Application of Fuzzy Control to Open Refrigerating Display Case

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1. Introduction

Open refrigerating display cases are cooled appliances for the purpose of displaying and selling meat, fish and vegetables. These refrigerating display cases exhibiting goods are classified as the following types: multi-deck, semi-multi-deck, and single-deck models. The multi-deck models, as shown in Fig. 1 and Fig. 2, are the most from this group.

The first requirement for an open refrigerating display cases is to maintain freshness of the goods it contains (freshness control). The second requirement is to effectively display those goods (exhibition method).

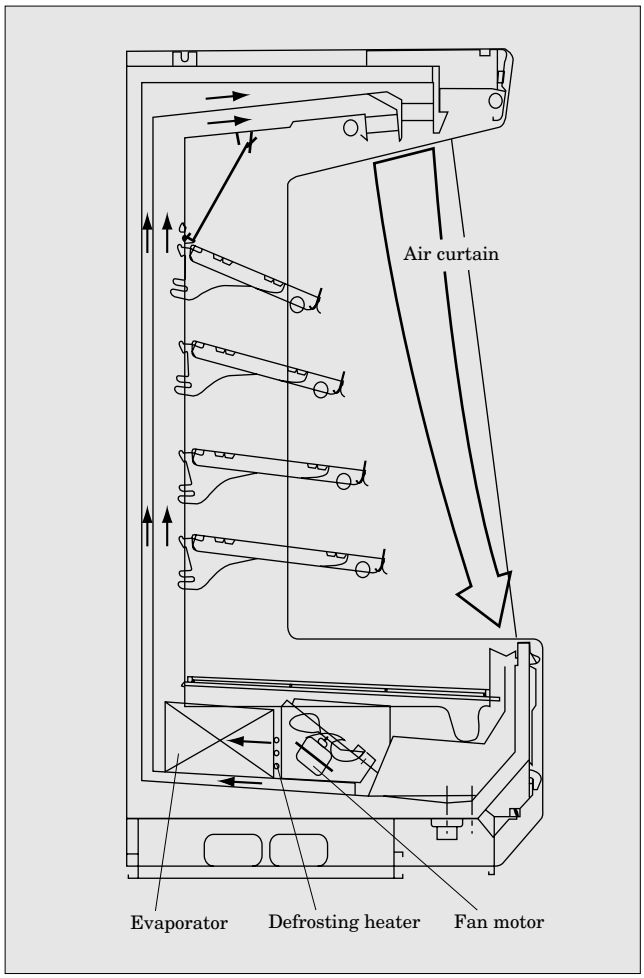
Performance of the freshness control directly affects loss of goods and is closely linked to the profit or loss of a supermarket. Improvement of the freshness control is one of the most significant requirements in this business.

Performance of the freshness control in open refrigerating display cases consists of two functions: refrigeration to maintain the inside of the refrigerating display case at an adequate homogeneous and constant low temperature, and defrosting to effectively melt frost deposited on the evaporator without rising temperature inside the refrigerating display case.

Improving the defrosting performance results in reduced temperature rise and consequently less heat shock to goods. Fuji Electric has been investigating various control systems for defrosting as a key technology for freshness control.

Fig. 1 External view of the open refrigerating display case (multi-deck type)

Fig. 2 Cross-section of the open refrigerating display case (multi-deck type)



2. Current Control Systems for Defrosting

Control systems for defrosting are classified according to their methods and timing for defrosting. Current systems and their problems are described below.

(1) Methods for defrosting

It is common to heat the evaporator with a heater. However, after a variety of technical trials, the performance of this method has already reached its limitations. To overcome this problem, one solution is to provide the system with a pair of evaporators that are alternately defrosted. Another solution is to use the heat of condensation, generated by the mixed gas and liquid refrigerant supplied from the refrigerator into the evaporator. However, because these two methods make the refrigerating display case unit and its on-site installation so costly, they are only suitable for a few specific customers.

(2) Timing for defrosting

Refrigerating display cases are generally operated as a group of several units. The start and end times for defrosting are set by a timer for each group. At the start time, the control system outputs a start signal to a refrigerating display case controller. Defrosting of each refrigerating display case is completed independently by a timed thermostat in each refrigerating display case controller. However, to avoid excessive temperature rises inside the refrigerating display case caused by defrosting for a long duration time due to equipment failure or other accidents, the control system also outputs an end signal to the refrigerating display case controller at the end time. Problems concerning the timing control for defrosting are related to the time interval to start defrosting. Conventionally, this interval is set independent of the deposited frost, that is, without any consideration of adverse ambient conditions such as high temperature and high humidity. For favorable ambient conditions (low temperature and low humidity), defrosting is inevitably performed more than necessary.

3. Application of Fuzzy Control

To limit the number of defrosting operations to the absolute minimum required, a controller that utilizes fuzzy logic has been developed to optimize the start time for defrosting based on the given ambient conditions and the amount of deposited frost.

This control system is called the “fuzzy-non-defrost” system, and its controller is the “fuzzy-non-defrost” controller. Fuji Electric’s use of this system in refrigerating display cases is an industry first.

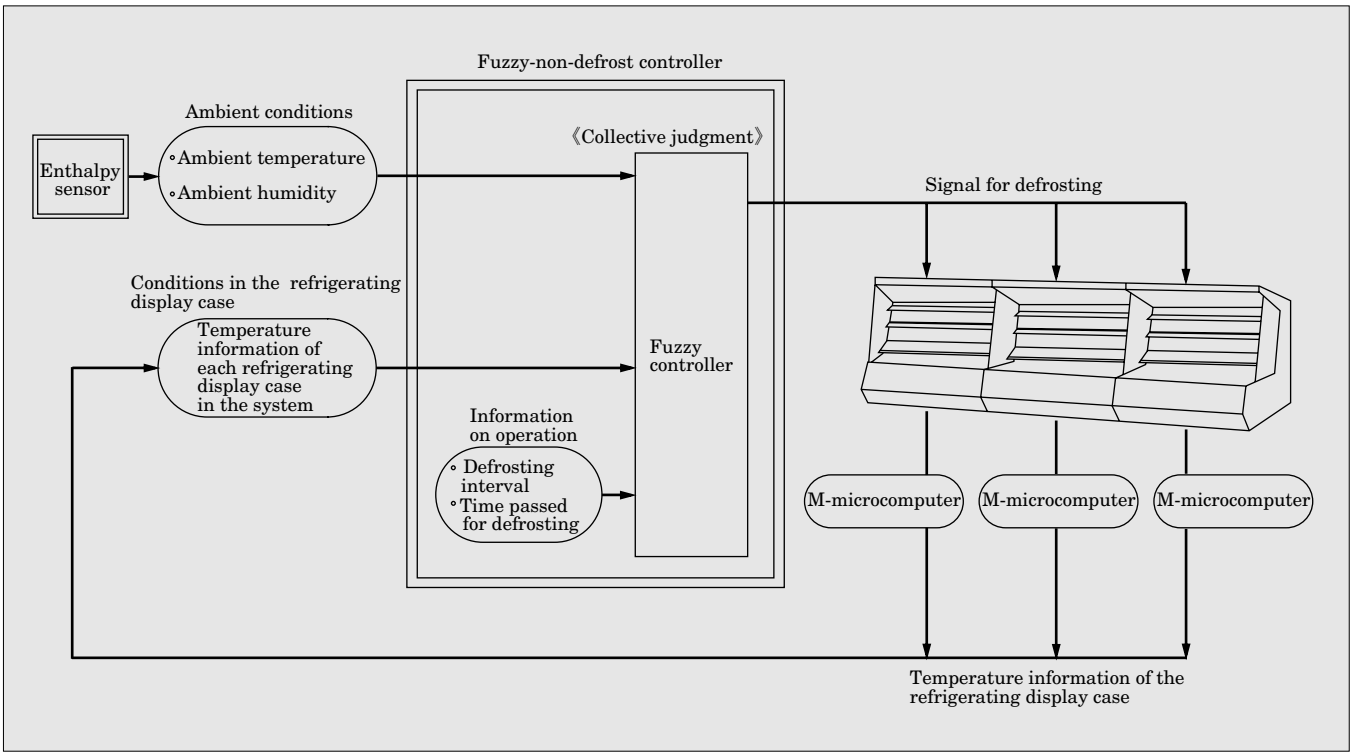
3.1 System configuration and features of the controller

3.1.1 System configuration

The system configuration shown in Fig. 3 consists of a fuzzy-non-defrost controller, an enthalpy sensor with built-in temperature sensor and a humidity sensor and an M-microcomputer controller.

The fuzzy-non-defrost controller and the enthalpy sensor are installed in the main refrigerating display case (master) of chain-connected display cases.

Fig. 3 Overall configuration



3.1.2 Features of the controller

The fuzzy-non-defrost controller collects through the above sensors and then stores this data. The controller uses fuzzy logic to determine the defrost timing.

When defrosting is necessary, the controller outputs a start signal to perform the defrosting process. Defrosting is not performed if there is not a thick layer of frost. The controller operates to avoid defrosting during business hours of the supermarket.

These features have resulted in improved freshness control and improved energy efficiency (reduced heater use during defrosting).

3.2 Concept of fuzzy control

It is very difficult for the microcomputer to determine the thickness of the frost layer form the temperature sensor data at a given time during operation of the refrigerating display case.

The temperature is detected at different locations of the refrigerating display case. Frost deposits are revealed as temperature rises or falls at these locations. However, these temperature characteristics are only suitable for ideal ambient conditions in which the frost is homogeneously deposited.

It is more difficult and complex to analyze characteristics of the temperature information in the real-world situation of the supermarket where the frost in the refrigerating display cases is not homogeneously deposited and customers adversely disturb the ambient conditions.

This is the reason why the fuzzy control has been introduced. Using the ambient temperature and humidity of the refrigerating display case, the time that has passed since defrosting, and weighting the input values with the membership function makes it possible to evaluate the entire situation and determine the exact amount of deposited frost in the variety of cases described above.

Moreover, if varying temperature information indicates a need for emergency defrosting, the fuzzy controller starts defrosting based upon the judgment of its fuzzy logic to prevent an abnormal layer of frost from accumulating on the evaporator (to prevent ice banking).

A basic control function sets a standard daily time, before opening of the supermarket, to start the defrosting process. Defrosting during business hours is avoided as much as possible.

In this manner, the defrosting start process is controlled such that defrosting is only performed as needed, resulting in improved freshness control and energy savings.

Fig. 4 Comparison of the number of defrosting operations during four seasons

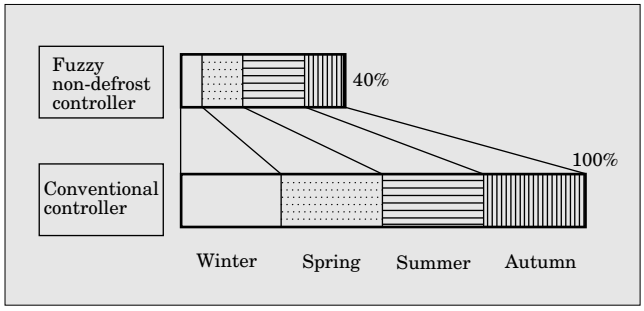


Table 1 Number of defrosting operations of the fuzzy-non-defrost controller

Season	Number of defrosting operations per day	
	Fuzzy-non-defrost controller	Conventional controller
Winter	1 to 2 times	4 or 6 times with fixed intervals
Spring	2 times	
Summer	3 times	
Autumn	2 times	

Note : The number of defrosting operations per day varies depending upon location.

4. Results of the Fuzzy Control

4.1 Results of fuzzy control

As shown in Fig. 4, the fuzzy-non-defrost controller annually reduces the number of defrosting operations to 40% of those of the conventional controller. Table 1 shows the number of daily defrosting operations of the fuzzy-non-defrost controller.

Increased quality and freshness of goods due to the decrease in defrosting operations produce a significant improvement in the loss factor of goods. The loss factor of goods refers to financial losses caused by a fall in prices due to deterioration in the freshness of goods. Decreasing the number of daily defrosting operations by one time reduces the economic loss factor of goods by 12.5%

One fuzzy-non-defrost controller is capable of controlling one system having an average of five refrigerating display cases. Therefore, the economical effect of

Fig. 5 Economical effect due to improved freshness performance

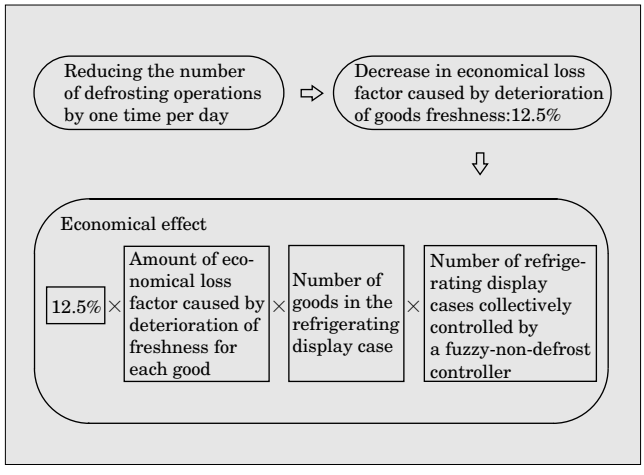
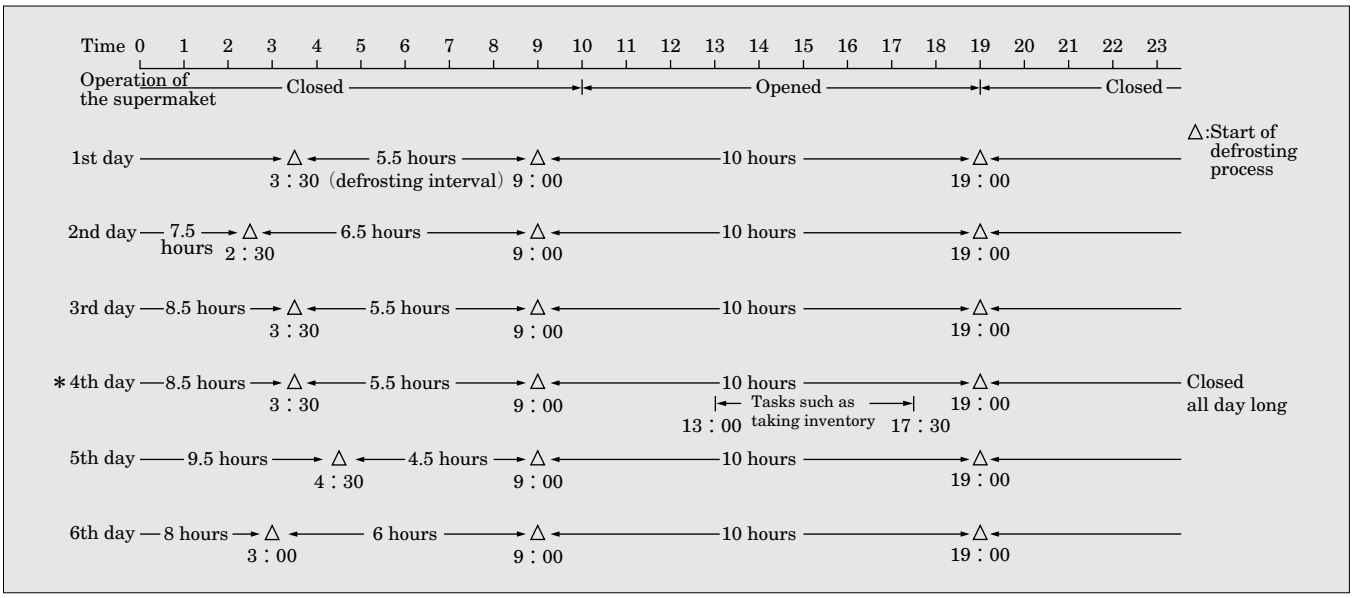


Fig. 6 Conditions of defrosting start process in the field test



goods whose loss factor can be reduced is multiplied as shown in Fig. 5, with the non-defrost-controller producing a greater economical effect than the conventional defrosting timer.

The fewer defrosting operations will reduce electric power consumption (save energy) in refrigerating display cases that use a heater for defrosting.

4.2 Field tests

At first, the fuzzy controller was tested for its performance. During test runs, fuzzy reasoning of the controller was successfully verified by adjusting fuzzy rules and membership functions. The reduction of defrosting operations and avoidance of defrosting operations during the daytime and prevention of ice banking have also been successfully checked.

Next, the fuzzy controller and a real refrigerating display case system were put to work in an operating supermarket for field tests. The field tests have been performed under all possible ambient conditions including summer, winter and the in-between seasons (covering the lowest and the highest temperature and humidity).

4.3 Test results

Figure 6 shows the start times of defrosting which were observed during a field test in the summer, when frost is thicker. This figure shows that defrosting is steadily performed 3 times a day. This number corresponds to the number of defrosting operations given in Table 1.

On the 4th day (marked∗), the supermarket was closed and inventory was taken during the daytime. In such an unstable situation of the refrigerating display case, the controller operation was stable.

The fuzzy-non-defrost controller has proven its ability to provide proper control for various situations of the refrigerating display case.

Thus, overall results of the field tests have verified the stable control characteristics that the design intended to realize.

5. Conclusion

After successful field test results, the fuzzy system was installed in products of the former refrigerating display case series, and has won a reputation for excellent performance from customer supermarkets.

To further improve the control performance, Fuji Electric will introduce new fuzzy control and neuro-computational technology to the control, not merely for the defrosting start process but also for the defrosting reset process and temperature adjustment, and will develop more economical refrigerating display cases that realize quality and freshness control.