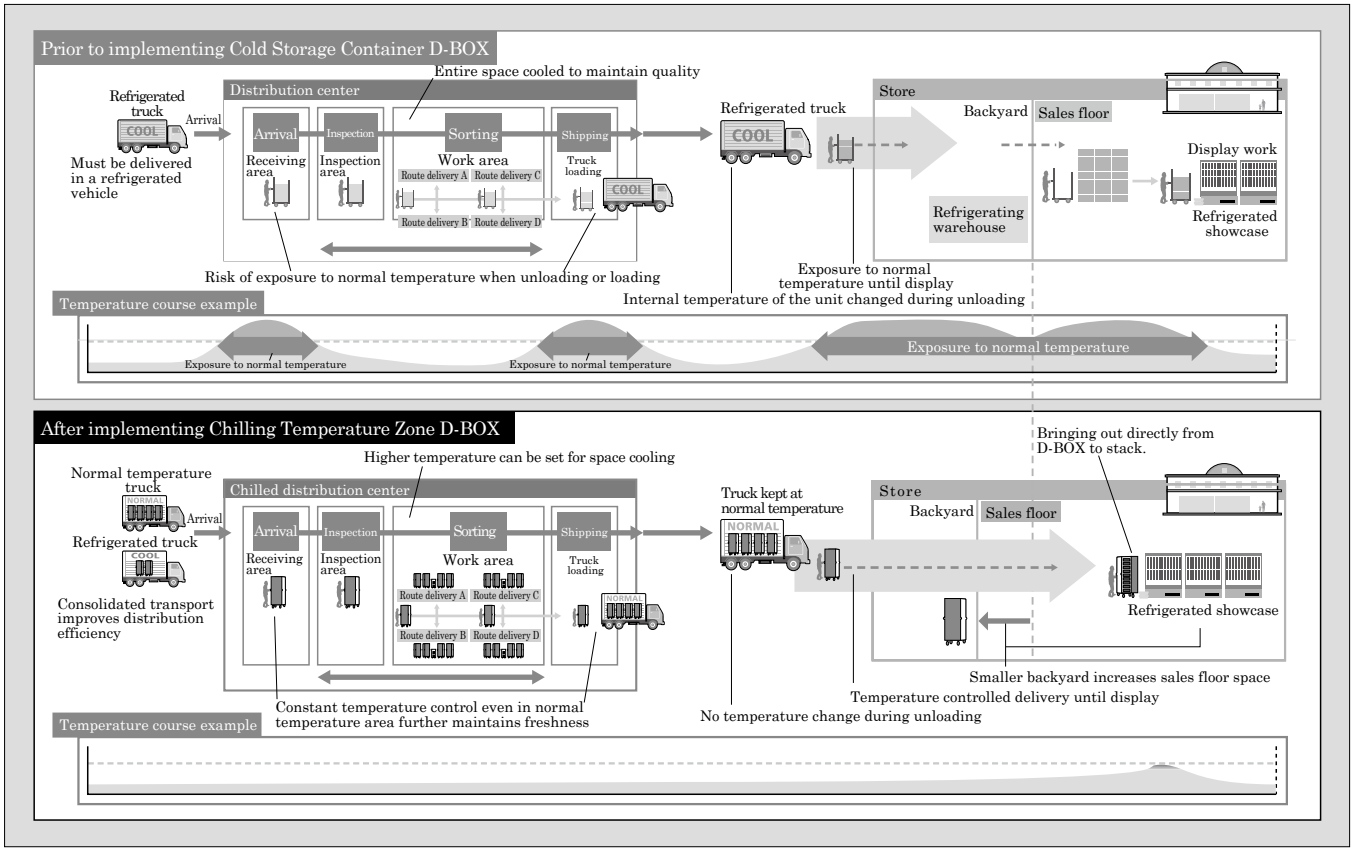

Fig.2 "Chilled Type D-BOX" implementation example

lets in a refrigerated truck

(b) The entire space of the distribution center is cooled for inspection and sorting

(c) Products are kept in a refrigerating warehouse from the point they are dropped off at stores to when they are displayed

However, products are taken and removed from cargo cars at the loading/unloading docks of the distribution center or in the store backyard, so there is a risk that products will be taken out of cold storage and exposed to normal temperatures. Furthermore, products could be exposed to normal temperatures for a longer period of time due to delivery truck arrival delays or worker mistakes, increasing the risk of reduced product quality.

Implementing Chilled Type D-BOX can eliminate the risk of products being exposed to normal temperatures during all processes, as products are constantly kept cool by the cold storage material inside the container. This also means that only the space used for sorting in the distribution center must be cooled, as it is possible to load those products together with processed food under normal-temperature control in trucks kept at normal temperature. There is also no need to install a refrigerating warehouse in store backyards. This can significantly contribute to reducing overall costs; for example, the space saved can be used to expand the sales floor.

Figure 3 shows the internal structure. Figure 4 demonstrates the D-BOX operation process. Table 1 lists the product specifications.

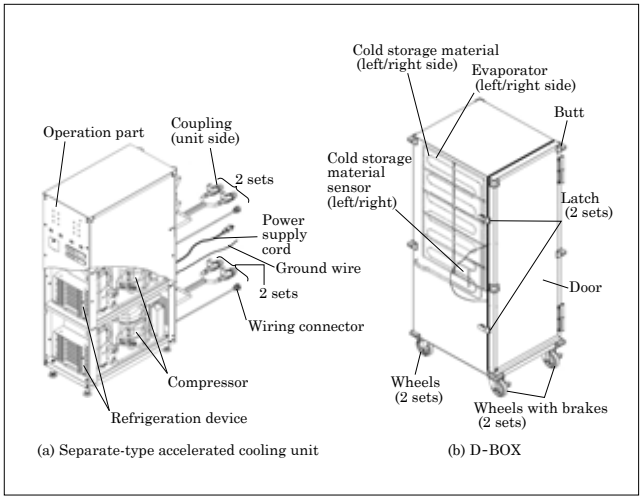

Fig.3 Internal structure

3.2 Long term cold storage performance

A market research showed that most products are distributed in the chilled temperature range (−5 °C to +5 °C). These results suggested that a performance capability of 5 hours of cold storage with an ambient temperature of 32 °C is required to distribute products in summer at the chilled temperature range in an integrated manner that covers the entire process from

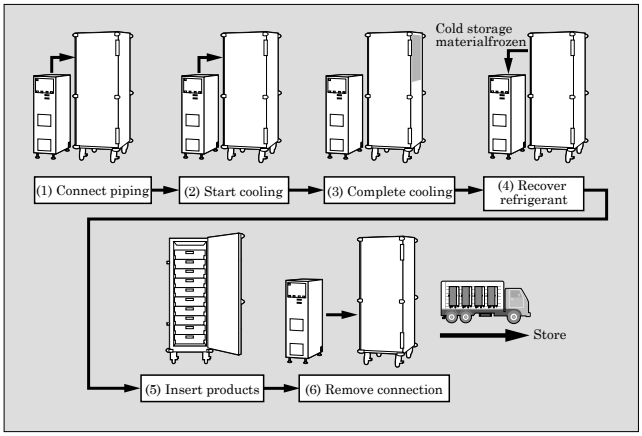

Fig.4 Operation process

Table 1 "Chilled Type D-BOX" specifications

Item		Specification
Standalone-type accelerated cooling unit	Model	DUNITAA1-15J
	Dimensions	W340×D678×H1,184 (mm)
	Mass	82 kg
	Power supply	Single-phase, 100 V, 15 A
	Refrigerant	R134a
	No. of refrigeration devices mounted	2 units
	No. of D-BOX units cooled simultaneously	4 units
	No. of D-BOX units that can be operated	16 units
D-BOX	Model	DBOXC1A11FC-111J
	Dimensions	W664×D793×H1,804 (mm)
	Usable internal dimensions	W469×D594×H1,488 (mm)
	Usable internal volume	415 L
	Cold storage temperature	−5 °C to +5 °C
	Cold storage time	5 hours
	Cooling time	3 hours
	Mass	105 kg
	Maximum loading capacity	250 kg
	Door	One door (270° opening angle)
	Wheels	Four free movement wheels (2 wheels with brakes)

product loading to truck transport, store backyard storage and product display.

3.3 Accelerated cooling system for cold storage materials

During busy periods, chilled distribution centers make a maximum of four deliveries per day. Deliveries took 3 to 4 hours per single cycle. In cases of repeated deliveries, in order to not hinder delivery schedules at centers, we designed a system that has an accelerated cooling capability of freezing cold storage materials in 3 hours and can completely cool four D-BOX units simultaneously with a single standalone-type accelerated cooling unit. This means that a single standalone-type accelerated cooling unit can be used to operate a maximum of 16 D-BOX units, four units operating four times a day. When adding containers in preparation for busy periods, customers can add only the number of D-BOX units needed for delivery, given that they have enough units that can be operated. This allows them to save equipment implementation costs.

3.4 Key points toward improving product transportation efficiency

Container dimensions and mass are extremely important aspects of truck transportation. In consideration of loading efficiency, we designed D-BOX with the dimensions and mass shown in the specifications listed in Table 1. The standalone-type accelerated cooling unit is also designed with the goal of reducing the weight of each D-BOX unit. A D-BOX unit was designed so that it has no noticeably uneven surfaces, and was given a highly heat-insulated, lightweight outer casing structure. Its dimensions allow for food crates (returnable plastic boxes) that contain products inside the unit to be efficiently loaded without any gaps. This improves both loading efficiency and operability.

4. Cold Storage Performance and Accelerated Cooling/Heat Insulating Technology

4.1 Cold storage performance

We utilized the heat insulating technology we have accumulated through developing vending machines, and combined it with newly developed technology that efficiently absorbs heat from the surface of the cold storage material to keep the unit cool, in order to give this product a highly heat-insulated and lightweight outer casing structure that is capable of keeping food products cool for a long period of time. It is particularly important to transport fresh food safely from chilled distribution centers to stores while also maintaining the freshness of said food. In order to confirm this, we measured changes in air temperature in the unit and dummy product temperature (see Fig. 5). In Fig. 5, 0 h is the moment the door was opened to insert the dummy product. The average air temperature in the unit increases between opening and closing the door.

Our measurements covered from the point products were loaded in the chilled distribution center, to when products were transported in a truck kept at normal temperature and stored in the store backyard. For loading work at the chilled distribution center, we opened the door, spent 2 minutes loading products at 0 °C under an ambient temperature of 15 °C, then closed the door. For storing products in the store backyard, we kept products cold for 5 hours at an ambient temperature of 32 °C.

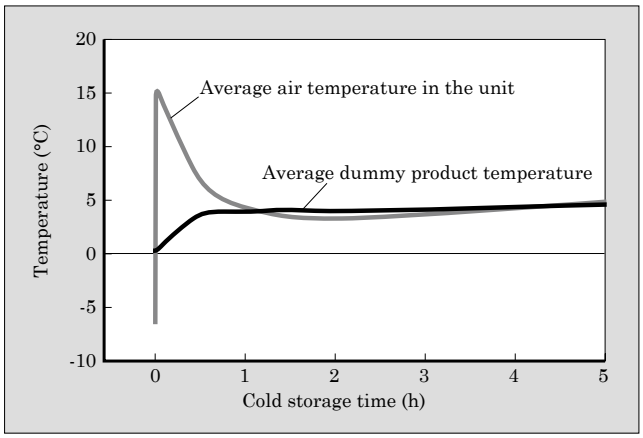

Fig.5 Changes in unit and dummy product temperature (ambient temperature of 32 °C)

Inside the D-BOX unit, product temperatures are kept at 5 °C or lower. When the door is opened and the air temperature in the unit rises to 15 °C, the temperature is cooled back down to 5 °C or less. During field testing conducted at customer chilled distribution centers, there was significantly less damage to the surfaces of products with a lot of moisture (such as slices of raw fish) caused by drying, because this product utilizes a cold storage system that does not use cooling fans inside the unit. The results proved the cold storage performance of this product, and demonstrated how effective it is in maintaining freshness for a long time.

4.2 Accelerated cooling/heat insulating technology for cold storage materials

In consideration of controlled temperature fluctuation in chilled distribution centers, we designed Chilled Type D-BOX to freeze the cold storage material for 3 hours at the maximum ambient temperature of 15 °C. Efficient cooling is required to see these results. As shown in Fig. 6 and Fig. 7, this product employs a direct cooling system where the heat exchanger makes direct contact with the cold storage material. It also uses vacuum heat insulating material, while combining the cold storage material and the heat exchanger

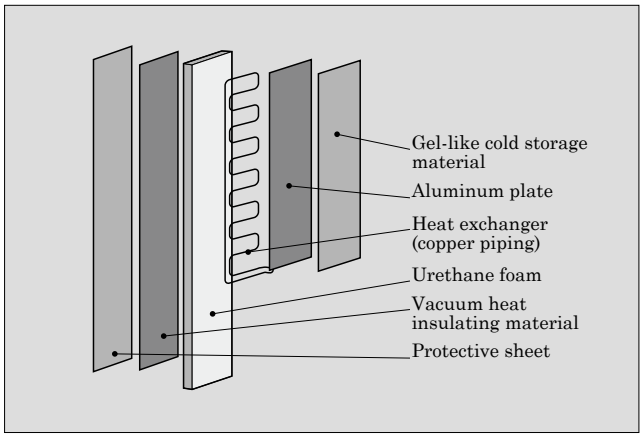

Fig.6 Structure of cold storage material cooling section

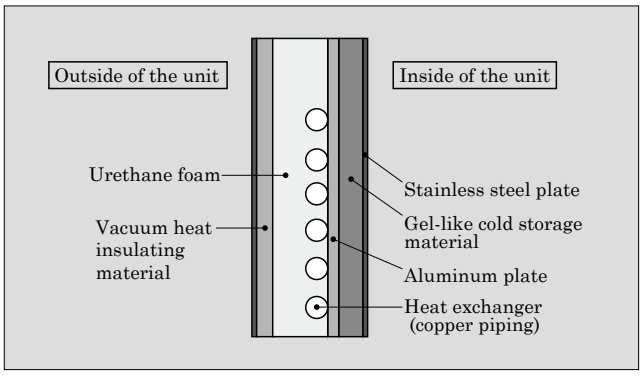

Fig.7 Cross-section structure

into a single urethane foam mold. This provides for stable contact between the cold storage material and heat exchanger over a wide area, and results in uniform cooling. We also set optimal foaming conditions to improve adhesion between the urethane foam and each component. This prevents corrosion caused by dew condensation or degradation of cold storage performance in the heat exchanger and cold storage material with a large ambient temperature difference.

For the cold storage material, serving as the core of cold storage, we used a gel substance with a very small difference between its melting and freezing points. It is also easy to handle if it should leak out due to damage. The cold storage material has a small difference between its melting and freezing points, so there is no need to cool it at a low temperature that could freeze fresh food. Sensible heat also prevents the temperature in the unit from falling immediately after the cold storage material is frozen. It is therefore effective in controlling product temperature, and the condensation temperature of the standalone-type accelerated cooling unit can be set high. For this reason, we adopted the widely popular refrigerant R134a. We also used a uniformly thin molding with a thickness of 10 mm for the cold storage material in order to improve its heat transfer performance, resulting in accelerated cooling.

5. Structure of Cooling Equipment

5.1 Standalone-type accelerated cooling unit

We adopted a separate type structure to save weight. Its design requirements included the ability for units to be installed and removed easily by users with no specialized knowledge, and high reliability that prevents refrigerant from leaking. In response, we developed a coupling on the connection to perform 2 separate actions: sealing the piping, and opening/blocking the refrigerant flow path during connection. This structure is able to significantly suppress refrigerant leakage when the flow path is opened during connection, as well as inhibit water or air from entering, which are issues with the single action system that is popular in the market. As a result, maintenance such as re-injecting refrigerant into the refrigeration device

Fig.8 Refrigerant piping connection

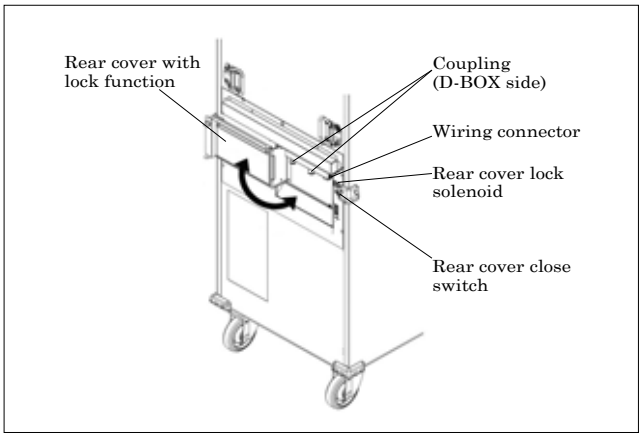

Fig.9 Structure of rear cover

is not required for 5 or more years. Furthermore, we use plastic hoses for the refrigerant piping to improve handling when attaching and detaching the coupling.

Finally, to prevent erroneous operation, the unit is equipped with a rear cover with a lock function on the piping connection so that piping cannot be tampered with during cooling operation. Figure 8 illustrates the refrigerant piping connection. Figure 9 shows the structure of the rear cover.

When the coupling is removed, the refrigerant recovery function causes the standalone-type accelerated cooling unit to automatically recover the refrigerant inside the refrigerant piping of the D-BOX unit. This unit employs a structure that releases the lock on the rear cover after refrigerant is recovered to the compressor, meaning that it can be operated by anyone.

5.2 Technology to cool multiple containers simultaneously by refrigeration device

The standalone-type accelerated cooling unit includes 2 refrigeration devices mounted on the upper and lower sections. A single refrigeration device can cool 2 D-BOX units. Therefore, a single accelerated cooling unit can cool a total of 4 D-BOX units. Figure 10 shows a cooling circuit diagram.

To control the amount of refrigerant, we developed

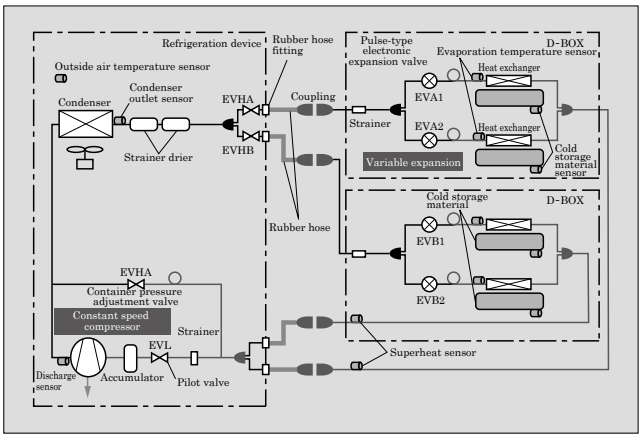

Fig.10 Cooling circuit diagram

a control that utilizes pulse-type electronic expansion valves. It determines the differing load fluctuations of the heat exchangers from the temperature data of each, and individually optimizes the amount of refrigerant circulation. This system can be used in any distribution scenario, and allows Chilled Type D-BOX to perform the following operations:

(a) Two-unit simultaneous cooling
(b) Single-unit independent cooling
(c) Time lag cooling where a second unit is connected while one unit is cooling

5.3 Antifreeze control

When cooling several heat exchangers with a single refrigeration device, the refrigerant circulation amount varies as the load balance changes, due to the effect of the installation environment and individual variations. The coupling, a part of the refrigerant piping, can freeze as a result, rendering it impossible to detach or attach.

For this reason, the refrigeration device incorporates coupling antifreeze control when cooling is complete, and optimizes the amount of refrigerant circulation during cooling. The temperatures of the cold storage material and piping are measured at fixed intervals. After cooling is complete, the pulse-type electronic expansion valves adjust the amount of refrigerant circulated and control the temperature of

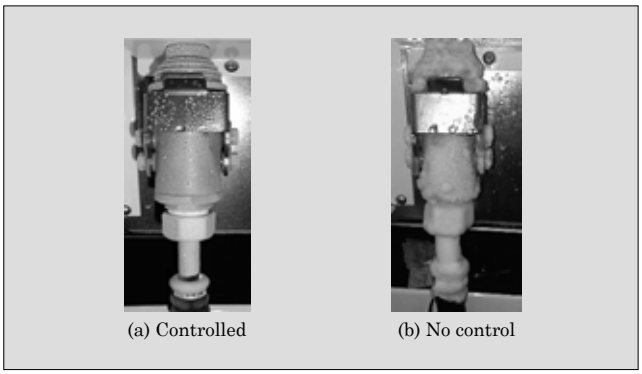

Fig.11 Effect of antifreeze control

the coupling. This keeps the cold storage material frozen, and prevents the low pressure side coupling and refrigerant piping from freezing. This prevents much frost from forming on the coupling, even under strict conditions such as long-term cooling in high humidity environments. Figure 11 demonstrates the effect of antifreeze control.

6. Postscript

This paper described the Cold Storage Container "Chilled Type D-BOX." In addition to adding "Frozen Type D-BOX" and "Normal Temperature Type D-BOX" to the D-BOX Series product lineup, Fuji Electric will continue to propose products to meet various distribution needs.