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Application of thermal battery in the ice storage air-conditioning system as a subcooler

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Abstract

This article experimentally investigates the thermal performance of a thermal battery used in the ice storage air-conditioning system as a subcooler. The thermal battery utilizes the superior heat transfer characteristics of two-phase closed thermosyphon and eliminates the drawbacks found in convectional energy storage systems. Experimental investigations are first conducted to study the thermal behavior of thermal battery under different charge temperatures (−5 °C to −9 °C) in which water is used as the energy storage material. This study also examines the thermal performance of the subcooled ice storage air conditioner under different cooling loads. Experimental data of temperature variation of water, ice fraction, refrigerant mass flow rate and coefficient of performance (COP) are obtained. The results show that supercooling phenomenon appears in the water and it can be ended when the charge temperature is lower than −6 °C. The system gives 28% more cooling capacity and 8% higher COP by the contribution of the thermal battery used as a subcooler.

Keywords: Air conditioning; Thermal storage; Ice tank; Experiment; Subcooling

Système de conditionnement d'air utilisé en tant que sous-refroidisseur: application de l'accumulation de glace

Mots clés : Conditionnement d'air ; Accumulation thermique ; Bac à glace ; Expérimentation ; Sous-refroidissement

1. Introduction

Ice storage air-conditioning system [1,2] is an important element of many energy conservation programs in industry and in commercial applications. Most of the ice storage systems utilize an active control method to store or release thermal energy. In the system design of thermal storage, a pump is included to transfer thermal energy from a high-temperature heat source to the thermal storage tank via flowing working fluid. To utilize the storage energy, an electromagnetic valve is used under control to change the flow path of the working fluid, so that the energy stored in the tank is released for use later. There are two drawbacks found in such systems. First,

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Nomenclature

COP	coefficient of performance of the system with subcooler (dimensionless)
C_p	specific heat (kJ kg^{-1} °C)
H	water level height (m)
h_e	latent heat of water (kJ kg^{-1})
h	enthalpy (kJ kg^{-1})
L_x	thermal battery width (m)
L_y	thermal battery length (m)
M	total mass of the energy storage material (kg)
m	mass (kg)
P	pressure (MPa)
$\dot{Q}_a$	cooling capacity (kW)
$\dot{Q}_b$	cold storage rate (kW)
$\dot{Q}_l$	cooling load (kW)
r	mass flow ratio of the refrigerant (dimensionless)
T	temperature (°C)

Greek symbol

ρ	density (kg m^{-3})

Subscripts

a	outdoor unit
b	thermal battery
c	charge heat exchanger
d	discharge heat exchanger
e	energy storage material
i	inlet
l	cooling load
n	level no. of water
o	outlet
s	solid
t	time
w	water

the thermal storage shall be unusable in case of pump or electromagnetic valve failure. Second, the charge and discharge function of the conventional storage systems basically relies on the system piping design, and therefore only two functions, energy store and energy release, are available in its operating modes.

The present article provides a new ice storage design – thermal battery [3] in which a passive type of control is adopted to eliminate drawbacks in the convectional ice storage systems. The thermal battery, as shown in Fig. 1, mainly includes an energy storage tank and a two-phase closed thermosyphon. The energy storage tank is filled with water. The thermosyphon includes three parts, namely, a group of parallel-fin tubes vertically disposed inside the energy storage tank, charge heat exchanger and discharge heat exchanger in a double-pipe type separately located at the upper and lower regions, respectively inside the storage tank. An adequate amount of working fluid (R-22) is filled in the thermosyphon.

Fig. 2a shows the function in which the system operates to store thermal (cold) energy. When low-temperature fluid flows into the charge heat exchanger, thermal energy contained in the water is transferred to the working fluid inside the parallel-fin tubes. The liquid working fluid undergoes film evaporation and absorbs thermal energy to solidify the water as ice in the storage tank. The vapor flows upward due to its buoyancy to the charge heat exchanger. As the thermal energy is transferred to the low-temperature fluid, the vapor working fluid undergoes film condensation on the outside surface of the charge heat exchanger. Then the condensate flows along the wall of parallel-fin tubes to complete the charge cycle.

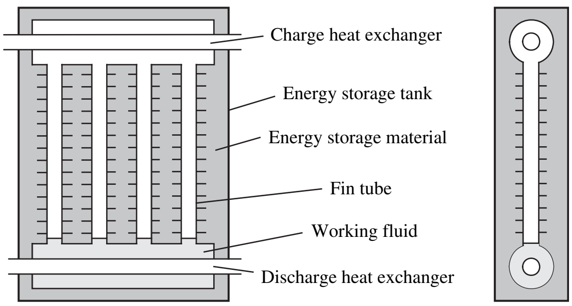

Fig. 1. Diagram of the thermal battery.

Fig. 2b illustrates the manner in which the system operates to release cold energy. When high-temperature fluid flows into the discharge heat exchanger, the ice inside the storage tank will absorb thermal energy to cool the high-temperature fluid. The liquid working fluid in the thermosyphon absorbs thermal energy from the high-temperature fluid through the discharge heat exchanger and gets boiled to produce vapor working fluid. The vapor flows upward and undergoes film condensation on the inner wall of the vertical fin tubes to release thermal energy to melt the ice. Then, the condensed working fluid flows downward and returns to the discharge heat exchanger to complete the discharge cycle.

The above-described charge and discharge operation modes work separately at different times. The third operation mode combines the above two operation modes, that is, the thermal battery also allows the operation of energy storage and energy release at the same time. As shown in Fig. 3a, when the cold energy supplied by the low-temperature flowing fluid is higher than that to be absorbed by the high-temperature flowing fluid, the thermal battery transfers the cold energy from the low-temperature fluid to the high-temperature fluid. Extra cold energy is stored inside the