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Research Paper

Cooling performance of a pump-driven two phase cooling system for free cooling in data centers

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HIGHLIGHTS

- A magnetic pump is used in the two-phase cooling system.
- The maximum cooling capacity reaches 3.429 kW and *EER* is 12.9 at the indoor and outdoor temperature difference of 10 °C.
- The maximum cooling capacity almost increases linearly with the indoor and outdoor temperature difference.

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ABSTRACT

The energy consumption of data centers is increasing rapidly with the development of technology. In order to reduce the energy consumption, free cooling technology instead of the conventional refrigeration system is feasible in the cold season. In the present work, a pump-driven two phase cooling system which is an excellent free cooling technology was developed and the prototype was investigated experimentally. The experimental results show that the efficiency of the magnetic pump was 7.7% at the motor frequency of 22 Hz, the cooling capacity of the system was able to reach 3.429 kW and 9.241 kW when the temperature differences between indoor and outdoor were 10 °C and 25 °C, respectively, and the *EER* were 12.9 and 29.7, which are extremely higher than the conventional refrigeration system.

1. Introduction

With the rapid development of information network and computer technologies, the energy consumption of data center is rising sharply. Electricity used in global data centers in 2010 likely accounted for between 1.1% and 1.5% of total electricity use [1]. At the same time, electricity consumed by data centers worldwide increased by about 56% from 2005 to 2010 [1]. In order to ensure the reliable operation of the data center, the cooling system must work all year round for controlling the indoor temperature and humidity. Among the energy consumption units of data center, the energy consumption of the cooling system accounts for 30~50% of the total consumption [2,3].

During the cool and cold seasons in most areas of China, the outdoor temperature is much lower than the required indoor temperature of the data centers. For the conventional cooling system, the compressor is needed to operate uninterruptedly no matter what the outdoor temperature is. Therefore, the compressor consumed a huge amount of energy at the low outdoor temperature. When the outdoor temperature is below a certain amount compared to the indoor temperature of data center, using free cooling technology by the type of directly [4,5] or indirectly [6–10], instead of the conventional cooling system, is an economic method to decrease the power consumption of data center.

Zhang et al. [11] reviewed the advancements of free cooling system in data centers from air side, water side and heat pipe. It was concluded that the heat pipe system has a great application potential due to its excellent heat transfer performance under the operation conditions of small temperature difference. Many significant studies have been focused on the cooling performance of two-phase cooling system [8–10]. For example, Tong et al. investigated a thermosyphon loop used to cool a data center, and the *EER* is 10.96 at the temperature difference of 10 °C [12]. Normally, heat pipe is mainly driven by gravity or capillary force. Although the cooling performance of heat pipe has been improved by optimizing the physical and geometrical parameters of the capillary structure [13], there are still many limitations in the high capacity and complex structures. In order to enhance the dynamic behaviors of the working medium, the driving force has been improved continuously by using various modes, such as electrokinetic force [14,15], hydromagnetic force [16], centrifugal force [17] and pump [18–21]. Among the four driving modes, the electrokinetic force or hydromagnetic force is still limited, and it is difficult to apply them in the cooling system of data center. Although the centrifugal force can provide

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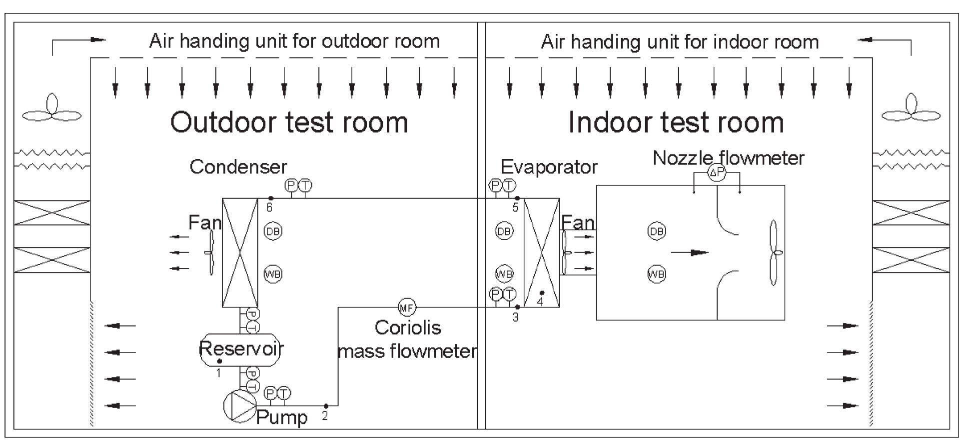
enough power to the devices, this driving mode is only suitable for specific occasions, such as motor or generator cooling, etc. Pump-driven two phase cooling system is an excellent thermal control cooling system and has many advantages, such as active temperature control, long heat transport distance and significant structural flexibility. The design and testing of the two-phase fluid thermal loops driven by pump for future large spacecraft have been investigated from 1982 to 1993 [18]. Liu et al. investigated the cooling performance of a mechanically pumped two-phase cooling loop for space thermal control [19,20]. These studies show that the cooling loop exhibits excellent performances and flexibility of structures. However, the structure and heat transfer mechanism are quite different from those in the ground compared with the space microgravity environment. In the past several years, active two-phase cooling technology for spray cooling has been investigated for the laser diode array cooling and other high heat flux application [21,22]. However, spray cooling is very complex due to its dependence on many factors. The fluid control of two phase mixed flow is one of the factors. Different concepts of two-phase on-chip cooling cycles were proposed and compared for cooling data center servers [23–25]. The results show that, when compared with traditional air cooling systems, the energy consumption of the data center could be reduced by as much as 50% when using a liquid pumping cycle. Further investigation indicates that a maximum *EER* of the liquid pump cycle is about 19 and that of the vapor compressor cycle is about 4, respectively. Zhang et al. designed and investigated a pump driven loop heat pipe for data center cooling [26]. The experimental results indicated that the *EER* is 3.75 at the temperature difference of 10 °C, and it increases to 9.37 at the temperature difference of 25 °C. Whereas, the existing system has the disadvantages which affect the performance as follows: (1) The heat dissipated by the canned pump is nearly absorbed by the working medium which increased the heat load of the system and affected the safe and steady operation of pump. (2) The flow resistance of the system is large which caused a higher sensible heat transfer.

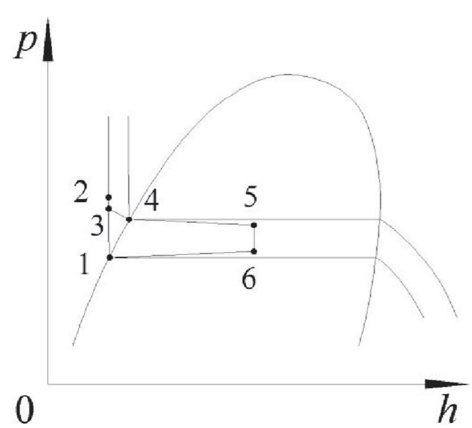
However, previous study of pump-driven two phase cooling system for data centers mainly focused on the on-chip cooling and the application with multiple evaporators. The objective of the present study is primarily to analyze the cooling performance in data center to obtain a higher cooling capacity and *EER*. For this purpose, a magnetic pump was used in the system to avoid the effect of the heat load by motor, and the designed heat exchanger and connecting pipe were considered to decrease the flow resistance of the system. Based on these, the performance characteristics of the magnetic pump and the system performances with mass flow rate and temperature difference were experimentally investigated.

2. Experiment setup

Fig. 1 illustrates the schematic diagram of experimental setup and the *p–h* diagram of the proposed cooling system. As shown in Fig. 1(a), the cooling system is mainly composed of a magnetic-driving pump, a tube–fin condenser, a tube–fin evaporator, a liquid reservoir and some connecting pipes. Fig. 1(b) shows the *p–h* diagram



(a) Schematic diagram of experimental setup



(b) *p-h* diagram of the proposed cooling system

Fig. 1. Schematic diagram of experimental setup and *p–h* diagram of the proposed cooling system. (a) Schematic diagram of experimental setup. (b) *p–h* diagram of the proposed cooling system.