

DESCRIPTION

Title of Invention: METHOD OF COOLING DOWN LIQUID CONTAINER AND STORAGE FACILITY

Technical Field

[0001] The present disclosure relates to a method of cooling down a liquid container and a storage facility.

Background Art

[0002] PTL 1 discloses a cool-down method of cooling down a low-temperature liquid container by spraying a low-temperature liquid from a spraying tube located in the low-temperature liquid container.

Citation List

Patent Literature

[0003] PTL 1: Japanese Laid-Open Patent Application Publication No. 2013-09453

Summary of Invention

Technical Problem

[0004] When cooling down a liquid container that stores a cryogenic liquid, the cryogenic liquid to be stored is sprayed in the liquid container. For a while since the start of the spraying of the cryogenic liquid, the cryogenic liquid vaporizes, and the volume thereof increases. Therefore, the pressure in the liquid container increases. However, when the spraying of the cryogenic liquid is further continued, the volume of the gas in the liquid container starts decreasing at a certain point of time, and the pressure in the liquid container decreases. Finally, the pressure in the liquid container may become negative pressure.

[0005] An object of the present disclosure is to provide a cool-down method and a storage facility each of which cools down a liquid container while suppressing a decrease in pressure in the liquid container.

Solution to Problem

[0006] A method according to one aspect of the present disclosure is a method of cooling down a liquid container that stores a cryogenic liquid. The method includes: combining spraying supply of supplying the cryogenic liquid into the liquid container by spraying and non-spraying supply of supplying the cryogenic liquid into the liquid container; and when a

temperature of the liquid container becomes lower than a predetermined threshold, starting the non-spraying supply or increasing the amount of cryogenic liquid supplied in the non-spraying supply.

[0007] Moreover, a storage facility according to one aspect of the present disclosure includes: a liquid container that stores a cryogenic liquid; a spraying supply pipe that supplies the cryogenic liquid into the liquid container by spraying; a non-spraying supply pipe that supplies the cryogenic liquid into the liquid container; and circuitry configured to execute a cool-down program that cools down the liquid container by combining supply of the cryogenic liquid from the spraying supply pipe and supply of the cryogenic liquid from the non-spraying supply pipe and in the cool-down program, when a temperature of the liquid container becomes lower than a predetermined threshold, start the supply of the cryogenic liquid from the non-spraying supply pipe or increase the amount of cryogenic liquid supplied from the non-spraying supply pipe.

Advantageous Effects of Invention

[0008] According to the above method and configuration, the cool-down method and the storage facility which cool the liquid container while suppressing the decrease in the pressure in the liquid container can be provided.

Brief Description of Drawings

[0009] FIG. 1 is a configuration diagram of a storage facility.

FIG. 2 is a flowchart of a cool-down program.

Description of Embodiments

[0010] Entire Structure

Hereinafter, a storage facility 100 according to an embodiment will be described. First, the entire structure of the storage facility 100 will be described. FIG. 1 is a configuration diagram of the storage facility 100. As shown in FIG. 1, the storage facility 100 includes a liquid container 10, a spraying supply pipe 20, a non-spraying supply pipe 30, a ventilation pipe 40, and circuitry 50. Hereinafter, these components will be described in order.

[0011] The liquid container 10 is a container that stores a cryogenic liquid. The cryogenic liquid is liquid hydrogen, liquid helium, or the like. The liquid container 10 of the present embodiment is of a spherical type. However, the liquid container 10 may be of a flat-bottom cylindrical type including: a lower portion that is a cylinder extending in an upper-lower direction; and an upper portion that is a bowl-shaped plate. Or, the liquid container 10 may be

of a pillow type including: a cylinder extending in a horizontal direction; and bowl-shaped plates located at both sides of the cylinder. Moreover, the liquid container 10 may be located on land or may be mounted on a movable body, such as a watercraft.

[0012] The liquid container 10 includes: an inner tank 11 made of metal; and an outer tank 12 made of metal and covering the inner tank 11. As one example, the inner tank 11 and the outer tank 12 are formed by SUS304L. However, the material of the inner tank 11 and the outer tank 12 is not limited to this. Moreover, as one example, a space between the inner tank 11 and the outer tank 12 is vacuum and is filled with a thermal insulator, such as perlite.

[0013] Temperature sensors 13, 14, and 15 are located at respective height positions of the liquid container 10, the height positions being different in height from each other. The temperature sensors 13, 14, and 15 measure temperatures of the corresponding height positions of the liquid container 10 (inner tank 11). In the present embodiment, the three temperature sensors 13, 14, and 15 are located at the liquid container 10. However, the number of temperature sensors located at the liquid container 10 is not limited. Moreover, a pressure sensor 16 that measures the pressure in the liquid container 10 is located at the liquid container 10.

[0014] The spraying supply pipe 20 is a pipe that performs “spraying supply” of supplying a cryogenic liquid into the liquid container 10 by spraying. To be specific, the spraying supply is a method of supplying the cryogenic liquid as particles into the liquid container 10. The spraying supply pipe 20 is connected to a common pipe 60 located outside the liquid container 10 and is supplied with the cryogenic liquid from the common pipe 60. The spraying supply pipe 20 extends from the common pipe 60, penetrates the liquid container 10 in a radial direction, and reaches an upper region inside the liquid container 10.

[0015] The spraying supply pipe 20 includes spraying supply nozzles 21. The spraying supply nozzles 21 are located in the upper region inside the liquid container 10. The cryogenic liquid which has been supplied from the common pipe 60 to the spraying supply pipe 20 is sprayed into the liquid container 10 through the spraying supply nozzles 21 (i.e., the spraying supply is performed). Moreover, a spraying supply valve 22 is located at the spraying supply pipe 20. The spraying supply is started by opening the spraying supply valve 22. The amount of cryogenic liquid supplied in the spraying supply is reduced by reducing the opening degree of the spraying supply valve 22. The spraying supply is stopped by completely closing the spraying supply valve 22.

[0016] The non-spraying supply pipe 30 is a pipe that performs “non-spraying supply” of supplying the cryogenic liquid into the liquid container 10 by welling-up or releasing (not by

spraying). To be specific, the non-spraying supply is a method of supplying the cryogenic liquid as a continuous liquid into the liquid container 10. As with the spraying supply pipe 20, the non-spraying supply pipe 30 is connected to the common pipe 60 and is supplied with the cryogenic liquid from the common pipe 60. To be specific, the common pipe 60 supplies the cryogenic liquid to both of the spraying supply pipe 20 and the non-spraying supply pipe 30. The non-spraying supply pipe 30 extends from the common pipe 60, penetrates the liquid container 10 in the radial direction, and reaches a lower region inside the liquid container 10.

[0017] The non-spraying supply pipe 30 includes a non-spraying supply nozzle 31. The non-spraying supply nozzle 31 is located in the lower region inside the liquid container 10. The cryogenic liquid which has been supplied from the common pipe 60 to the non-spraying supply pipe 30 is supplied into the liquid container 10 through the non-spraying supply nozzle 31 by welling-up or releasing (i.e., the non-spraying supply is performed). Moreover, a non-spraying supply valve 32 is located at the non-spraying supply pipe 30. The non-spraying supply is started by opening the non-spraying supply valve 32. The amount of cryogenic liquid supplied in the non-spraying supply is reduced by reducing the opening degree of the non-spraying supply valve 32. The non-spraying supply is stopped by completely closing the non-spraying supply valve 32.

[0018] Moreover, the non-spraying supply nozzle 31 of the present embodiment supplies the cryogenic liquid from an inner surface of the liquid container 10 toward a middle region of the liquid container 10. To be specific, the cryogenic liquid is supplied so as to gush out from the non-spraying supply nozzle 31. However, the non-spraying supply pipe 30 may be located so as to extend inside the liquid container 10 and may supply the cryogenic liquid toward the inner surface of the liquid container 10 through the non-spraying supply nozzle 31 located in the vicinity of the inner surface of the liquid container 10. Moreover, the non-spraying supply nozzle 31 does not have to be located in the lower region inside the liquid container 10. During the operation of the storage facility 100, the non-spraying supply pipe 30 serves as a pipe that fills the liquid container 10 with the cryogenic liquid or carries the cryogenic liquid from the liquid container 10 to an outside of the liquid container 10.

[0019] The ventilation pipe 40 is a pipe that carries a boil off gas, generated by vaporization of the cryogenic liquid in the liquid container 10, to the outside of the liquid container 10. The ventilation pipe 40 includes a take-out nozzle 41 that is open in the upper region inside the liquid container 10. The boil off gas in the liquid container 10 flows into the ventilation pipe 40 through the take-out nozzle 41 and is carried to the outside of the liquid container 10. Moreover, a ventilation pipe valve 42 is located at the ventilation pipe 40.

[0020] The circuitry 50 is a device that performs various control operations. The circuitry 50 includes a processor, a volatile memory, a non-volatile memory, an I/O interface, and the like. The non-volatile memory of the circuitry 50 stores various programs including a below-described cool-down program and various data. The processor performs calculation processing based on the programs by using the volatile memory.

[0021] The circuitry 50 is electrically connected to the temperature sensors 13, 14, and 15 located at the liquid container 10. The circuitry 50 can acquire the temperature of the liquid container 10 by receiving a measurement signal from the temperature sensor 13, 14, or 15. Moreover, the circuitry 50 is electrically connected to the pressure sensor 16 located at the liquid container 10. The circuitry 50 can acquire the pressure in the liquid container 10 by receiving a measurement signal from the pressure sensor 16. Furthermore, the circuitry 50 is electrically connected to the spraying supply valve 22, the non-spraying supply valve 32, and the ventilation pipe valve 43. The circuitry 50 can control the opening degrees of the valves 22, 32, and 43 by transmitting control signals to the valves 22, 32, and 43. The circuitry 50 may open or close each of the valves 22, 32, and 43 by using a motor or by using pneumatic pressure or hydraulic pressure.

[0022] The functionality of the elements disclosed herein may be implemented using circuitry or processing circuitry which includes general purpose processors, special purpose processors, integrated circuits, ASICs (“Application Specific Integrated Circuits”), conventional circuitry and/or combinations thereof which are configured or programmed to perform the disclosed functionality. Processors are considered processing circuitry or circuitry as they include transistors and other circuitry therein. In the disclosure, the circuitry, units, or means are hardware that carry out or are programmed to perform the recited functionality. The hardware may be any hardware disclosed herein or otherwise known which is programmed or configured to carry out the recited functionality. When the hardware is a processor which may be considered a type of circuitry, the circuitry, means, or units are a combination of hardware and software, the software being used to configure the hardware and/or processor.

[0023] **Cool-Down Program**

Next, the cool-down program executed by the circuitry 50 will be described. The cool-down program is a program for cooling down the liquid container 10. For example, when the liquid container 10 having a normal temperature is filled with the cryogenic liquid through the non-spraying supply nozzle 31, a portion of the liquid container 10 which is located around the non-spraying supply nozzle 31 is locally cooled down. Therefore, the temperature difference between the portion around the non-spraying supply nozzle 31 and the other portion of

the liquid container 10 increases. As a result, the liquid container 10 may be damaged.

Therefore, when filling the liquid container 10 having the normal temperature with the cryogenic liquid, performed first is a cool-down in which the liquid container 10 is cooled down by slowly supplying the cryogenic liquid to the entire inside of the liquid container 10.

[0024] FIG. 2 is a flowchart of the cool-down program. As shown in FIG. 2, when the cool-down program is started, the circuitry 50 opens the spraying supply valve 22 to perform the spraying supply and closes the non-spraying supply valve 32 (Step S1). To be specific, when the cryogenic liquid is sprayed from the spraying supply nozzles 21 of the spraying supply pipe 20, the cryogenic liquid is sprayed from the upper region inside the liquid container 10 toward an internal space of the liquid container 10. Thus, the gas in the liquid container 10 is cooled down, and the cooled gas uniformly cools down the entire liquid container 10. To be specific, the liquid container 10 is indirectly cooled by the cryogenic liquid via the gas inside the liquid container 10.

[0025] By performing the spraying supply, the cryogenic liquid which has been sprayed into the liquid container 10 vaporizes, and this generates the boil off gas in the liquid container 10. By the generation of the boil off gas, the pressure in the liquid container 10 increases. At this time, part of the boil off gas generated in the liquid container 10 is emitted to the outside of the liquid container 10 through the ventilation pipe 40. The amount of boil off gas emitted can be adjusted by controlling the opening degree of the ventilation pipe valve 42. In the present embodiment, opening or closing the ventilation pipe valve 42 is controlled based on the pressure in the liquid container 10 which has been acquired from the pressure sensor 16. However, by closing the ventilation pipe valve 42 at the time of the cool-down, the boil off gas may be prevented from being emitted to the outside of the liquid container 10.

[0026] Next, the circuitry 50 acquires the temperature of the liquid container 10 (Step S2). In the present embodiment, the circuitry 50 acquires the temperature of the liquid container 10 from each of the temperature sensors 13, 14, and 15. The temperature of the liquid container 10 in the present embodiment denotes the temperature of the inner surface of the inner tank 11 of the liquid container 10.

[0027] Next, the circuitry 50 determines whether or not the temperature of the liquid container 10 which has been acquired in Step S2 is lower than a predetermined threshold (Step S3). As described above, when the cryogenic liquid is sprayed in the liquid container 10, the pressure in the liquid container 10 increases as long as the pressure is not emitted to the outside through the ventilation pipe 40. Therefore, by opening or closing the ventilation pipe valve 42, the pressure in the liquid container 10 is adjusted so as not to exceed maximum working pressure

of the liquid container 10. However, when the spraying of the cryogenic liquid is continued, at a certain point of time, the volume of the liquefied gas which decreases since the temperature of the liquefied gas in the liquid container 10 decreases becomes larger than the volume of the liquefied gas which increases since the liquefied gas is sprayed into the liquid container 10 and vaporizes, in accordance with the decrease in the temperature of the liquid container 10. As a result, the pressure in the liquid container 10 decreases. When this is continued, the pressure in the liquid container 10 becomes lower than zero and reaches negative pressure. The threshold in Step S3 described above is the temperature of the liquid container 10 immediately before the pressure in the liquid container 10 becomes the negative pressure. The threshold may be determined based on a test result of the cool-down performed in advance by using the liquid container 10 or may be a value obtained by desk study or a value obtained based on experience.

[0028] In Step S3, when the temperature of the liquid container 10 is not lower than the threshold (No in Step S3), i.e., when there is no possibility that the pressure in the liquid container 10 becomes the negative pressure, the circuitry 50 returns to Step S2. On the other hand, in Step S3, when the temperature of the liquid container 10 is lower than the threshold (Yes in Step S3), i.e., when there is a possibility that the pressure in the liquid container 10 becomes the negative pressure, the circuitry 50 closes the spraying supply valve 22 to stop the spraying supply and opens the non-spraying supply valve 32 to start the non-spraying supply (Step S4).

[0029] In Step S4, the spraying of the cryogenic liquid from the upper region inside the liquid container 10 is stopped by closing the spraying supply valve 22. Thus, the cooling of the gas in the liquid container 10 is suppressed, and therefore, the decrease in the volume of the gas in the liquid container 10 is suppressed. As a result, the decrease in the pressure in the liquid container 10 can be suppressed. Moreover, in Step S4, by opening the non-spraying supply valve 32, the cryogenic liquid is supplied from the non-spraying supply pipe 30 to the liquid container 10, and the liquid container 10 is directly cooled down. At this time, the cryogenic liquid supplied from the non-spraying supply pipe 30 vaporizes, and this generates the boil off gas. As a result, the amount of gas in the liquid container 10 increases, and therefore, the decrease in the pressure in the liquid container 10 can be suppressed.

[0030] Next, the circuitry 50 determines whether or not the cool-down of the liquid container 10 has been completed (Step S5). For example, when the temperature of the liquid container 10 has become a predetermined cool-down completion temperature or lower, the circuitry 50 may determine that the cool-down has been completed. When the temperature of the liquid container 10 is higher than the cool-down completion temperature, the circuitry 50 may determine that the cool-down has not been completed yet. Moreover, for example, when

the cryogenic liquid supplied to the liquid container 10 does not vaporize and starts being accumulated in the liquid container 10, and the liquid level of the cryogenic liquid becomes a predetermined reference liquid level or higher, the circuitry 50 may determine that the cool-down has been completed. When the liquid level of the cryogenic liquid is lower than the reference liquid level, the circuitry 50 may determine that the cool-down has not been completed yet.

[0031] When the circuitry 50 determines in Step S5 that the cool-down has not been completed yet (No in Step S5), the circuitry 50 returns to Step S5. On the other hand, when the circuitry 50 determines in Step S5 that the cool-down has been completed (Yes in Step S5), the circuitry 50 terminates the cool-down program. The foregoing has described the cool-down program in the present embodiment.

[0032] When the cool-down program is terminated (i.e., when the cool-down of the liquid container 10 has been completed), the circuitry 50 starts filling the liquid container 10 with the cryogenic liquid. The liquid container 10 is filled with the cryogenic liquid by the non-spraying supply pipe 30 or by both of the spraying supply pipe 20 and the non-spraying supply pipe 30. The amount of cryogenic liquid supplied from the non-spraying supply pipe 30 at this time may be larger than that in Step S4. To be specific, the amount of cryogenic liquid supplied from the non-spraying supply pipe 30 to the liquid container 10 can be increased after the cool-down.

[0033] Moreover, in the above cool-down program, when the temperature of the liquid container 10 becomes lower than the threshold, the non-spraying supply valve 32 is opened, and the supply (non-spraying supply) of the cryogenic liquid from the non-spraying supply pipe 30 is started (see Step S4). However, the non-spraying supply may be performed in advance at the start of the cool-down program by opening the non-spraying supply valve 32 (Step S1), and when the temperature of the liquid container 10 becomes lower than the threshold (Yes in Step S3), the amount of cryogenic liquid supplied in the non-spraying supply may be increased by increasing the opening degree of the non-spraying supply valve 32.

[0034] Similarly, in the above cool-down program, when the temperature of the liquid container 10 becomes lower than the threshold, the spraying supply valve 22 is closed, and the supply (spraying supply) of the cryogenic liquid from the spraying supply pipe 20 is stopped (Step S4). However, when the temperature of the liquid container 10 becomes lower than the threshold (Yes in Step S3), the amount of cryogenic liquid supplied in the spraying supply may be reduced by reducing the opening degree of the spraying supply valve 22.

[0035] Moreover, in the above cool-down program, closing the spraying supply valve 22 and opening the non-spraying supply valve 32 are performed at the same time in Step S4, but do not have to be performed at the same time. To be specific, in Step S4, the non-spraying supply

valve 32 may be opened (the non-spraying supply may be started) after the elapse of a predetermined period of time since the spraying supply valve 22 is closed (the spraying supply is stopped). Or, the spraying supply valve 22 may be closed (the spraying supply may be stopped) after the elapse of a predetermined period of time since the non-spraying supply valve 32 is opened (the non-spraying supply is started).

[0036] Moreover, in the above embodiment, the cool-down of the liquid container 10 is performed in such a manner that the circuitry 50 executes the cool-down program. However, the cool-down of the liquid container 10 may be manually performed by an operator.

[0037] **Conclusion**

A method according to the above embodiment is a method of cooling down a liquid container that stores a cryogenic liquid. The method includes: combining spraying supply of supplying the cryogenic liquid into the liquid container by spraying and non-spraying supply of supplying the cryogenic liquid into the liquid container; and when a temperature of the liquid container becomes lower than a predetermined threshold, starting the non-spraying supply or increasing the amount of cryogenic liquid supplied in the non-spraying supply.

[0038] As above, when the temperature of the liquid container becomes lower than the predetermined threshold, the non-spraying supply is started, or the amount of cryogenic liquid supplied in the non-spraying supply is increased. Thus, the liquid container starts being directly cooled by the cryogenic liquid, or the liquid container is directly cooled by a larger amount of cryogenic liquid. At this time, since the liquid container is locally cooled, the cooling of the gas in the liquid container is suppressed as a whole, and therefore, the decrease in the volume of the gas is suppressed. Moreover, the cryogenic liquid supplied by the non-spraying supply vaporizes, and this generates the boil off gas. Therefore, the amount of gas in the liquid container increases. As a result, the decrease in the pressure in the liquid container can be suppressed.

[0039] Moreover, in the method according to the above embodiment, when the temperature of the liquid container becomes lower than the threshold, the spraying supply is stopped, or the amount of cryogenic liquid supplied in the spraying supply is reduced.

[0040] As above, since the spraying supply is stopped, or the amount of cryogenic liquid supplied in the spraying supply is reduced, the cooling of the gas in the liquid container is suppressed. Thus, the decrease in the volume of the gas in the liquid container is suppressed, and therefore, the decrease in the pressure in the liquid container can be suppressed.

[0041] Moreover, in the method according to the above embodiment, in the spraying supply, the cryogenic liquid is supplied from an upper region inside the liquid container, and in the non-

spraying supply, the cryogenic liquid is supplied from a lower region inside the liquid container.

[0042] As above, in the spraying supply, the cryogenic liquid is supplied from the upper region inside the liquid container. Thus, when there is no possibility that the pressure in the liquid container becomes the negative pressure, the entire liquid container can be uniformly cooled down by the cooled gas. Moreover, in the non-spraying supply, the cryogenic liquid is supplied from the lower region inside the liquid container. Thus, when there is a possibility that the pressure in the liquid container becomes the negative pressure, the cryogenic liquid is easily accumulated in a bottom portion of the liquid container, and therefore, the liquid container is locally cooled. Thus, the gas in the liquid container is hardly cooled as a whole, and therefore, the decrease in the pressure in the liquid container can be suppressed.

[0043] Moreover, a storage facility according to the above embodiment includes: a liquid container that stores a cryogenic liquid; a spraying supply pipe that supplies the cryogenic liquid into the liquid container by spraying; a non-spraying supply pipe that supplies the cryogenic liquid into the liquid container; and circuitry configured to execute a cool-down program that cools down the liquid container by combining supply of the cryogenic liquid from the spraying supply pipe and supply of the cryogenic liquid from the non-spraying supply pipe and in the cool-down program, when a temperature of the liquid container becomes lower than a predetermined threshold, start the supply of the cryogenic liquid from the non-spraying supply pipe or increase the amount of cryogenic liquid supplied from the non-spraying supply pipe.

[0044] As above, when the temperature of the liquid container becomes lower than the predetermined threshold, the cryogenic liquid starts being supplied by the non-spraying supply, or the amount of cryogenic liquid supplied from the non-spraying supply pipe is increased. Thus, the liquid container starts being directly cooled by the cryogenic liquid, or the liquid container is directly cooled by a larger amount of cryogenic liquid. At this time, since the liquid container is locally cooled, the cooling of the gas in the liquid container is suppressed as a whole, and therefore, the decrease in the volume of the gas is suppressed. Moreover, the cryogenic liquid supplied from the non-spraying supply pipe vaporizes, and this generates the boil off gas. Therefore, the amount of gas in the liquid container increases. As a result, the decrease in the pressure in the liquid container can be suppressed.

Reference Signs List

[0045]	10	liquid container
	20	spraying supply pipe
	30	non-spraying supply pipe

- 50 circuitry
- 100 storage facility

CLAIMS

- [Claim 1] A method of cooling down a liquid container that stores a cryogenic liquid, the method comprising:
combining
 spraying supply of supplying the cryogenic liquid into the liquid container by spraying and
 non-spraying supply of supplying the cryogenic liquid into the liquid container;
and
 when a temperature of the liquid container becomes lower than a predetermined threshold, starting the non-spraying supply or increasing the amount of cryogenic liquid supplied in the non-spraying supply.
- [Claim 2] The method according to claim 1, wherein when the temperature of the liquid container becomes lower than the threshold, the spraying supply is stopped, or the amount of cryogenic liquid supplied in the spraying supply is reduced.
- [Claim 3] The method according to claim 1 or 2, wherein:
 in the spraying supply, the cryogenic liquid is supplied from an upper region inside the liquid container; and
 in the non-spraying supply, the cryogenic liquid is supplied from a lower region inside the liquid container.
- [Claim 4] A storage facility comprising:
a liquid container that stores a cryogenic liquid;
a spraying supply pipe that supplies the cryogenic liquid into the liquid container by spraying;
a non-spraying supply pipe that supplies the cryogenic liquid into the liquid container; and
circuitry configured to
 execute a cool-down program that cools down the liquid container by combining supply of the cryogenic liquid from the spraying supply pipe and supply of the cryogenic liquid from the non-spraying supply pipe and
 in the cool-down program, when a temperature of the liquid container becomes lower than a predetermined threshold, start the supply of the cryogenic liquid from the non-

spraying supply pipe or increase the amount of cryogenic liquid supplied from the non-spraying supply pipe.