A Study on the Supercooling Release of an Encapsulated Ice Thermal Storage System

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Heat storage technology contributes greatly to the effective use of energy, and as a result, we are involved in the development of the supercooling release agent of water for improving the efficiency of a thermal storage system. From the cycle calculation of a chiller, it was found that the charging COP declined 3% as the freezing temperature by 1°C. The efficiency of the microorganism was determined by investigating a new safety supercooling release agent instead of AgI. Furthermore, from the measurement of the thermal storage capacity of the test system containing microorganism added capsules, a microorganism is effective as a release agent because the performance is equal to AgI, with superior safety.

1. Introduction

There is much demand for the various forms of heat throughout our daily life. If waste or surplus heat could be properly stored and used when necessary, it would contribute greatly to the effective use of energy. Moreover, thermal energy storage technologies can play an important role in reshaping patterns of electricity use as well. Recent cooling demands have significantly contributed to high demand charges and environmental problems. Related to the need to reduce consumption is the need to reduce peak electricity demands and to shift the timing of electricity use. One method uses surplus electric power during the night to store cold heat in the form of ice, which is utilized for the air conditioning of buildings during the daytime. Among those air-conditioning systems that use ice as their thermal storage material, we focused on capsule-type ice-thermal storage systems, in which the water or ice are packed into the capsule. In particular, we have been investigating the supercooling of water, which interrupts the thermal storage operation, evaluating the quantitative effects of supercooling on system performance, and seeking effective release agents [1].

Silver iodide (AgI), a well-known supercooling release agent, was first discovered by Vonnegut [2]. This substance has a crystalline structure that closely resembles ice and has the longest history of use as ice-nuclei for developing rain and snow. However, because AgI is poisonous and requires extremely careful handling, researchers are looking for a much safer substance.

It is known that certain microorganisms contain powerful ice nuclei in their surface cell layers and that they cause super-cooled water to freeze [3-5]. This function is derived from ice nucleation-active (ina) genes that are linked to ice-nuclei creation. Microorganisms having such genes are collectively referred to as ice-nucleating bacteria, which possess the strongest nucleating capacity among the known nucleating agents [6].

When these microorganisms are used in thermal storage systems, they must have a superior supercooling release capacity, and more importantly, they must be able to maintain that ability even during continuous sustained operation. To date, however, no research on the durability of ice-nucleating bacteria has been undertaken.

In this paper, we first calculated the influence of supercooling on the ice thermal storage system. Next, we showed that a microorganism was effective as a supercooling release agent in place of AgI, and then, made test capsules in which the microorganism was added as the supercooling release agent, and evaluated the effect to the system performance.

2. Trial Calculation of System Performance

The supercooling phenomenon of water is a serious problem with the encapsulated ice thermal storage system. If the water in the capsule does not easily freeze by supercooling, the temperature of the brine to cool the capsules must be lowered, the load of the chiller increases, and the system performance declines. It is necessary, therefore to start with a calculation, which was used to determine by how much the supercooling influences the system performance.

2.1. System Schematic and Calculation Condition A schematic of the encapsulated ice storage system is shown in Fig. 1. It comprises of the capsule filled with water, the cooling tank in which the capsules are placed, the brine that cools the capsules, and the chiller to cool the brine etc.

We estimated the charging COP, which is the coefficient of performance, in other words, the value of the thermal output versus the consumed electric power, for the case when the freezing temperature is 0 (no supercooling), –5, and –10°C.

In this calculation, we used the CYCLE DESIGN PROGRAM of the National Institute of Standards and Technology. In this calculation, only the evaporative temperature of the chiller was a parameter, and the size of tank and capsules and packing rate were not considered. The calculation conditions were as follows:

Compressor; 2t-compressor
Refrigerant; HCFC22
Evaporative temperature;
Before release/ water temp. – 10°C
After release/ freezing temp. – 10°C
Condensing Temperature; 40°C
Super refrigerant; 5°C
Degree of subcooling; 5°C
Fan power; 0
Pump power; 0
Piping heat loss; 0
Charging run; 10 hours

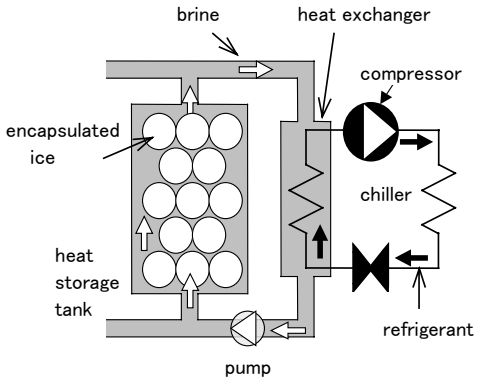

Fig.1. Encapsulated ice system.

2.2. Calculation Results The results of calculation are shown in Table 1. The value inside the parenthesis shows the relative value for no supercooling and is made 100.

From the table, as the supercooling increases the system performance declines, and consequently the charging COP declines by about 3% every time the freezing temperature decreases by 1°C, in other words, every time the supercooling is charged by 1°C. It was found that the supercooling exerted a significant influence on the system performance.

Table 1. Calculated results for charging COP.

Freezing Temp. (°C)	Total Power Consumption (MJ)	Storage Capacity (MJ)	Charging COP (-)
0	268	653	2.4
	(100)	(100)	(100)
-5	245	510	2.1
	(91)	(78)	(85)
-10	221	392	1.8
	(82)	(60)	(73)

3. Experimental Methods

We considered the applicability of an ecological microorganism called an ice-nucleating bacterium as a new safety release agent instead of AgI. We found that ultraviolet rays sterilization was effective for the ice-nucleating bacterium, although the release ability was difficult with a live bacterium. The durability of the release agent of the microorganism use and the heat storage properties when it was added to the capsules will be examined in the following section.

3.1. Preparation of Bacterial Specimens We selected a representative ice-nucleating bacterial strain, namely *Erwinia ananas* (*E ananas*) [7]. We gratefully accepted a sample of *E.ananas* from the National Institute of Agrobiological Sciences (Tsukuba), an independent administrative institution.

The freeze-stored bacterial strain was used in a Luria-Bertani medium in a thermostat at 15°C for 48h, and then centrifuged and re-suspended.

Sterilizing the bacteria after centrifugal separation and washing treatment was examined, using, ultraviolet (UV) irradiation with 260-nm UV rays from a distance of 20 cm for 20 min.

The bacterial counts in the live specimens were estimated using the colony counting method [8], in which we spread step-diluted bacterial suspensions onto agar media plates and then count the number of grown colonies.

3.2. Supercooling Release Experiment To evaluate the durability of the UV sterilized *E.ananas*, a freeze-thaw cycle test was carried out. Firstly, 1 ml of the sterilized specimens suspended solution containing approximately 10^8 cells was transferred to a test tube, diluted to 8ml, and then placed in a thermostat (Cosmopia; Hitachi, Tokyo). In the thermostat, the water to which microorganisms were added was repeatedly frozen to –10°C and thawed to 25°C.

We measured the water temperature every 2 s using a thermocouple inserted into the test tube. For all of these measurements, we used a Keyence measuring system (NR-250; Keyence, Osaka). The point where the temperature showed the largest drop during the cooling process in the repeated freeze-thaw test of water to which microorganisms were added was plotted against the freezing temperature.

3.3. Apparatus for Heat Storage Experiment Test capsules were made, in which the microorganism release agent was added. The thermal storage properties for the prototype encapsulated ice system (Fig. 2) were then evaluated.

The thermal storage capsules are made from polypropylene with a diameter of 4 cm, and UV irradiated *E.ananas* was added as the supercooling release agent. The thermal storage capacity of the test system containing 2200 capsules was measured.

Fig.2. Prototype of encapsulated ice system.

4. Results and Discussion

4.1. Freeze-Thaw Cycle Test of Bacterial Specimens Any industrial application of ice-thermal storage capsules as supercooling release agents requires that the activity be sustained through thousands of freeze-thaw cycles. Therefore, we further evaluated the long-term durability of the UV-irradiated *E.ananas* specimen that exhibited promising behavior in the above-described test.

The results of 2000 test cycles are summarized in Fig. 3. To confirm the reproducibility, 4 samples were separately prepared and then tested. The 2000 test cycles correspond to approximately a two-year

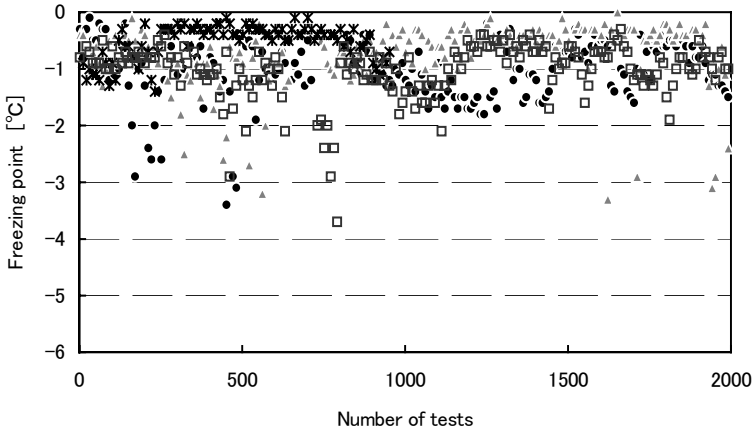

Fig.3. Freezing point of water to which UV sterilized *E.ananas* are added.

test period.

Each specimen caused the water in the test tube to freeze at about –1°C, indicating the long-term durability of the superior supercooling release capacity. A variety of the samples exhibited freezing temperatures that temporarily dropped to –3 or –4°C. Although we prepared the specimens under consistent conditions, slight fluctuations at the preparation stage, e.g., external disturbances during cultivation and sterilization, appeared to have influenced the long-term performance. However, it is our opinion that it does not have any influence on the thermal storage capacity of the system, because not all the capsules show a performance decline at the same time in the actual system due to the enormous number of capsules.

In addition, UV rays have a much lower energy level than ionizing radiation, and it is a less suitable method for large-scale sterilization, Therefore, we have evaluated the influence of γ-ray ionizing radiation on the durability of the supercooling release capacity. As a result, the γ-ray was found to be most effective, when the strength of the γ-ray was chosen correctly[9].

4.2. Evaluation of System Performance As already mentioned, the evaluation at test tube level has been completed. We tried to make a test capsule in which the microorganism release agent was added, and evaluate the thermal storage properties for the prototype encapsulated ice system.

As for the estimation of the thermal storage capacity, the brine inflow temperature to the heat storage tank and outflow temperature were measured, the specific heat and a mass flow rate of brine were incorporated into these temperature differences, and the amount of heat exchange was integrated in the charging time (10 hours).

The result of the thermal storage capacity is shown in Fig. 4. For an efficient improvement, it is desirable to reach this theoretical line without lowering the brine inflow temperature. For the water only capsules, it reaches the theoretical line at –8°C. In contrast, for the microorganism or AgI addition, it is reached at –4°C. There is a difference of 4°C, when compared with the above trial calculation, and a 10% efficiency improvement can be anticipated by the addition of the release agent.

Concerning the effect of the microorganism as the release agent, it is thought that the original performance is attained when it is considered that the water was frozen before and after –1°C during the examination of the test tube. This suggests that one should adopt UV irradiation for large-scale sterilization. Still, a microorganism is effective as a release agent because the performance is equal to AgI and its safety is superior to AgI.

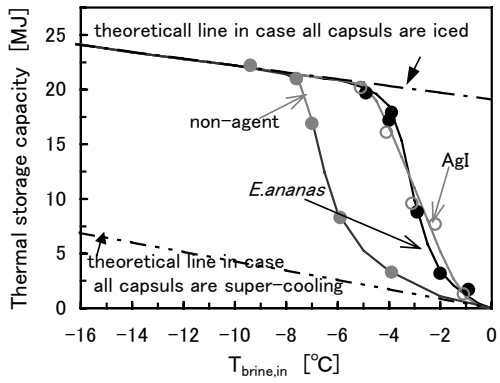

Fig.4. Comparison of thermal storage capacity.

5. Conclusions

From the cycle calculation of the capsule-type ice thermal storage system, it was found that the charging COP declined 3% as the freezing temperature decreased by 1°C, and a decrease in supercooling significantly contributes to the improvement in the system performance.

We experimentally confirmed that UV sterilized or γ-ray irradiation specimens of *E.ananas* were able to maintain a high supercooling release capacity through many freeze-thaw cycles. In terms of heat storage capacity, this microorganism agent showed a performance equal to AgI.

References and Notes

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