PERGAMON

International Journal of Heat and Mass Transfer 45 (2002) 1407–1412

International Journal of
HEAT and MASS
TRANSFER

www.elsevier.com/locate/ijhmt

Experimental characteristics of a storage tank on a harvest-type ice storage system

I.S. Choi [a], J.D. Kim [b], E. Kim [a,*], J.I. Yoon [a]

[a] *School of Mechanical Engineering, Pukyong National University, Namgu, Pusan 608-737, South Korea*
[b] *Tongmyong College, 505, Yongdang Dong, Namgu, Pusan 608-740, South Korea*

Received 1 March 2001; received in revised form 3 August 2001

Abstract

This paper is concerned with the development of a new method for making and separating ice and saving floated ice by installing an evaporation plate at underwater within a storage tank. In a conventional harvest-type ice storage system, a tank saves ice by separating a formed ice from an installed evaporation plate, which is located above an ice storage tank as an ice storage system. A new harvest-type method shows better heat transfer efficiency than a convectional method. It is because the evaporation panel is directly contacted with water in a storage tank. Also, at a conventional system a circulating pump, a circulating water distributor and a piping are installed, but these components are not necessary in a new method. In this study two kinds of ice storage systems are experimentally investigated to study the thermal characteristics of ice storage tanks. The results show the applicable possibility and performance enhancement of a new type. © 2002 Elsevier Science Ltd. All rights reserved.

---

1. Introduction

Ice storage systems, which store thermal energy, are one of useful types used in refrigeration and air-conditioner applications [1]. Ice storage systems can be classified as a static type and a dynamic type. An external melt ice-on-coil type, an internal melt ice-on-coil type and an encapsulated ice type are static types, and an ice-harvesting type and an ice slurry type are dynamic types. Specially, an ice-harvesting type among ice thermal storage systems, which are actively studied in recent years, periodically separates ice generated at the surface of an evaporator, and stores ice at a thermal storage tank installed beneath a heat transfer plate. During the discharge mode water is circulated at a thermal storage tank. Typically, an ice-harvesting system shows higher discharge efficiency, easy maintenance, and long durability of the machine [2,3]. However, water must continuously circulate around an evaporator installed at the upper part of a storage tank requiring extra equipment such as a circulation pump and piping. Also, electric power is necessary to run a circulation pump and the size of a system is not compact enough. This system provides bad heat transfer due to ice produced at an evaporator plate installed at the upper part of a storage tank [4–6]. To overcome this problem an evaporator plate producing ice is located at underwater of a storage tank. This is a new ice-producing type which produces formed ice at underwater. After ice is produced from an evaporator it is harvested by sending hot refrigerant gas into the evaporator. Then, ice separates from the surface of the outer evaporator plate, and floats by the density difference and is stored at the upper part of the storage tank.

In this study, a conventional and an underwater ice-harvesting system are applied to the same equipment. Heat and performance characteristics during ice generation and discharge modes within a storage tank are experimentally conducted. The results of a set of experimental data can be used for system maximization and performance enhancement.

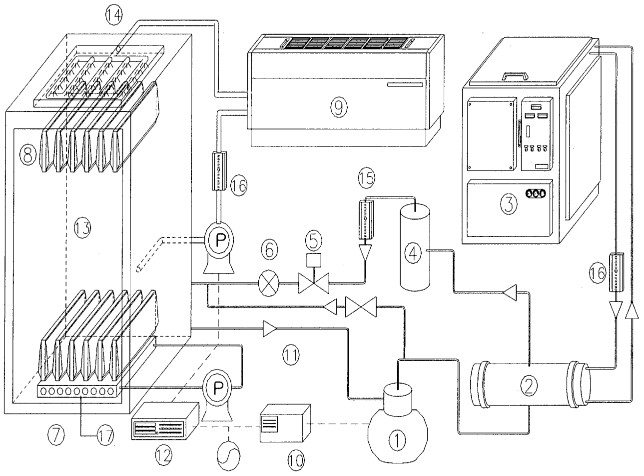
2. Experimental apparatus and method

Fig. 1 depicts a schematic of the experimental facilities. The apparatus is composed of a refrigeration

---

[*] Corresponding author. Tel.: +82-51-620-6441; fax: +82-51-620-6446.
E-mail address: ekim@mail.pknu.ac.kr (E. Kim).

0017-9310/02/$ - see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0017-9310(01)00264-2



① Compressor
② Condenser
③ Thermostatic onven
④ Receiver
⑤ Solenoid valve
⑥ Expansion valve
⑦ New type evaporator
⑧ Conventional type evaporator
⑨ FCU
⑩ Power meter
⑪ Power supply
⑫ Data logger
⑬ Storage tank
⑭ Return water nozzle
⑮ Refrigerant flow meter
⑯ Water flow meter
⑰ Water jet nozzle

Fig. 1. Schematic diagram of experimental apparatus.

apparatus of a compression type and an ice storage tank, which accumulates ice. During the generation of ice, ice is formed at the surface of the plate type evaporator located at the bottom of the ice storage tank. The charge mode changes to the discharge mode when the exit temperature of the evaporator is −2 °C. At this time, by a four-way valve installed at the inlet of an expansion valve, hot gas is injected to the inside of the evaporator. Then, ice is separated from the surface of the outside of the evaporator. Ice floated from the bottom of the tank by buoyancy effect is stored serially at the topside of the tank. In the new type the buoyancy of ice in water is weak compared to the ice–gravity–stripping in air of the conventional type. To make the stripping of ice, water jet nozzles are installed at the bottom of the evaporator.

The refrigeration apparatus is composed of a compressor, a condenser, an expansion valve, a filter-drier, an electric valve, and flow meters. The ice storage tank has many vertical plate type evaporators at the bottom of the tank, water injection nozzles and a circulation pump (PH-255A, 1/3HP) to increase the discharge velocity at the discharge mode. A compressor is a small screw type, and an evaporator can be used for water- and air-cooling types. In this experiment only the water-cooling mode is used. Thermocouples are installed to measure temperature profiles, and a water flow meter is installed for the flow rate of cooling water. At a uniform-temperature tank the constant temperature of cooling water is supplied. To control the ice generation mode and discharge mode, on–off switches and electronic valves are installed. To measure temperature distributions during the ice generation and discharge modes, 4 thermocouples are installed at each section (see Fig. 2). At the positions of 20, 140, 260, 380, 500 and 620 mm, thermocouples are installed (see Fig. 3). Totally, 24 thermocouples are installed to measure the temperature distributions in the storage tank. The experiment is conducted at the ice generation mode after the temperature in the storage tank becomes a constant value. When the inlet refrigerant temperature of the evaporator reaches the predetermined value, the temperature is measured at each position of thermocouples. The experiment is conducted at the ice generation mode first and at the discharge mode next. In the ice generation experiment, the refrigerant temperature at the inlet of the evaporator satisfies each experimental condition. The discharge condition starts when the refrigerant temperature at the exit of the evaporator reaches the predetermined temperature. Temperature controller installed at the exit of the evaporator is set to −2 °C, the temperature occurring the discharge of the thermal storage. In the ice discharge experiment, the inlet/outlet water temperature distributions at the storage tank and fan coil unit (FCU) are studied when the circulation flow

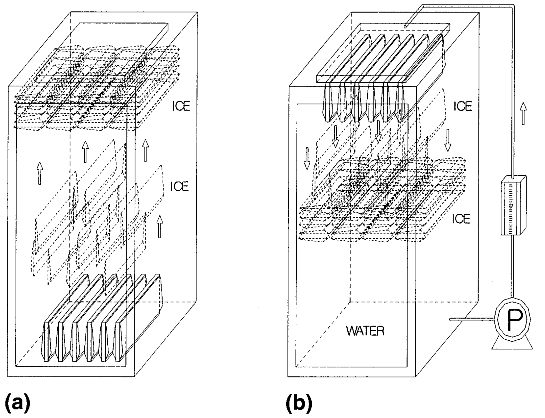


Fig. 2. Schematic diagram of ice making tanks: (a) new method, (b) conventional method.

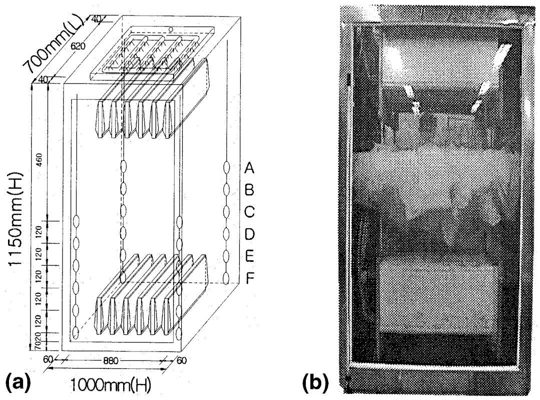


Fig. 3. Schematic diagram of ice storage tanks: (a) detailed configuration, (b) photograph.

rate of cooling water varies. In the discharge mode, returned water from the load part used FCU for cooling is constantly injected to the tank and exchanges heat with ice. Cool water flowed from the load part exchanges enough heat at the thermal storage tank. Table 1 shows the experimental conditions for the present experiment.

Table 1
Experimental conditions

Parameter	Conditions
Refrigerant	HCFC-22
Refrigerant flow rate, R_f (kg/h)	57.6
Defrost refrigerant temperature, T_d (°C)	−2
Initial water temperature, T_i (°C)	25
Cooling water flow rate, T_c (°C)	20 ± 0.5
Cooling water flow rate, T_{cf} (l/min)	12
Cooled water flow rate, Q_c (l/min)	35
Charging processing time, R_t (h)	10
Using limit temperature, T_Θ (°C)	10

3. Experimental results and discussion

After 10-h operation in the ice generation mode with the conditions of 57.6 kg/h refrigerant circulation rate, −2 °C ice generation set temperature, and 25 °C initial water temperature, the temperature distributions within the storage tank are shown in Figs. 4 and 5 for a new type and conventional type, respectively. Ice amount in the storage tank and ice packing factor before discharging are not measured, because ice amount and ice packing factor can be changed by initial water temperature or water amount of the storage tank. In comparison of experimental results between two types the experimental conditions are the same (see Table 1). In Figs. 4 and 5, the temperature distributions of each position are average values at 20(F), 140(E), 260(D), 380(C), 500(B), and 620(A) mm starting from the bottom part of the tank. In Fig. 4, with the increase of heights, temperature difference is clear. Above the middle sections (380, 500 and 620 mm) of the tank, the initial water temperature maintains almost up to 2 h. However, at the lower parts (20 and 140 mm) the evaporator plate becomes cool rapidly. The water temperatures at 260 mm are a little lower than those above middle positions due to heat diffusion coming from the bottom part of the tank. The cooling of the evaporator plate installed at the bottom of the tank makes the temperature at the lower part of the tank decrease rapidly, but heat diffusion and convection do not occur actively to the top of the tank. After 2-h operation, the discharge of ice starts, and simultaneously, the temperatures above the middle section become low by mixed convection as ice separated from the lower part of the

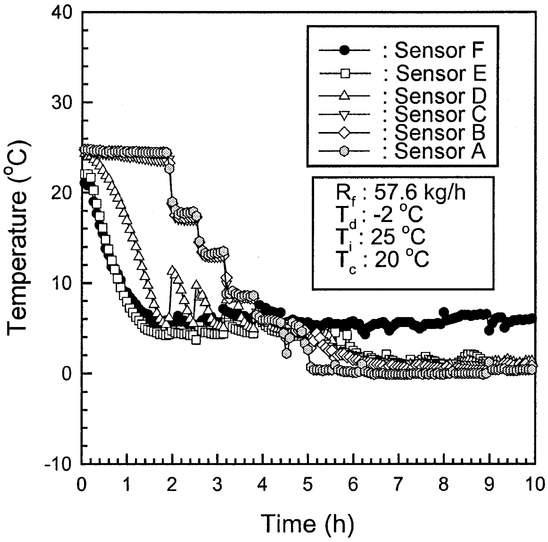


Fig. 4. Temperature distributions of the new method in the storage tank on the charge process.

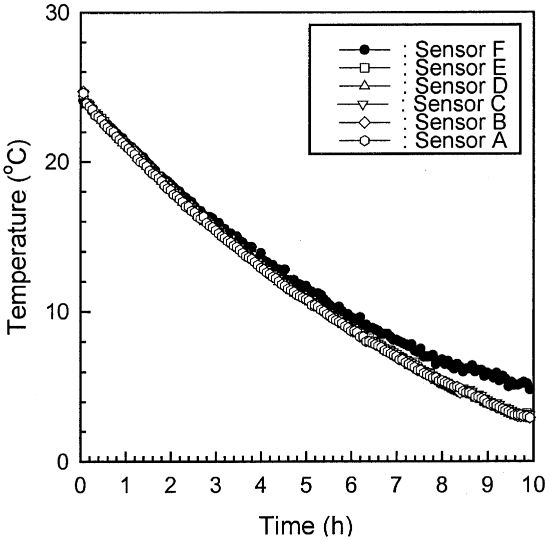


Fig. 5. Temperature distributions of the conventional method in the storage tank on the charge process.

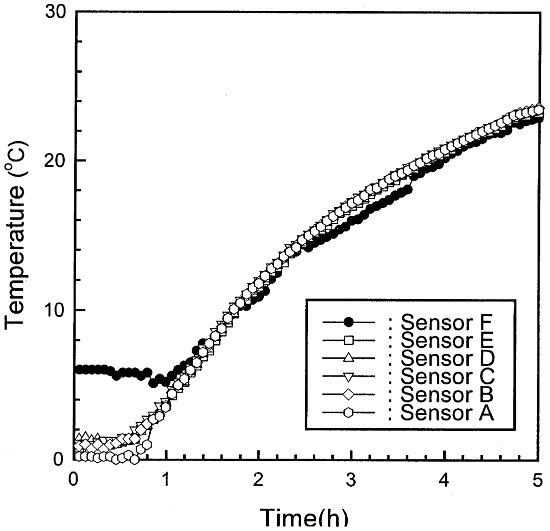


Fig. 6. Temperature distributions of the new method in storage tanks on the discharge process.

tank goes to the upper part. After the first discharge of ice, discharges occur continually with a constant time interval, and stepladder temperature profiles above the middle part and mixed phenomena occur. This is because the ice at the upper section of the storage tank absorbs the latent heat of fusion by the temperature difference between ice and water. Due to the latent heat of fusion, the temperature distributions are constant. After 4-h operation, the temperature at the upper part becomes lower than that at the lower part. From this moment, absorption capacity of the latent heat of fusion of ice decreases. Ice in the upper part makes convection flow to the lower part of the tank. With the same experimental conditions in Fig. 4, the temperature distributions for the conventional method are shown in Fig. 5. As time increases, the temperature in the tank decreases linearly. It is because a circulation pump continuously supplies water from the bottom to the top within the tank. While water falls down on the surface of the evaporator plate, ice is produced. However, the needed time for producing ice by exchanging heat between the evaporator plate and circulating water in the tank is not enough in the conventional type, and ice is produced when water circulates in the tank. This delays the producing and growing of ice. In the new type, water exchanges heat directly with the evaporator plate at the bottom of the tank, In Fig. 5, the temperature at the upper part becomes lower after 1 h passes, but over the entire operation, the temperature difference between the bottom and top does not occur largely. After the completion of the ice generation mode in the new type, the temperature distributions with varying heights at 35 l/min circulation flow rate in the storage tank for discharge progress are shown in Fig. 6. At the beginning of the discharge mode, the temperature is the highest at the very bottom part, and the lowest at the very upper part of the tank. It is because the ice stored at the upper part of the tank absorbs the latent heat of fusion when the ice exchanges heat with circulating water. Thus, the temperature profiles keep constant for 60 min as 0 °C at the upper part and 6 °C at the lower part of the tank. With the same conditions in Fig. 6, Fig. 7 shows the temperature distributions in the conventional method.

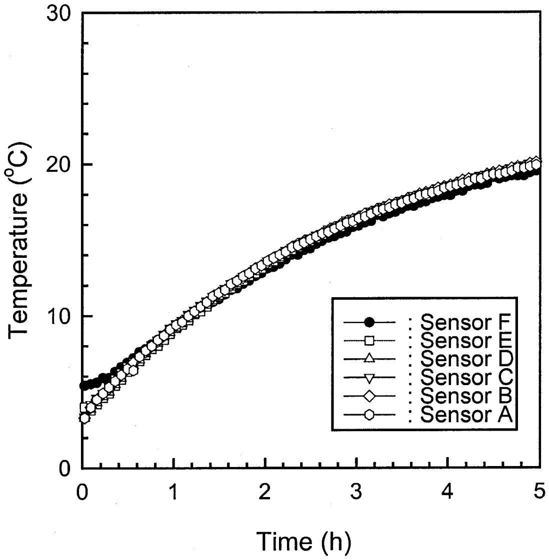


Fig. 7. Temperature distributions of the conventional method in storage tanks on the discharge process.

Up to 1-h discharge of cold, the temperature difference in the tank does not occur clearly except at the bottom surface of the tank. After 30-min operation, the temperature differences in the whole domain of the tank become constant. Fig. 8 shows the comparison of the inlet/outlet temperature variations of FCU for two different types in the discharge mode. Discharge experiments of FCU are conducted at the same experimental conditions between two different modes. For 35 l/min circulation flow rate in the new type, the exit temperature profile of FCU does not change to 65 min, and during this period, the system is operated at 3.5 °C. About 100 min takes to reach 10 °C which is the usable limit temperature used in the experimental condition. In the conventional method with the same conditions, the exit temperature increases linearly. It takes about 60 min to reach the usable limit temperature. Compared to the new type, the temperature of the conventional type reaches fast to the setting temperature. Fig. 9 shows the discharge capacity and inlet/outlet temperature differences in FCU in the discharge mode for two different types. The quantity of discharge is not calculated by an air volume flow rate and inlet air temperature of FCU. It is calculated by a water flow meter installed at the inlet of FCU, because inlet temperatures and wetness conditions of FCU continuously vary. As time passes, both discharge capacity and temperature differences decrease. The temperature difference is about 2.5 °C in the new type, and 1.2 °C in the conventional type. The discharge capacity in the new type shows about 60% higher than that in the conventional type.

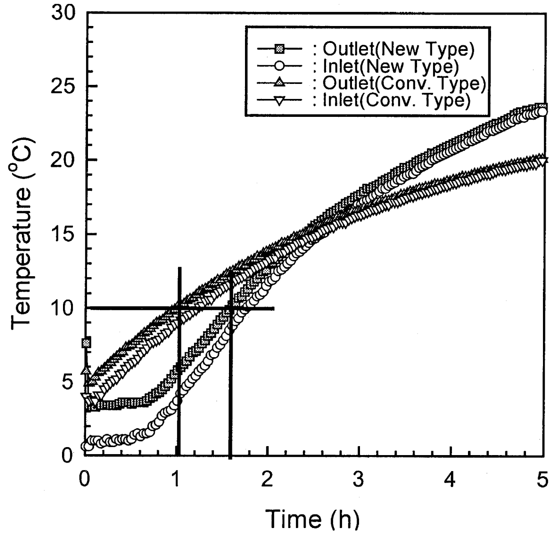


Fig. 8. Inlet and outlet temperature distributions of fan coil unit on the discharge process.

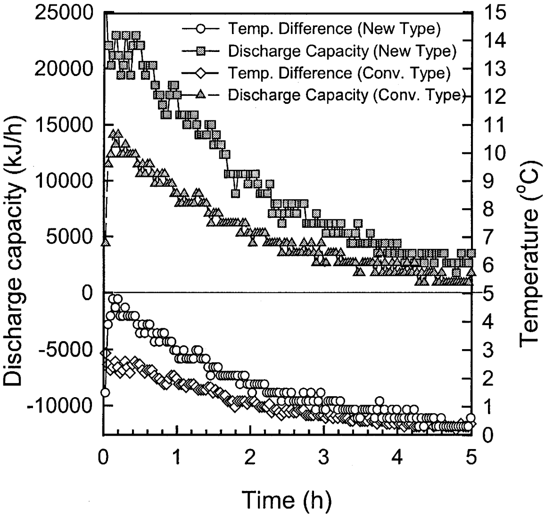


Fig. 9. Discharge capacity and temperature difference distributions of fan coil unit on the discharge process.

4. Conclusions

In ice-harvesting type systems, the conventional type and the new type producing ice at underwater are experimentally conducted. The temperature distributions and performance characteristics in the tank for two modes, ice generation mode and discharge mode, are investigated. Before the first discharge of ice in the new type, the vertical temperature differences are very clear. However, in the convention type, the temperature differences vary linearly. In the discharge mode, the temperature distributions in the new type keep the initial temperature to 90 min. The temperature difference in the conventional type is not large, and it varies linearly with the increase of time. About 100 min is needed to reach the 10 °C usable limit temperature in the new type. However, in the conventional it takes about 60 min. The discharge capacity and temperature difference of FCU in the new type show about 60% higher than these in the conventional type.

References

[1] M.C. Jang, Characteristics of electric power demand and promotion of the distribution of ice storage cooling system, in: Proceedings of the SAREK 2000 Summer Annual Conference (I), 2000, pp. 795–804.

[2] K.C. Cheng, M. Takeuchi, Transient natural convection of water in a horizontal pipe with constant cooling rate through 4 °C, J. Heat Transfer 98 (1976) 581–587.

[3] J.D. Kim, J.I. Yoon, Temperature and flow characteristics of ice storage materials, in: Proceedings of the SAREK 1998 Summer Annual Conference, 1998, pp. 997–1002.

[4] C.W. Carey, J.W. Mitchell, M.J. Brandemuehl, A simulation environment for the analysis of ice storage controls, Int. J. HVAC Res. 3 (2) (1997) 128–148.
[5] D.H. Spethmann, Optimal control for cool storage, ASHRAE Trans. (1989) 1009–1015.
[6] A. Ohira, M. Yanadori, Ice melting characteristics of an ice thermal storage container filled with harvest ice, Trans. JSRAE 1 (1999) 77–88.