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# A novel concept of rapid cooling method of refrigeration system

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**Abstract**

This paper describes a novel cooling method of enhancing refrigeration capacity during short time (order of 1 min) by storing low-temperature liquid refrigerant. This method actively controls the refrigerant mass flow rate for the evaporator. The compressor of the refrigerator, therefore, does not have to be oversized to cope with intermittent large cooling load of the system. During a short period of time, a higher cooling capacity than that of the steady operation is achieved by the increased mass flow rate of liquid refrigerant. An experimental apparatus was designed and fabricated to validate the proposed cooling methodology. Two reservoirs as temporary sequential storages of the refrigerant were set up before and after the evaporator. Several on/off solenoid valves were installed to control the refrigerant flow. From the experimental results, we confirmed a successful operation of rapid cooling process as designed. This rapid cooling methodology shall be useful for temporarily enhancing the refrigeration capacity in other low-capacity refrigeration systems. The practical system must optimize the design of refrigerant reservoirs to reduce the whole system size.


*Keywords:* Refrigerating system; Compression system; Design; Storage; Liquid; Low temperature

# Méthode de refroidissement rapide: un nouveau concept

*Mots clés:* Système frigorifique ; Système à compression ; Conception ; Accumulation thermique ; Liquide ; Basse température

## 1. Introduction

A compressor size is generally determined by the peak cooling load of a refrigeration system and the system control is usually performed to reduce its capacity according to the load condition [1]. When the large cooling capacity is required even for short period, the refrigerator components such as compressor and condenser must be needlessly large enough to handle the required maximum cooling capacity. Fig. 1 shows a possible intermittent cooling load condition of a refrigerator. If the refrigeration capacity of a refrigerator is somehow accumulated, the instantaneous rapid cooling power for short period can be larger than its nominal steady-state operation value. The whole refrigeration system does not have to be oversized just to cope with such infrequent intensive cooling requirements. This paper describes a refrigerant storage method in a vapor compression refrigerator to enhance the intermittently required cooling capacity. Without using an inverter-driven

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**Nomenclature**

| | |
|---|---|
| $h$ | specific enthalpy (kJ kg$^{-1}$) |
| $m$ | mass of refrigerant (kg) |
| $\dot{m}$ | mass flow rate of refrigerant (kg s$^{-1}$) |
| $q$ | heat transfer rate (kW) |
| $Q_{\max}$ | maximum cooling load (kW) |
| $Q_o$ | nominal steady-state cooling load (kW) |
| $t$ | time (s) |
| $T$ | period (s) |
| $\Delta t$ | rapid cooling period (s) |
| $V$ | volume (m$^3$) |
| $W$ | power (kW) |

*Greek letters*

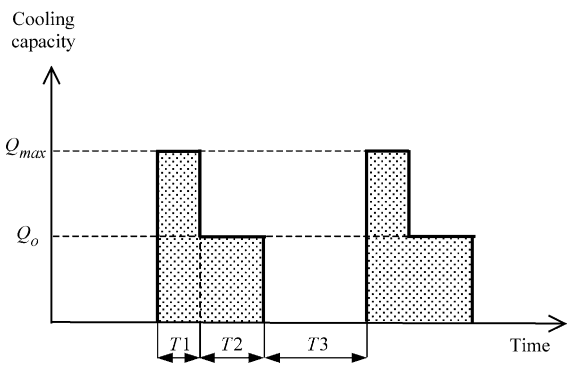
| | |
|---|---|
| $\rho$ | density (kg m$^{-3}$) |

*Subscripts*

| | |
|---|---|
| 1 | inlet of compressor |
| 2 | outlet of compressor |
| 3 | outlet of condenser |
| 4 | inlet of evaporator |
| C | with cooling of water |
| Comp | compressor |
| Evap | evaporator |
| f | saturated liquid of refrigerant |
| NC | without cooling of water |
| R1 | reservoir 1 |
| R2 | reservoir 2 |

compressor, the instant mass flow rate through the evaporator can be properly increased according to the required cooling load on demand.

There are two methods to store refrigerant; one at high-pressure state before the expansion device and the other at low-pressure state after the expansion device. In comparison to the former method, the latter would obviously require some thermal insulation system to maintain the expanded two-phase refrigerant at low temperature. In spite of this added complexity, we selected the low-pressure low-temperature storage method in this paper, because the liquid portion of the low-temperature two-phase refrigerant can be solely supplied to the evaporator without being limited by the expansion device size. This operation method maximizes the cooling effect of refrigeration system when the intensive cooling is required. This methodology resembles the Granryd cycle [2] which utilizes a phase-separator to improve refrigeration capacity. The Granryd cycle, although it tries to recover the throttle loss power of refrigerator, virtually decreased the mass flow rate of the refrigerant in the evaporator. The rapid cooling system described in this paper, however, accumulates liquid refrigerant at low temperature and enables a large amount of refrigerant to flow through the evaporator for short required time.




$T1$ : Rapid(Maximum) cooing period

$T2$ : Nominal(Steay-state) cooling period

$T3$ : Stand-by period

Fig. 1. Intermittent cooling load conditon of a refrigerator.

In order to verify the proposed rapid-cooling concept, the liquid refrigerant storage method is applied to the cooling of water in a cold-water purifier system in this paper. A large amount of cold water is sometimes necessary for intermittent demand. In this case, a cold-water purifier can utilize the refrigerant storage method to acquire cold water during the time when users require it. Since most filtered cold-water purifiers store low-temperature cooled water for its immediate demand by users, a cold-water storage method experiences sanitary problems such as bacteria growth and leakage of water while the water is being stored. A cold-water purifier using the refrigerant storage method can surely satisfy this rapid cooling demand as we will see in this paper.

## 2. Low-temperature low-pressure refrigerant storage method

### 2.1. Design concept

The low-temperature low-pressure refrigerant storage method is proposed to achieve a higher cooling capacity for short period of time than that of the steady operation [3]. Fig. 2 is the schematic diagram for the proposed concept and the prototype refrigerator is fabricated to realize it. This is a