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Performance analysis on the liquid-ice thermal storage system for optimum operation

Masahiko Yamada*, Shoichiro Fukusako, Tsuyoshi Kawanami

Division of Mechanical Science, Graduate School of Engineering, Hokkaido University N13-W8, Kita-Ku, Sapporo 060-8628, Japan

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Abstract

For the purpose of determining the optimum operation condition of liquid-ice thermal storage system, the performance analysis has been carried out. The target system was consisted of refrigerator, its auxiliary devices, liquid-ice production device, piping system, and thermal load section. The system performances were widely investigated analytically for the variety of operation conditions including the cycle performance of a refrigerator. The optimum operation condition of the liquid-ice thermal storage system from the viewpoint of coefficient of performance and the performance of heat release were discussed.

Keywords: Emulsion; Water; Ice; Mixture; Slurry; Design; Thermal storage; Performance; Optimization

Analyse de la performance d'un système d'accumulation thermique afin d'optimiser le fonctionnement

Résumé

On a analysé la performance d'un système d'accumulation thermique à coulis de glace. Le système comprenait un système frigorifique, des dispositifs auxiliaires, un système de production de coulis de glace, une tuyauterie, et une section à charge thermique. On a étudié les performances du système de facon analytique afin d'étudier un éventail de conditions de fonctionnement, y compris la performance du cycle frigorifique. Le fonctionnement optimal du système d'accumulation thermique à coulis de glace, en termes du coefficient de performance et de libération de chaleur, est exposé © 2002 Elsevier Science Ltd and IIR. All rights reserved.

Mots clés : émulsion ; eau ; glace ; mélange ; coulis ; conception ; accumulation ; performance ; optimisation

1. Introduction

Recently, for the purpose of energy saving and normalization of the difference of electric power demand among the seasons, both the research works and the actual usage of the cold thermal storage system have been increasing [1,2]. Liquid ice is regarded as a mixture of fine ice particles and some kind of liquid such as aqueous binary solution. Due to its high responsibility to the load change and its good portability, liquid ice is considered to be good as cold thermal storage materials for the future. A number of research works on the actual system including its production, melting [3], and transportation characteristics have been carried out. However, it seems that there may be few studies on the performance of the cold thermal storage system and its appropriate operation conditions.

* Corresponding author. Tel.: +81-11-706-6425.
E-mail address: myamada@eng.hokudai.ac.jp (M. Yamada).

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Nomenclature

C_i	initial concentration of ethylene glycol solution, mass%
COP	coefficient of performance ($=Q/W$)
IPF	ice packing factor (mass of ice / mass of liquid ice) mass%
K_p	overall heat transfer coefficient of the piping system $Wm^{-2}\,K^{-1}$
K_r	overall heat transfer coefficient of the evaporator $Wm^{-2}\,K^{-1}$
K_t	overall heat transfer coefficient of the storage tank $Wm^{-2}\,K^{-1}$
M_a	mass flow rate of the air kg s^{-1}
POR	performance of release mode ($=$ Q′/W)
q	cooling capacity of refrigerator kW
Q	integrated cooling capacity kJ
q'	released heat at air-cooler kW
Q'	integrated heat at release mode kJ
S_p	surface area of piping system m^2
S_r	surface area of evaporator m^2
S_s	surface area of liquid surface m^2
S_t	surface area of storage tank m^2
T	temperature °C
T_e	evaporation temperature of the refrigerator °C
T_s	temperature of liquid ice °C
ΔT	temperature difference °C
ΔT_m	logarithmic temperature difference °C
w	power input to refrigerator kW
W	integrated power input to refrigerator kJ
a_s	heat transfer coefficient at the liquid surface $Wm^{-2}\,K^{-1}$

Subscripts

a	air
ai	inlet of air cooler
ao	outlet of air cooler

In the present study, liquid-ice cold thermal storage system was constructed, and the simulation investigated the effects of the operation mode of the system such as the combination of the ice-storage time and its release time on the system performance.

2. Analysis

2.1. Target system of the simulation

Fig. 1 shows the schematic diagram of experimental apparatus. The system consists mainly of liquid-ice production and storage section, liquid-ice circulating loop, thermal load section, and measurement facilities. The production storage section of the slush ice consists basically of a refrigerator, evaporator, and the storage tank. Ethylene glycol aqueous solution in the storage tank was efficiently cooled by being circulated. Consequently, the liquid ice was continuously produced in the storage tank.

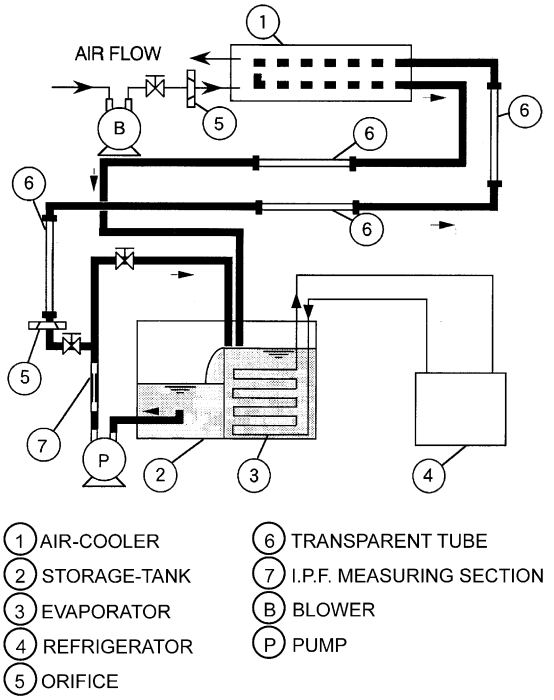

Fig. 1. Schematic diagram of the target system.

Fig. 1. Schéma du système proposé.

The evaporator of the refrigerator was made of copper tube whose diameter was 12 mm, and was installed in the storage tank. The surface of the copper tube was covered with polyolefin film to make the ice easy to remove from the surface. The thermostat controlled the refrigerator so that the surface temperature of evaporator may be maintained at a constant temperature. The temperatures at each point of the cycle were measured by 0.3 mm C–A thermocouples, and both the suction pressure and the power input of the compressor were measured as an electrical signal through the transducer. The piping system of the slush ice was made of a vinyl chloride tube of 40 mm diameter. And the flow rate of the slush ice was favorably measured by the orifice and manometer system.

At the outlet of the circulation pump in the piping system, a measuring device of ice packing factor (IPF) of the liquid ice was installed. For the measurement of the ice fraction in the liquid ice flow, some methods have been proposed in previous studies [4–6]. In the