DESCRIPTION

Title of Invention

REFRIGERATOR

Technical Field

[0001]

The present invention relates to a refrigerator, especially a refrigerator having a function of bringing an object to be cooled into a supercooled state.

Background Art

[0002]

In general, it is desirable that, when storing food while maintaining the quality thereof, the food be kept at as low a temperature as possible without being frozen. As a method for realizing such a storage, a method for storing food in a supercooled state is proposed. Note that the supercooled state is a state in which, even if the temperature of food reaches the freezing point or below, freezing does not start and the food stays in a non-frozen state. However, in a case where food is stored at the freezing point or below (e.g., 0 degrees C or below), the supercooled state may be terminated due to a shock or other causes, and thereby ice crystals may be generated in the food. In addition, if the food is left while the supercooled state is being terminated, the freezing of the food progresses, thereby causing deterioration in the quality of the food due to cell damages caused by the freezing.

[0003]

To avoid such a problem, a method for melting ice crystals generated due to termination of a supercooled state by changing a temperature periodically is proposed. For example, Patent Literature 1 describes a refrigerator that, after performing a supercooling operation that brings food into a supercooled state, starts the supercooling operation again when operation and suspension of a

cooling unit based on a set temperature in a refrigeration operation are repeated one or more times. Even if freezing of food starts to progress due to the supercooling operation, the refrigerator of Patent Literature 1 performs a refrigeration operation at a set temperature higher than a set temperature of a supercooling operation, thereby preventing the food from being completely frozen.

[0004]

Furthermore, Patent Literature 2 describes a refrigerator that repeats a temperature-lowering process in which a compartment set temperature is set to a temperature lower than the freezing point of food and a temperature-raising process in which the compartment set temperature is set to a temperature higher than the freezing point. In the refrigerator of Patent Literature 2, even if a supercooled state of the food is terminated in the temperature-lowering process and thereby ice crystals are generated in the food and freezing is started, the ice crystals generated when the supercooling is terminated can be melted by starting the temperature-raising process at a predetermined timing. Then, by performing the temperature-lowering process again, the supercooled state is realized and the supercooled state of the food can be stably maintained.

Citation List

Patent Literature

[0005]

Patent Literature 1: Japanese Patent No. 4647047

Patent Literature 2: Japanese Patent No. 4948562

Summary of Invention

Technical Problem

[0006]

In the refrigerator of Patent Literature 1, a time period over which a refrigeration operation is performed is set to a time period in which a cycle of a normal refrigeration operation is repeated one or more times, and thus the relationship between a time period over which a supercooling operation is performed and a heat quantity in each operation is not considered. Therefore, if, for example, a time period over which a refrigeration operation is performed is too short with respect to a time period over which a supercooling operation is performed, ice crystals in food cannot be melted sufficiently, and thereby the freezing of the food progresses. In addition, if a time period over which a refrigeration operation is performed is too long with respect to a time period over which a supercooling operation is performed, the average temperature of the food in a storage period increases, thereby the quality of the food may deteriorate.

[0007]

Furthermore, in the refrigerator of Patent Literature 2, the time period of the temperature-lowering process is set to completely melt the ice crystals generated in the temperature-lowering process. More specifically, in the refrigerator of Patent Literature 2, the time period of the temperature-lowering process is set to satisfy the relationship $Q3 \geq Q1+Q2$, where Q1 represents a latent heat that is released when water changes into ice, Q2 represents a latent heat that is taken away from water while freezing is in progress, and Q3 represents a heat that is given to ice while melting is in progress. With such setting, the ice crystals formed in the temperature-lowering process can be completely melted, however, the time period of the temperature-raising process increases and, as a result, the average temperature of the food in a storage period becomes higher than the freezing temperature, and thereby deterioration in the quality may occur.

[0008]

The present invention provides a refrigerator capable of preventing an object to be cooled from being completely frozen without causing deterioration in the quality of the object to be cooled even if a supercooled state is terminated.

Solution to Problem

[0009]

A refrigerator of one embodiment of the present invention includes: a storage compartment for storing an object to be cooled; a cooling unit configured to supply cool air into the storage compartment; and a controller configured to control the cooling unit to perform a first process for a first time period and a second process for a second time period repeatedly, the first process being a process to decrease a temperature of the storage compartment to a first temperature that is lower than a freezing point of the object to be cooled, and the second process being a process to increase the temperature of the storage compartment to a second temperature that is higher than the freezing point of the object to be cooled, wherein a time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during the temperature in the storage compartment remains lower than the freezing point of the object to be cooled, and a time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during the temperature in the storage compartment remains higher than the freezing point of the object to be cooled are equal to each other.

Advantageous Effects of Invention

[0010]

According to one embodiment of the present invention, since the time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during the temperature in the storage

compartment remains lower than the freezing point of the object to be cooled, and the time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during the temperature in the storage compartment remains higher than the freezing point of the object to be cooled are equal to each other, the object to be cooled can be maintained in the same state as the supercooled state, and the average temperature of the object to be cooled in a storage period can be reduced. Therefore, completion of the freezing of the object to be cooled can be prevented without having an adverse influence on the object to be cooled.

Brief Description of Drawings

[0011]

[Fig. 1] Fig. 1 is a schematic front view of a refrigerator of Embodiment 1 of a present invention.

[Fig. 2] Fig. 2 is a schematic longitudinal sectional view of the refrigerator of Embodiment 1 of the present invention.

[Fig. 3] Fig. 3 is a schematic sectional view of a refrigerator compartment of Embodiment 1 of the present invention.

[Fig. 4] Fig. 4 is a diagram illustrating a control configuration of the refrigerator of Embodiment 1 of the present invention.

[Fig. 5] Fig. 5 is a functional block diagram relating to temperature control of a low-temperature compartment by a controller of Embodiment 1 of the present invention.

[Fig. 6] Fig. 6 is a graph illustrating changes in a set temperature and a compartment temperature of a low-temperature compartment with time when temperature control is performed in Embodiment 1 of the present invention.

[Fig. 7] Fig. 7 is a flowchart illustrating a temperature control process for a low-temperature compartment in Embodiment 1 of the present invention.

[Fig. 8] Fig. 8 is a graph illustrating changes in a set temperature and a compartment temperature of a low-temperature compartment with time, a heat quantity q1 that an object to be cooled releases, and a heat quantity q2 that is supplied to the object to be cooled when temperature control is performed in Embodiment 1 of the present invention.

[Fig. 9] Fig. 9 is a graph illustrating the relationship between the progress time of freezing (freezing time) after supercooling of the object to be cooled is terminated and the number of breaking peaks in cutting the object to be cooled in a case where a low set temperature θL is set to -3 degrees C.

[Fig. 10] Fig. 10 is a graph illustrating changes in a set temperature, a compartment temperature and a food temperature of a low-temperature compartment with time when temperature control is performed in Embodiment 1 of the present invention, illustrating an example where supercooling is not terminated.

[Fig. 11] Fig. 11 is a graph illustrating changes in a set temperature, a compartment temperature and a food temperature of a low-temperature compartment with time when temperature control is performed in Embodiment 1 of the present invention, illustrating an example where supercooling is terminated.

[Fig. 12] Fig. 12 is a graph illustrating changes in a set temperature, a compartment temperature and a food temperature of a low-temperature compartment with time when temperature control is performed in a comparative example, illustrating an example where a temperature-raising process time period is set to satisfy heat quantity q1 > heat quantity q2.

[Fig. 13] Fig. 13 is a graph illustrating changes in a set temperature, a compartment temperature and a food temperature of a low-temperature compartment with time when temperature control is performed in a comparative

example, illustrating an example where a temperature-raising process time period is set to satisfy heat quantity q1 < heat quantity q2.

[Fig. 14] Fig. 14 is a schematic sectional view of a refrigerator compartment of a refrigerator of Embodiment 2 of the present invention.

[Fig. 15] Fig. 15 is a diagram illustrating a control configuration of the refrigerator of Embodiment 2 of the present invention.

Description of Embodiments

[0012]

The embodiments of a refrigerator of the present invention will be explained in detail with reference to the drawings.

Embodiment 1

Fig. 1 is a schematic front view of a refrigerator 1 of Embodiment 1 of a present invention. Fig. 2 is a schematic longitudinal sectional view of the refrigerator 1 of Embodiment 1. Note that, in the following drawings including Fig. 1 and Fig. 2, the relationships among the sizes of component members and the shapes and the like of the component members may differ from actual features. Furthermore, in the description, the positional relationships (e.g., vertical relationship) among the component members are basically given for a case where the refrigerator 1 is installed in a usable state.

[0013]

(Configuration of Refrigerator 1)

As shown in Fig. 2, the refrigerator 1 is provided with a heat insulation case body 90 in which a front face (main face) is opened and a storage space is formed inside. The heat insulation case body 90 is composed of an outer case made of steel, an inner case made of resin, and an insulator provided in a space between the outer case and the inner case. The storage space formed inside the heat insulation case body 90 is partitioned, by a plurality of partition

members, into a plurality of storage compartments in which an object to be cooled, such as food, is stored. As shown in Fig. 1 and Fig. 2, the refrigerator 1 of Embodiment 1 is provided with, as a plurality of storage compartments, a refrigerator compartment 100 installed at an uppermost stage, a switching compartment 200 installed below the refrigerator compartment 100, an ice-making compartment 300 installed adjacently to a side of the switching compartment 200, a freezer compartment 400 installed below the switching compartment 200 and the ice-making compartment 300, and a vegetable compartment 500 installed at a lowermost stage below the freezing compartment 400. The storage temperature zone of the switching compartment 200 may be switched into any temperature zone, such as a freezing temperature zone (e.g., about -18 degrees C), a refrigeration temperature zone (e.g., about 3 degrees C), a chilled temperature zone (e.g., about 0 degrees C), and a soft-freezing temperature zone (e.g., about -7 degrees C). Note that the types and the number of the storage compartments provided in the refrigerator 1 are not limited to the above.

[0014]

An opening section formed on the front face of the refrigerator compartment 100 is provided with revolving doors 8 to open and close the opening section. The doors 8 of Embodiment 1 are double doors (hinged double doors) and composed of a right door 8a and a left door 8b. An outer surface of the door 8 (e.g., left door 8b), which is the front face of the refrigerator 1, is provided with an operation panel 6. The operation panel 6 is provided with an operation section 61 (Fig. 4) for adjusting a set temperature for each storage compartment, and a display section 62 (Fig. 4) for displaying the temperature and the stock information of each storage compartment. The operation section 61 is composed of operation switches, for example, and the display section 62 is

composed of a liquid crystal display, for example. In addition, the operation panel 6 may be composed of a touch panel in which the operation section 61 is integrally formed on the display section 62.

[0015]

The switching compartment 200, the ice-making compartment 300, the freezer compartment 400 and the vegetable compartment 500 are opened and closed by means of respective drawer-type doors. Each of the drawer-type doors is configured to open and close in a depth direction (front-back direction) of the refrigerator 1 by sliding frames, which are fixed to the door, with respect to rails formed horizontally on left and right inner wall surfaces of each storage compartment. In the vegetable compartment 500, a storage case 501 for storing an object to be cooled therein is stored so as to be freely drawn out. The storage case 501 is supported by the frames of the door and is configured to slide in a front-back direction in conjunction with the opening and closing of the door. Similarly, in the switching compartment 200 and the freezer compartment 400, a storage case 201 and a storage case 401 for storing foods or the like therein are stored respectively so as to be freely drawn out. In addition, in the ice-making compartment 300, a storage case (not shown) is stored so as to be freely drawn out. The number of storage cases provided in each storage compartment is one, but two or more storage cases may be provided if the storage performance or ease of organizing is improved while taking the total capacity of the refrigerator 1 into consideration.

[0016]

The back side of the refrigerator 1 is provided with a compressor 2, a cooler (evaporator) 3, a fan 4, and an air passage 5 as a cooling unit that supplies cold air to each storage compartment. The compressor 2 and the cooler 3 form a refrigeration cycle together with a condenser (not shown) and an

expansion device (not shown), and generate cold air to be supplied to each storage compartment. The cold air generated by the compressor 2 and the cooler 3 is sent to the air passage 5 by the fan 4, and is supplied to the freezer compartment 400, the switching compartment 200, the ice-making compartment 300 and the refrigerator compartment 100 from the air passage 5 via a damper. The vegetable compartment 500 is cooled by cold air returning from the refrigerator compartment 100, the returning cold air being supplied from a return air passage (not shown) for the refrigerator compartment via a damper. The cold air supplied to the vegetable compartment 500 is returned to the cooler 3 via a return air passage (not shown) for the vegetable compartment.

[0017]

Fig. 3 is a schematic sectional view of the refrigerator compartment 100 of Embodiment 1. As shown in Fig. 3, the refrigerator compartment 100 is provided with a door opening/closing detection switch 9 that detects an opening/closing state of the door 8, door pockets 10 installed at an inner side of the door 8, and shelves 11 that partition the inside of the refrigerator compartment 100 into a plurality of stages of spaces. Note that the number of the door pockets 10 and the number of the shelves 11 are not limited to the numbers shown in Fig. 3, and one or more door pockets 10 and shelves 11 may be installed. Furthermore, a lower portion of the inside of the refrigerator compartment 100 is configured into two upper and lower stages, and a chilled compartment 12, the internal temperature of which is kept at 0 degrees C or higher, is formed in the upper stage and a low-temperature compartment 13 that stores, without freezing, an object to be cooled at a freezing point or below is formed in the lower stage.

[0018]

The air passage 5 at the back side of the refrigerator compartment 100 is divided into an air passage 5a that sends cold air to the refrigerator compartment 100 and the chilled compartment 12 and an air passage 5b that sends cold air to the low-temperature compartment 13. The air passage 5a is provided with a damper 16, and the air passage 5b is provided with a damper 17. The damper 16 and the damper 17 adjust the air volumes of cold air supplied to the refrigerator compartment 100 and the low-temperature compartment 13, respectively. Furthermore, the back of the refrigerator compartment 100 is provided with a temperature sensor 14 that detects an internal temperature of the refrigerator compartment 100, and the back of the low-temperature compartment 13 is provided with a temperature sensor 15 that detects an internal temperature of the low-temperature compartment 13. The temperature sensor 14 and the temperature sensor 15 are formed of thermistors, for example.

[0019]

Note that each of the switching compartment 200, ice-making compartment 300, the freezer compartment 400 and the vegetable compartment 500 is provided with a temperature sensor (not shown) for detecting the internal temperature thereof. Furthermore, an inlet, from the air passage 5, of each of the switching compartment 200, the ice-making compartment 300, and the freezer compartment 400 and an inlet, from the return air passage for the refrigerator compartment, of the vegetable compartment 500 are provided with dampers (not shown) that adjust the air volume of cold air supplied to the respective compartments.

[0020]

Furthermore, an upper portion of the refrigerator compartment 100 is provided with a controller 7 that controls operation of the refrigerator 1. The controller 7 is composed of an arithmetic device, such as a microcomputer or a

CPU, and software to be executed on the arithmetic device. Note that the controller 7 may be composed of hardware such as a circuit device that realizes the function thereof. Fig. 4 is a diagram illustrating a control configuration of the refrigerator 1 of Embodiment 1. In Fig. 4, the same configurations as the components illustrated in Figs. 1 to 3 are denoted by the same signs.

[0021]

As shown in Fig. 4, detection signals transmitted from the temperature sensors, including the temperature sensors 14 and 15, that detect the temperature of the respective storage compartments, detection signals transmitted from the door opening/closing detection switch 9 and operation signals transmitted from the operation section 61 of the operation panel 6 are input into the controller 7. On the basis of each input signal, the controller 7 controls the cooling unit, in accordance with an operation program that has been stored in advance, to maintain the inside of each of the refrigerator compartment 100, the chilled compartment 12, the low-temperature compartment 13, the switching compartment 200, the ice-making compartment 300, the freezer compartment 400 and the vegetable compartment 500 at a temperature that has been set for the corresponding compartment. The cooling unit includes, for example, the compressor 2, the fan 4 and the dampers, including the dampers 16 and 17, installed for the respective storage compartments, and the controller 7 controls the output of the compressor 2, the air blow volume of the fan 4, and the opening degree of each damper. On the basis of input signals, the controller 7 outputs display signals relating to the temperature, the stock information and other information of each compartment to the display section 62 of the operation panel 6.

[0022]

(Temperature Control of Low-Temperature Compartment 13)

Next, temperature control of the low-temperature compartment 13 in the refrigerator 1 of Embodiment 1 will be explained. Fig. 5 is a functional block diagram relating to temperature control of the low-temperature compartment 13 by the controller 7 of Embodiment 1. Fig. 6 is a graph illustrating changes in a set temperature θs and a compartment temperature θ of the low-temperature compartment 13 with time when temperature control is performed in Embodiment 1. As shown in Fig. 6, the controller 7 of Embodiment 1 repeatedly performs a temperature-lowering process that decreases the compartment temperature θ of the low-temperature compartment 13 to a temperature lower than a freezing point θf of an object to be cooled and a temperature-raising process that increases the compartment temperature θ thereof to a temperature higher than the freezing point θf of the object to be cooled.

[0023]

As shown in Fig. 5, the controller 7 has a clocking section 71 that measures time, a counter 72 that counts a count value, a process shift section 73, a temperature setting section 74, a comparison section 75, a control section 76, and a storage section 77. Each of them is realized, as a functional section realized by means of software, by executing a program by the CPU constituting the controller 7 or is realized by means of an electronic circuit, such as a DSP, an ASIC (Application Specific IC), or a PLD (Programmable Logic Device).

[0024]

The process shift section 73 performs shifting of processes on the basis of the time measured by the clocking section 71 and the count value counted by the counter 72. The temperature setting section 74 sets the set temperature θs of the low-temperature compartment 13 in accordance with the process shifted by the process shift section 73. The comparison section 75 compares the set temperature θs set by the temperature setting section 74 with the compartment

temperature θ detected by the temperature sensor 15 of the low-temperature compartment 13, and outputs a comparison result to the control section 76. On the basis of the comparison result output from the comparison section 75, the control section 76 controls the compressor 2, the fan 4 and the damper 17 so that the compartment temperature θ to be detected by the temperature sensor 15 becomes the set temperature θs. The storage section 77 is formed of, for example, a non-volatile semiconductor memory and stores various data and operation programs to be used in the temperature control.

[0025]

The temperature control of the low-temperature compartment 13 performed by the controller 7 will be explained in detail with reference to Fig. 6. As shown in Fig. 6, the temperature control of the low-temperature compartment 13 repeats a cycle consisting of the temperature-lowering process and the temperature-raising process. More specifically, when a temperature-lowering process time period ΔTL has elapsed after the start of the temperature-lowering process, the process shift section 73 shifts the process to the temperature-raising process. In addition, when a temperature-raising process time period ΔTH has elapsed after the start of the temperature-raising process, the process shift section 73 shifts the process to the temperature-lowering process again. The temperature-lowering process time period ΔTL and the temperature-raising process time period ΔTH are determined for each refrigerator by using the methods to be described later, and then stored in the storage section 77. Note that the temperature-lowering process corresponds to "the first process" of the present invention and the temperature-raising process corresponds to "the second process" of the present invention. Furthermore, the temperature-lowering process time period ΔTL corresponds to "the first time period" of the

present invention and the temperature-raising process time period ΔTH corresponds to the "second time period" of the present invention.

[0026]

In the temperature-lowering process, the set temperature θs is set to a low set temperature θL by the temperature setting section 74, and the internal temperature of the low-temperature compartment 13 is decreased to the low set temperature θL by means of the control section 76. The low set temperature θL is a temperature lower than the freezing point θf (e.g., 0 degrees C) of an object to be cooled stored in the low-temperature compartment 13, and is -4 to -2 degrees C, for example. In the temperature-raising process, the set temperature θs is set to a high set temperature θH by the temperature setting section 74, and the internal temperature of the low-temperature compartment 13 is increased to the high set temperature θH by means of the control section 76. The high set temperature θH is a temperature higher than the freezing point θf of the object to be cooled stored in the low-temperature compartment 13, and is 1 to 2 degrees C, for example. The low set temperature θL and the high set temperature θH have the relationship of θH>θL, and are stored in the storage section 77 in advance. Note that the low set temperature θL and the high set temperature θH may be changed or set by a user via the operation section 61. The low set temperature θL corresponds to the first temperature of the present invention and the high set temperature θH corresponds to the second temperature of the present invention.

[0027]

Furthermore, the temperature-lowering process includes an introduction process and a low-temperature maintenance process. As shown in Fig. 6, in the introduction process, the temperature setting section 74 decreases in stages the set temperature θs every predetermined time. Those stages are counted by

the counter 72, and the process shift section 73 shifts the process to the low-temperature maintenance process when the count value of the counter 72 reaches a prescribed value. The prescribed value is predetermined in such a manner that the set temperature θs reaches the low set temperature θL at a time point TL1. In the low-temperature maintenance process, the temperature setting section 74 sets the set temperature θs to the low set temperature θL, and the internal temperature of the low-temperature compartment 13 is decreased to the low set temperature θL by means of the control section 76. By the temperature-lowering process as described above, the object to be cooled in the low-temperature compartment 13 is brought into a supercooled state in which the object to be cooled is in a non-frozen state at the freezing point θf or below. Then, when reaching the time point TL, that is, when the temperature-lowering process time period ΔTL has elapsed after the start of the temperature-lowering process, the process shift section 73 terminates the temperature-lowering process and shifts the process to the temperature-raising process.

[0028]

In the temperature-raising process, the set temperature θs of the low-temperature compartment 13 is set to a high set temperature θH by the temperature setting section 74, and the temperature of the low-temperature compartment 13 is increased to the high set temperature θH by means of the control section 76. More specifically, the control section 76 stops a state in which cold air flows into the low-temperature compartment 13 by closing the damper 17 to increase the compartment temperature of the low-temperature compartment 13. As another method of increasing the compartment temperature of the low-temperature compartment 13, the fan 4 may be operated while the compressor 2 is being stopped, and then the damper 17 may be opened to circulate the air inside the refrigerator 1. As still another method, by

providing an air passage that communicates between the refrigerator compartment 100 or the vegetable compartment 500 and the low-temperature compartment 13, and by providing, in the air passage, a damper that controls air flow between the refrigerator compartment 100 or the vegetable compartment 500 and the low-temperature compartment 13, the damper may be opened in the temperature-raising process to allow air having a temperature higher than that of the low-temperature compartment 13 to flow into the low-temperature compartment 13 from the refrigerator 100 or the vegetable compartment 500. Then, when reaching a time point TH, that is, when the temperature-raising process time period ΔTH has elapsed after the start of the temperature-raising process, the process shift section 73 terminates the temperature-raising process and shifts the process to the temperature-lowering process.

[0029]

Fig. 7 is a flowchart illustrating a temperature control process for the low-temperature compartment 13 in Embodiment 1. This process is initiated when the power of the refrigerator 1 is turned ON or when the start of the process is selected by using the operation panel 6. First, the temperature sensor 15 detects the compartment temperature θ of the low-temperature compartment 13, and it is determined whether or not the detected compartment temperature θ is equal to or higher than the high set temperature θH (S101). Then, if the compartment temperature θ is lower than the high set temperature θH (S101: NO), the process proceeds to step S112 to start a temperature-raising process. On the other hand, if the compartment temperature θ is equal to or higher than the high set temperature θH (S101: YES), a temperature-lowering process is started. Then, the clocking section 71 resets an elapsed time T, and measurement of an elapsed time T is started (S102).

[0030]

First in the temperature-lowering process, an introduction process is performed. In the introduction process, the temperature setting section 74 sets the set temperature θs to θH-Δθ (S103). Then, a count value i of the counter 72 is set to 0 (S104). In addition, the clocking section 71 resets an elapsed time t, and measurement of an elapsed time t is started (S105). Through these steps, the set temperature θs of the low-temperature compartment 13 is set to a temperature lower than the high set temperature θH by a temperature Δθ (e.g., 0.3 degrees C), and counting of the stages in the introduction process and measuring of the elapsed time t of each stage are started.

[0031]

Next, the temperature setting section 74 determines whether or not the elapsed time t is equal to or greater than a time period Δt (S106). The time period Δt is a time period of each stage in the introduction process, and is 20 minutes, for example. Then, if the elapsed time t is less than the time period Δt (S106), the set temperature θs, which has been set in step S103, will be kept until the elapsed time t becomes the time period Δt or greater. On the other hand, if the elapsed time t is equal to or greater than the time period Δt (S106: YES), the set temperature θs is set to θs-Δθ (S107), and the count value i is incremented by 1 (S108).

[0032]

Next, the process shift section 73 determines whether or not the count value i is equal to or greater than a value n (S109). The value n represents the number of stages in the introduction process, and is 12, for example. If the count value i is less than the value n (S109: NO), the process returns to step S105 to repeat the subsequent steps. Consequently, the set temperature θs of the low-temperature compartment 13 is decreased in stages by the temperature

Δθ every predetermined time period Δt, thereby decreasing the compartment temperature θ to the set temperature θs.

[0033]

On the other hand, if the count value i is equal to or greater than the value n (S109: YES), the process shift section 73 shifts the process to a low-temperature maintenance process. Then, the temperature setting section 74 sets the set temperature θs to the low set temperature θL (S110). Then, it is determined whether or not the elapsed time T after the start of the temperature-lowering process is equal to or greater than the temperature-lowering process time period ΔTL (S111). If the elapsed time T is less than the temperature-lowering process time period ΔTL (S111: NO), the set temperature θs (that is, the low set temperature θL), which has been set in step S110, will be kept until the elapsed time T becomes the temperature-lowering process time period ΔTL or greater. On the other hand, if the elapsed time T is equal to or greater than the temperature-lowering process time period ΔTL (S111: YES), the process proceeds to step S112 to start a temperature-raising process.

[0034]

In the temperature-raising process, the clocking section 71 resets the elapsed time T, and measurement of the elapsed time T is started again (S112). Then, the temperature setting section 74 sets the set temperature θs of the low-temperature compartment 13 to the high set temperature θH (S113). Next, the process shift section 73 determines whether or not the elapsed time T is equal to or greater than the temperature-raising process time period ΔTH (S114). Then, if the elapsed time T is less than the temperature-raising process time period ΔTH (S114: NO), the set temperature θs (that is, the high set temperature θH), which has been set in step S113, will be kept until the elapsed time T becomes the temperature-raising process time period ΔTH or greater. On the other hand,

if the elapsed time T is equal to or greater than the temperature-raising process time period ΔTH (S114: YES), the temperature-raising process is terminated and the process returns to step S102 to start a temperature-lowering process again.

[0035]

In the temperature-lowering process, an object to be cooled stored in the low-temperature compartment 13 is in a supercooled state where the object is not frozen even at the freezing point θf or below, however, the supercooled state is an unstable state in terms of energy. Therefore, if a rapid temperature change occurs inside the low-temperature compartment 13 due to a shock caused by opening/closing of the door 8, for example, or other causes, the supercooled stated may be terminated. Once the supercooled state of the object to be cooled is terminated, fine ice crystals start to form substantially uniformly inside the object to be cooled, thereby freezing is started. For this reason, if a temperature-lowering process time period ΔTL has elapsed after the start of a temperature-lowering process as described above, the process is shifted to a temperature-raising process to avoid progress and completion of the freezing, and thereby it is possible to prevent tissues, cells or the like of the object to be cooled from being damaged by the ice crystals. Furthermore, if a temperature-raising process time period ΔTH has elapsed after the start of a temperature-raising process, deterioration in the quality of the object to be cooled can be suppressed by shifting the process to a temperature-lowering process.

[0036]

However, deterioration in the quality of the object to be cooled may occur depending on the lengths of the temperature-lowering process time period ΔTL and the temperature-raising process time period ΔTH. For example, if a temperature-raising process time period ΔTH is too short with respect to a temperature-lowering process time period ΔTL, the ice crystals in the object to be

cooled cannot be sufficiently melted, and thus the freezing of the object to be cooled progresses. In addition, if a temperature-raising process time period ΔTH is too long with respect to a temperature-lowering process time period ΔTL, the average temperature of the object to be cooled in a storage period becomes higher than the freezing point θf, and thus deterioration in the quality of the object to be cooled may occur. For this reason, in Embodiment 1, the temperature-lowering process time period ΔTL and the temperature-raising process time period ΔTH are set by taking the time until the freezing of the object to be cooled is recognized and the balance among heat quantities into consideration.

[0037]

The settings for the temperature-lowering process time period ΔTL and the temperature-raising process time period ΔTH in Embodiment 1 will be explained with reference to Fig. 8 and Fig. 9. Fig. 8 is a graph illustrating changes in a set temperature and a compartment temperature of the low-temperature compartment 13 with time, a heat quantity q1 that an object to be cooled releases, and a heat quantity q2 that is supplied to the object to be cooled when the temperature control is performed in Embodiment 1. Fig. 9 is a graph illustrating the relationship between the progress time of freezing (freezing time) after supercooling of the object to be cooled is terminated and the number of breaking peaks in cutting the object to be cooled in a case where the low set temperature θL is set to -3 degrees C.

[0038]

(Setting for Temperature-Lowering Process Time Period ΔTL)

The temperature-lowering process time period ΔTL is set to satisfy the following conditions that are obtained by simple experiments. First, a cooling speed in the introduction process is set so that an object to be cooled, such as food, can be brought into a supercooled state. For example, in a case where

the low set temperature θL is set to -3 degrees C, it has been found in an experiment that, if a cooling time for 1 degree C is set to 35 minutes or greater, the object to be cooled enters a supercooled state with very high probability. Therefore, the cooling speed in the introduction process is arbitrarily set to satisfy this condition. Consequently, as shown in Fig. 8, a time period ΔTf1 from the start of the temperature-lowering process, that is, the start of the introduction process, until the freezing point θf of the object to be cooled is reached, and a time point TL1 until the termination of the introduction process are determined. Then, the temperature-lowering process time period ΔTL is set to satisfy time point TL1 < time point TL.

[0039]

Furthermore, the temperature-lowering process time period ΔTL needs to be set to a time until the freezing of the object to be cooled is recognized or less. Now, reasons why the temperature-lowering process time period ΔTL is set to a time until the freezing of the object to be cooled is recognized or less will be explained with reference to Fig. 9.

[0040]

As freezing progresses after supercooling is terminated, generation and growth of ice crystals in an object to be cooled processes, and thereby the texture of food, which is the object to be cooled, may be changed. Hardness by touch and a gritty feeling caused when an ice particle is broken by cutting are examples of changes that people recognizes as signs that an object to be cooled is frozen. However, it has been found in an experiment that the texture of an object to be cooled scarcely changes over several hours after supercooling has been terminated since, even if ice crystals are generated, the ice crystals are too fine and the amount thereof is too small. The number of breaking peaks in Fig. 9 is the number of maximum points in a temporally changing waveform of a

cutting load from the start of cutting to the end of cutting, and indicates gritty feelings caused by the breaking of ice particles. Fig. 9 also indicates, on each graph, a deviation in the number of breaking peaks for each freezing hour. As shown in Fig. 9, in a non-frozen state (0 freezing hour) and in a state after 6 hours have elapsed from the start of freezing, there is almost no difference in the number of breaking peaks. That is, it is found that, even if 6 hours have elapsed from the start of freezing, the texture of the object to be cooled is scarcely changed from a non-frozen state and freezing of the object to be cooled is not recognized. In addition, from Fig. 9, it is found that the boundary between a non-frozen state (0 freezing hour) and a state where freezing is recognized is established at 8 hours. Therefore, by setting the temperature-lowering process time period ΔTL to 8 hours or less (e.g., 300 minutes), the process can be shifted to a temperature-raising process before the freezing of the object to be cooled is recognized. Hereinafter, the time period until the freezing of the object to be cooled is recognized is referred to as an "allowable freezing time period". Note that the time period of 8 hours is given as an example and the allowable freezing time period may vary depending on the refrigerator and the low set temperature θL.

[0041]

(Setting of Temperature-Raising Process Time Period ΔTH)

From Fig. 9, it is found that the same state as the non-frozen state can be substantially maintained, without melting all generated ice crystals, by returning the state to a state immediately after the supercooling has been terminated or a state a few hours after the supercooling was terminated. Therefore, the need for completely melting generated ice crystals in a temperature-raising process is eliminated by setting the temperature-lowering process time period ΔTL equal to or less than an allowable freezing time period (e.g., 8 hours), which is the time

period until the freezing of the object to be cooled is recognized. However, to prevent further freezing, it is necessary to keep the balance of heat quantities between the temperature-lowering process and the temperature-raising process. Thus, the temperature-raising process time period ΔTH is set to keep the balance of the heat quantities between the temperature-lowering process and the temperature-raising process.

[0042]

Now, referring back to Fig. 8, in a temperature-lowering process, a time point when the compartment temperature θ(T) detected by the temperature sensor 15 reaches the freezing point θf of the object to be cooled is called Tf1. In a temperature-raising process, a time point when the compartment temperature θ(T) reaches the freezing point θf of the object to be cooled is called Tf2. In the temperature-lowering process of a subsequent cycle, a time point when the compartment temperature θ(T) reaches the freezing point θf of the object to be cooled is called Tf3. In addition, a time period until the compartment temperature θ(T) reaches the freezing point θf of the object to be cooled after the start of the temperature-raising process is called ΔTf2. A time period until the compartment temperature θ(T) reaches the freezing point θf of the object to be cooled after the start of the temperature-lowering process of the subsequent cycle is called ΔTf1.

[0043]

A heat quantity q1 is a heat quantity released by an object to be cooled, the temperature of which is kept constant at the freezing point θf, during a time period ΔT1 in which the compartment temperature θ(T) remains lower than the freezing point θf, that is during a period of Tf2-Tf1. In addition, a heat quantity q2 is a heat quantity supplied to the object to be cooled, the temperature of which is kept constant at the freezing point θf, during a time period ΔT2 in which the

compartment temperature θ(T) remains higher than the freezing point θf, that is during a period of Tf3-Tf2. The heat quantity q1 corresponds to a slanted section of the slanted areas of Fig. 8, the slanted section being formed between θf between Tf1 and Tf2 and the compartment temperature θ(T), and is represented as the following formula (1). That is, the heat quantity q1 is a time integral value of a difference between the freezing point θf and the compartment temperature θ(T) during the compartment temperature θ(T) remains lower than the freezing point θf. The heat quantity q2 corresponds to a slanted section of the slanted areas of Fig. 8, the slanted section being formed between θf between Tf2 and Tf3 and the compartment temperature θ(T), and is represented as the following formula (2). That is, the heat quantity q2 is a time integral value of a difference between the compartment temperature θ(T) and the freezing point θf during the compartment temperature θ(T) remains higher than the freezing point θf. Note that the heat quantity q1 corresponds to the first heat quantity of the present invention, and the heat quantity q2 corresponds to the second heat quantity of the present invention.

[0044]

[Formula 1]

$$q1 = \int_{T1}^{T2} (\theta f - \theta(T))\ dT \qquad (1)$$

[0045]

[Formula 2]

$$q2 = \int_{T2}^{T3} (\theta(T) - \theta f)\ dT \qquad (2)$$

[0046]

In Embodiment 1, the temperature-raising process time period ΔTH is set to balance the heat quantity q1 and the heat quantity q2. That is, the

temperature-raising process time period ΔTH is set so that the heat quantity q1 and the heat quantity q2 become equal to each other, or heat quantity q1=q2 is satisfied. Note that, cases where the heat quantity q1 and the heat quantity q2 become equal to each other include not only a case where the heat quantity q1 and the heat quantity q2 are exactly the same but also a case where the heat quantity q1 and the heat quantity q2 are not the same but in a balanced state. As described above, a temperature-lowering process time period ΔTL is set equal to or less than an allowable freezing time period, and therefore, the need for completely melting ice crystals of an object to be cooled as in conventional methods is eliminated, thereby reducing a temperature-raising process time period ΔTH compared with conventional cases in which ice crystals of an object to be cooled are completely melted.

[0047]

A temperature-raising process time period ΔTH can be obtained from a temperature-lowering process time period ΔTL as described below. First, a time period ΔTf2 until the compartment temperature θ(T) reaches the freezing point θf from the start of a temperature-raising process and a time point Tf2 can be obtained from a temperature-raising speed. The temperature-raising speed is obtained by experimentation. Next, from the slanted areas of Fig. 8, the heat quantity q1 represented by formula (1) is represented by an approximate expression as the following formula (3). From the slanted areas of Fig. 8, the heat quantity q2 represented by formula (2) is represented by an approximate expression as the following formula (4). From the formulae (3) and (4), the temperature-raising process time period ΔTH can be obtained to satisfy heat quantity q1 = heat quantity q2. The temperature-raising process time period ΔTH is 240 minutes, for example.

[0048]

[Formula 3]

$$q1 \approx \{\Delta T1+(Tf2-TL1)\}\times(\theta f-\theta L)\times 1/2$$
$$=\{(\Delta TL-\Delta Tf1+\Delta Tf2)+(Tf2-TL1)\}\times(\theta f-\theta L)\times 1/2 \quad (3)$$

[0049]

[Formula 4]

$$q2 \approx \{\Delta T2+(TH-Tf2)\}\times(\theta H-\theta f)\times 1/2$$
$$=\{(\Delta TH-\Delta Tf2+\Delta Tf1)+(\Delta TH-\Delta Tf2)\}\times(\theta H-\theta f)\times 1/2 \quad (4)$$

[0050]

As described above, in Embodiment 1, the temperature-lowering process time period ΔTL is set to satisfy time point TL1 < time point TL and to become equal to or less than an allowable freezing time period. Furthermore, on the basis of the temperature-lowering process time period ΔTL, the heat quantity q1 and the heat quantity q2, the temperature-raising process time period ΔTH is set to balance the heat quantity q1 and the heat quantity q2.

[0051]

(Temperature Transition of Object to be Cooled)

Next, the temperature transition of an object to be cooled (e.g., food) when the temperature control of Embodiment 1 is performed will be explained. Fig. 10 and Fig. 11 are graphs each illustrating changes in the set temperature, the compartment temperature and the food temperature of the low-temperature compartment 13 with time when the temperature control of Embodiment 1 is performed. Fig. 10 shows a case where supercooling of food is not terminated in the temperature-lowering process, and Fig. 11 shows a case where supercooling of food is terminated in the temperature-lowering process.

[0052]

First, as shown in Fig. 10, in a case where supercooling of food is not terminated, the food temperature continuously changes to match the change of

the compartment temperature from the low set temperature θL to the high set temperature θH with a slight delay from the change of the compartment temperature of the low-temperature compartment 13. In this way, a return to a supercooled state of the food inside the low-temperature compartment 13 can be repeated in temperature-lowering processes.

[0053]

In addition, as shown in Fig. 11, if supercooling is terminated at a time point Tf at which the food temperature falls to the freezing point θf or below, fine ice crystals are generated in the food and freezing is started. Then, at a time point TL, the set temperature θs of the low-temperature compartment 13 is switched to the high set temperature θH to start melting of the fine ice crystals in the food. Then, at a time point TH at which the temperature-raising process is terminated, the food returns to the same state as the non-frozen state. In a subsequent cycle after the cycle in which a supercooled state occurred, at a time point Tf1 at which the food temperature falls to the freezing point θf or below, the food starts freezing without entering a supercooled state, thereby entering a phase change state.

[0054]

At that time, in Embodiment 1, the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 = heat quantity q2, and therefore, the heat quantity q1 that allows freezing to progress and the heat quantity q2 that melts ice crystals are equalized. In addition, the temperature-lowering process time period ΔTL is set equal to or less than the allowable freezing time period. Thus, at a time point TH_2 at which the temperature-raising process is terminated, the refrigerator 1 can return the food to the same state as the state immediately after supercooling of the object to be cooled has been terminated, that is at the time point Tf1, and the state immediately after freezing has started.

[0055]

Meanwhile, Fig. 12 and Fig. 13 are graphs each illustrating changes in the set temperature, the compartment temperature and the food temperature of the low-temperature compartment 13 with time when the temperature control of a comparative example is performed. Fig. 12 shows an example where the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 > heat quantity q2, and Fig. 13 shows an example where the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 < heat quantity q2.

[0056]

As shown in Fig. 12, if the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 > heat quantity q2, ice crystals generated in a supercooled state grow every cycle, and thereby the freezing progresses, and, finally, the freezing will be completed. More specifically, at a time point Tf at which the temperature of food falls to the freezing point θf or below, supercooling of the food is terminated and freezing is started with the generation of fine ice crystals. Then, at a time point TL, the set temperature θs of the low-temperature compartment 13 is switched to the high set temperature θH to start melting of the fine ice crystals in the food. If a time period from the time point Tf to the time point TL is short, the food returns to the same state as the non-frozen state at the time point TH at which the temperature-raising process is terminated.

[0057]

In a subsequent cycle after the cycle in which the terminations of the supercooled state occurred, at a time point Tf1 at which the food temperature falls to the freezing point θf or below, the food starts freezing without entering a supercooled state, thereby entering a phase change state. At that time, the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 > heat quantity q2, and therefore, the heat quantity q1 that allows freezing to

progress is greater than the heat quantity q2 that melts ice crystals. Consequently, the freezing of the food progresses, and, at any time point, the freezing will be completed. That is, if the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 > heat quantity q2, it is difficult to prevent the progress of freezing in food in which supercooling is terminated.

[0058]

Fig. 13 shows a case where the temperature-raising process time period ΔTH is set to satisfy heat quantity q1 < heat quantity q2, and, more specifically, shows a case where the temperature-raising process time period ΔTH is set to satisfy q0+q1≤q2 with consideration of a heat quantity q0 that food or the like releases when supercooling is terminated, for example. The heat quantity q0 corresponds to the third heat quantity of the present invention, and is obtained by the following formula (5), for example. In this formula, θT represents a temperature at which supercooling is terminated, W represents a moisture content of food, and Cp represents a heat capacity of water.

[0059]

[Formula 5]

$$q0 = \Delta(\theta T - \theta L) \times W \times Cp \qquad (5)$$

[0060]

By setting the temperature-raising process time period ΔTH to satisfy q0+q1≤q2, all ice crystals generated in food when supercooling is terminated are melted, and the food can be returned completely to the non-frozen state. Thus, the food can be brought into a supercooled state in a next cycle without fail, and therefore, the heat quantity q1 becomes a heat quantity that the food, the temperature of which is constant at the freezing point θf, releases during the low-temperature maintenance process. However, in such a case, all ice crystals generated in the food are melted, and therefore, the temperature-raising process

time period ΔTH increases, thereby consequently increasing the average temperature of the food.

[0061]

As described above, according to Embodiment 1, the temperature-lowering process time period ΔTL and the temperature-raising process time period ΔTH are set by taking the allowable freezing time period of an object to be cooled and the balance of heat quantities into consideration, and periodic temperature controls are performed. More specifically, the temperature-lowering process time period ΔTL is set to be within the allowable freezing time period, and the temperature-raising process time period ΔTH are set to obtain a state where the heat quantity q1, which allows freezing to progress, and the heat quantity q2, which melts ice crystals, are balanced. Consequently, an object to be cooled, such as food, can be returned to the same state as a supercooled state without completely melting the ice crystals, and the average temperature of the object to be cooled in a storage period can be reduced. Therefore, the refrigerator 1 of Embodiment 1 is capable of preventing completion of the freezing of an object to be cooled without having an adverse influence on the object to be cooled.

[0062]

Furthermore, since the temperature-lowering process has the introduction process and the low-temperature maintenance process, an object to be cooled in the low-temperature compartment 13 can be brought into a supercooled state. In addition, in the temperature-raising process, since the temperature of the low-temperature compartment 13 is increased by controlling the damper 17, the need of a heat source for increasing the temperature is eliminated, thereby preventing increases in the number of components and the power consumption.

[0063]

Embodiment 2

Next, a refrigerator 1A of Embodiment 2 will be explained. The refrigerator 1A of Embodiment 2 differs from Embodiment 1 in that a heating unit configured to heat a low-temperature compartment 13 to increase the temperature thereof is provided.

[0064]

Fig. 14 is a schematic sectional view of a refrigerator compartment 100A of the refrigerator 1A in Embodiment 2. As shown in Fig. 14, a heater 18, as a heating unit configured to heat the low-temperature compartment 13 to increase the temperature thereof, is embedded below the low-temperature compartment 13, that is in the bottom of the refrigerator compartment 100A. By providing the heater 18 below the low-temperature compartment 13, the temperature of the low-temperature compartment 13 can be increased efficiently.

[0065]

Fig. 15 is a diagram illustrating a control configuration of the refrigerator 1A of Embodiment 2. As shown in Fig. 15, the heater 18 is controlled by a controller 7. On the basis of detection signals transmitted from temperature sensors, including temperature sensors 14 and 15, detection signals transmitted from door an opening/closing detection switch 9 and operation signals transmitted from an operation section 61 of an operation panel 6, the controller 7 controls a cooling unit, in accordance with an operation program that has been stored in advance, to maintain the inside of each of the refrigerator compartment 100A, a chilled compartment 12, the low-temperature compartment 13, a switching compartment 200, an ice-making compartment 300, a freezer compartment 400 and a vegetable compartment 500 at a temperature that has been set for the corresponding compartment. The cooling unit includes, for example, a compressor 2, a fan 4 and dampers, including dampers 16 and 17,

and the heater 18. More specifically, in a temperature-raising process, the controller 7 controls heating and stopping of the heater 18 as well as controls the damper 17 so that the temperature in the low-temperature compartment 13 detected by the temperature sensor 15 becomes a high set temperature θH.

[0066]

As described above, according to Embodiment 2, in addition to the effects of Embodiment 1, the temperature of the low-temperature compartment 13 can be increased efficiently by performing temperature-raising control using the heater 18 in a temperature-raising process. Note that, in the abovementioned explanation, the controller 7 controls the heater 18 as well as controls the damper 17 in a temperature-raising process, but is not limited thereto. For example, in a temperature-raising process, the controller 7 may control only the heater 18, without controlling the damper 17, to increase the temperature of the low-temperature compartment 13. Furthermore, the heating unit is not limited to the heater 18 but may be a heat exchanger or a Peltier device.

[0067]

As described above, the embodiments of the present invention were explained with reference to the drawings, however, a specific configuration of the present invention is not limited thereto, and can be modified without departing from the scope of the invention. For example, in the abovementioned embodiments, the ice crystals generated when supercooling of an object to be cooled is terminated do not need to be completely melted in a temperature-raising process, and therefore, a temperature-raising process time period ΔTH is set to satisfy heat quantity q1 = heat quantity q2. In such a case, the relationship among the heat quantities, including a heat quantity q0 that an object to be cooled releases when supercooling is terminated, becomes $q1=q2<(q0+q1)$. Even if heat quantity q1 = heat quantity q2 is not strictly

satisfied but q2<q0+q1 is satisfied, the heat quantity q1 and the heat quantity q2 are in a balanced state even if heat quantity q1 < heat quantity q2, and thereby the same effects as the abovementioned embodiments can be obtained. Therefore, a temperature-raising process time period ΔTH can be obtained to satisfy heat quantity q1 < heat quantity q2 and heat quantity q2 < (heat quantity q0 + heat quantity q1).

[0068]

Furthermore, the objects to be cooled of the present invention include not only food but also all matters that can be stored in a supercooled state, such as a matter that is sampled from nature like inedible raw meat of a small animal, or raw meat of an experimental animal such as a clone animal.

Reference Signs List

[0069]

1, 1A refrigerators 2 compressor 3 cooler 4 fan 5 air passage 5a air passage 5b air passage 6 operation panel 7 controller 8 door 8a right door 8b left door 9 door opening/closing detection switch 10 door pocket 11 shelf 12 chilled compartment 13 low-temperature compartment 14, 15 temperature sensors 16, 17 dampers 18 heater 61 operation section 62 display section 71 clocking section 72 counter 73 process shift section 74 temperature setting section 75 comparison section 76 control section 77 storage section 90 heat insulation case body 100, 100A refrigerator compartments 200 switching compartment 201, 401, 501 storage cases 300 ice-making compartment 400 freezer compartment 500 vegetable compartment

CLAIMS

[Claim 1]

A refrigerator comprising:

a storage compartment for storing an object to be cooled;

a cooling unit configured to supply cool air into the storage compartment; and

a controller configured to control the cooling unit to perform a first process for a first time period and a second process for a second time period repeatedly,

the first process being a process to decrease a temperature of the storage compartment to a first temperature that is lower than a freezing point of the object to be cooled, and

the second process being a process to increase the temperature of the storage compartment to a second temperature that is higher than the freezing point of the object to be cooled, wherein

a time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during a time period in which the temperature in the storage compartment remains lower than the freezing point of the object to be cooled, and a time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during a time period in which the temperature in the storage compartment remains higher than the freezing point of the object to be cooled are equal to each other.

[Claim 2]

A refrigerator comprising:

a storage compartment for storing an object to be cooled;

a cooling unit configured to supply cool air into the storage compartment; and

a controller configured to control the cooling unit to perform a first process for a first time period and a second process for a second time period repeatedly,

the first process being a process to decrease a temperature of the storage compartment to a first temperature that is lower than a freezing point of the object to be cooled, and

the second process being a process to increase the temperature of the storage compartment to a second temperature that is higher than the freezing point of the object to be cooled, wherein

the second time period is a length of time taken for a time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during a time period in which the temperature in the storage compartment remains lower than the freezing point of the object to be cooled, and a time integral value of a temperature difference between the freezing point and a temperature in the storage compartment during a time period in which the temperature in the storage compartment remains higher than the freezing point of the object to be cooled to be equalized with each other.

[Claim 3]

A refrigerator comprising:

a storage compartment for storing an object to be cooled;

a cooling unit configured to supply cool air into the storage compartment; and

a controller configured to control the cooling unit to perform a first process for a first time period and a second process for a second time period repeatedly,

the first process being a process to decrease a temperature of the storage compartment to a first temperature that is lower than a freezing point of the object to be cooled, and

the second process being a process to increase the temperature of the storage compartment to a second temperature that is higher than the freezing point of the object to be cooled, wherein

a first heat quantity during a time period in which the temperature in the storage compartment remains lower than the freezing point of the object to be

cooled falls less than a second heat quantity during a time period in which the temperature in the storage compartment remains higher than the freezing point of the object to be cooled, and the second heat quantity falls less than a total value of the first heat quantity and a third heat quantity,

the first heat quantity is a time integral value of a temperature difference between the freezing point and the temperature in the storage compartment during a time period in which the temperature in the storage compartment remains lower than the freezing point of the object to be cooled,

the second heat quantity is a time integral value of a temperature difference between the freezing point and the temperature in the storage compartment during a time period in which the temperature in the storage compartment remains higher than the freezing point of the object to be cooled, and

the third heat quantity is obtained from a difference between the second temperature and the temperature in the storage compartment when supercooling of the object to be cooled is terminated.

[Claim 4]

A refrigerator comprising:

a storage compartment for storing an object to be cooled;

a cooling unit configured to supply cool air into the storage compartment; and

a controller configured to control the cooling unit to perform a first process for a first time period and a second process for a second time period repeatedly,

the first process being a process to decrease a temperature of the storage compartment to a first temperature that is lower than a freezing point of the object to be cooled, and

the second process being a process to increase the temperature of the storage compartment to a second temperature that is higher than the freezing point of the object to be cooled, wherein

the second time period is a length of time in which a first heat quantity during a time period in which the temperature in the storage compartment remains lower than the freezing point of the object to be cooled falls less than a second heat quantity during a time period in which the temperature in the storage compartment remains higher than the freezing point of the object to be cooled, and the second heat quantity falls less than a total value of the first heat quantity and a third heat quantity,

the first heat quantity is a time integral value of a temperature difference between the freezing point and the temperature in the storage compartment during a time period in which the temperature in the storage compartment remains lower than the freezing point of the object to be cooled,

the second heat quantity is a time integral value of a temperature difference between the freezing point and the temperature in the storage compartment during a time period in which the temperature in the storage compartment remains higher than the freezing point of the object to be cooled, and

the third heat quantity is obtained from a difference between the second temperature and the temperature in the storage compartment when supercooling of the object to be cooled is terminated.

[Claim 5]

The refrigerator of any one of claims 1 to 4, wherein

the first time period is equal to or less than an allowable freezing time period that is a time period until freezing of the object to be cooled is recognized.

[Claim 6]

The refrigerator of claim 5, wherein

the allowable freezing time period is predetermined according to the first temperature.

[Claim 7]

The refrigerator of claim 6, wherein

the allowable freezing time period is eight hours if the first temperature is set to -3 degrees C.

[Claim 8]

The refrigerator of any one of claims 5 to 7, wherein

the allowable freezing time period is a time period when a number of breaking peaks obtained when the object to be cooled is cut is larger than that obtained at a start of freezing.

[Claim 9]

The refrigerator of any one of claims 1 to 8, wherein

the first process includes:

an introduction process to decrease in stages a set temperature of the storage compartment to the first temperature; and

a low-temperature maintenance process to maintain the set temperature of the storage compartment at the first temperature after the introduction process.

[Claim 10]

The refrigerator of any one of claims 1 to 9, wherein

the cooling unit is provided with a damper configured to adjust an air volume to be supplied to the storage compartment, and

the controller controls the damper in the second process to increase the temperature of the storage compartment to the second temperature.

[Claim 11]

The refrigerator of any one of claims 1 to 9, further comprising a heating unit configured to heat the storage compartment, wherein

the controller controls the heating unit in the second process to increase the temperature of the storage compartment to the second temperature.

[Claim 12]

The refrigerator of any one of claims 1 to 11, wherein

the first temperature is set in a range of -4 to -2 degrees C.