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Experimental study of a miniature vapor compression refrigeration system with two heat sink evaporators connected in series or in parallel

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ABSTRACT

A miniature vapor compression refrigeration system included two heat sinks connected in series (indicated as series system) or in parallel (indicated as parallel system) was built. The performance of the series system was studied and compared with that of the parallel system. The results indicate that the largest cooling capacity of the two systems is about 160 W and the optimal refrigerant charge is about 0.6 M_{total} in the miniature vapor compress refrigeration (VCR) system. There is no relation between the optimal refrigerant charge and the arrangement of the heat sinks. The coefficient of performance (COP) of the series system ranged from 1.81 to 3.22, while the COP of the parallel system was in the range of 1.51–2.92 under the cooling capacity of 100 W. The cooling of the heat sink 2 lag behind that of the heat sink 1 in the serial system, while the refrigerant is difficult to equally distribute in the parallel system.

Etude expérimentale d'un système frigorifique miniature à compression de vapeur avec deux évaporateurs à puits thermiques connectés en série ou en parallèle

Mots clés : Système miniature à compression de vapeur ; Puits thermique ; En série ; En parallèle ; Etude expérimentale

1. Introduction

The vapor compression refrigeration (VCR) cycle, used to maintain a region of space at a temperature below that of the environment, is suitable for thermal control system to collect heat released from electronic devices and transport heat to environments. It is well known that the VCR systems, such as refrigerators or air conditioners, are widely used. Because the growing demand on better functionality and processing

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Nomenclature

COP	coefficient of performance [–]
d	diameter [mm]
h	enthalpy [J kg^{-1}]
I	current [A]
L	length [m]
M	mass [g]
P	pressure [Pa]
q_m	mass flow rate [g s^{-1}]
Q_1	cooling load of the first heat sink [W]
Q_2	cooling load of the second heat sink [W]
Q_c	condenser power output [W]
Q_e	total cooling capacity of the system [W]
T	temperature [°C]
U	voltage [V]
V	volume [m^3]
W	power consumption of the compressor [W]
x	direct measurement [–]
y	indirect measurement [–]

Greek

ρ	density [kg m^{-3}]

Subscripts

cond	condenser
filt	filter
hs	heat sink
pipe	total pipe

capacity, combined with the efforts for equipment miniaturization, it is important for the electronic system designers to put the thermal management solution on the highest priority. Electronic devices at low temperatures mean lower losses, higher reliability and longer service life. As compared to air, liquid or thermoelectric cooling solutions currently adopted, the VCR is becoming more and more attractive for its high energy efficiency and better performance. This study focus on a VCR systems that can be miniaturized and incorporated into electronics packaging at the chip, substrate, or board level.

Recently, many researchers have made great efforts on miniature VCR systems. Trutassanawin and Groll (2004) studied the influence of evaporator thermal resistance to the COP in a miniature vapor compression refrigeration system. Chiriac and Chiriac (2006) developed a VCR system and built an analytical model of heat sink to analyze the electronic cooling. Wu and Du (2011) designed a miniature VCR system and incorporated a heat sink to increase the efficiency of the system, whose cooling capacity was about 200 W and the COP reached 8.6. Jeng and Teng (2013) developed a VCR system with a micro-channel heat sink for the cooling of CPU. Rao et al. (2007) built a VCR system enabling thermal management of high performance computer. Sathe et al. (2008) studied the performance of a manufactured heat sink matching with the Aspen rotary compressor in the VCR system, and found that the estimated cooling capacity varied from 163 W to 489 W and the COP varied from 2.1 to 7.4, respectively. Marcinichen et al. (2010) proposed and simulated the performance of a hybrid two-phase cooling cycle with micro-evaporator for direct cooling of chips. Thome and Bruch (2008) simulated a two-phase cooling elements for microprocessors with micro-evaporation. The experiments show that the two-phase heat sink cooling system appeared to be more energy-efficient than the single-phase one. Corberan et al. (2008) analyzed the influence of the design of heat sink and operating conditions on the optimal refrigerant charge. The design of the evaporator, such as the material, evaporating temperature and the superheat, will influence its property.

In the abovementioned, these works have expanded the breadth and strengthened the depth of miniature refrigeration systems. However, in all the miniature vapor compression systems ever studied, only one evaporator was used for heat dissipation. While in actual spacecraft applications, there usually might be several scattered electronic equipment that need to be cooled down simultaneously. Therefore, it is necessary to develop and study a miniature VCR system with two or more heat sinks used as evaporator to collect and dissipate heat. To be specific, the kind of connection among multiple heat sinks should be considered. In this study two heat sinks were set up in the experimental miniature VCR system, which were connected in series or in parallel and either of which can be utilized to collect and dissipate produced heat generated by electronic devices. Two heating modules were used to simulate the heat produced by electronic devices at different levels. This paper mainly focused on the performances of the miniature VCR system by experiment.

2. Experimental system and methods

2.1. Schematic diagram of experimental miniature VCR system

Fig. 1 and Fig. 2 show the schematic of the miniature VCR system with two heat sinks connected in series (series system)

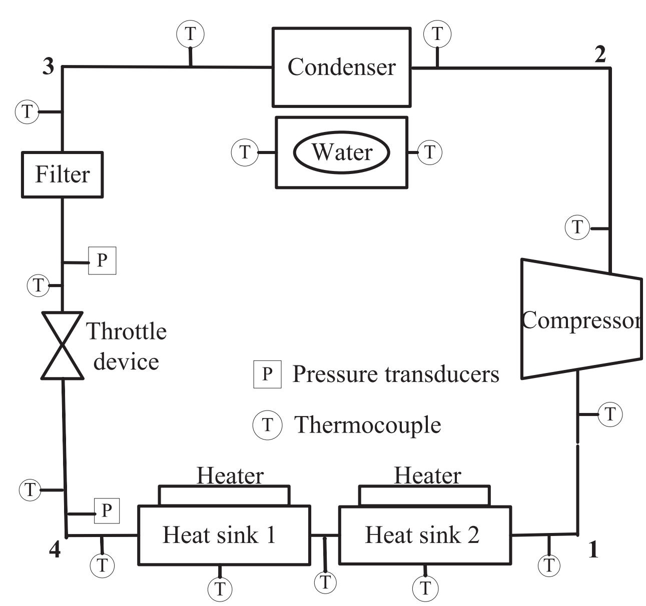

Fig. 1 – Experiment system with two heat sinks connected in series (series system).