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Structure Optimization on Water-Air Mixed Cooling Heat Sink When Used for Server Cooling[#]

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ABSTRACT

With the rapid development of data centers, data center servers generate a lot of heat when working, and timely heat discharge is beneficial to the normal operation of servers. To reduce the energy consumption of the data center cooling system, a water-air hybrid cooling heat sink is designed and its structure is optimized to meet the memory and chip cooling demand but meanwhile without discharging heat to the atmosphere. When taking the chip temperature, memory temperature, outlet air temperature, and pressure drop as target variables, the heat sink structure optimization is done by analyzing their effect on server cooling performance. Also, the optimal required air inlet speed is explored based on obtained optimized structures. The results show that the optimal duct number is 2, the optimal duct width is 35 mm, the optimal distance between ducts is 14 mm, the optimal heat sink width is 41 mm, and the fin height is 1.5 mm. The optimal required inlet air speed is 4 m s^{-1} when the air inlet temperature is 25 °C.

Keywords: water-cooled, air-cooled, heat sinks

1. INTRODUCTION

With the rapid development of electronic technology, the performance of electronic chips is constantly improving and the size tends to be miniaturized, however, this will generate extremely high heat. The chip is the main heat-generating component within the data center server. To ensure the chip's working performance, reliability, safety, and service life, the heat should be removed in a timely and effective manner. Common heat sink cooling methods are air-cooled and water-cooled. Tuckerman and Pease first proposed the microchannel heat sink technique for chip cooling [1]. Currently, air cooling using fans is the predominant cooling method for chips [2]. Air cooling is an air-cooled heat sink above the chip, where a fan rotates to carry away the heat generated by the chip [3,4]. With the increasing heat flow density of the chip, [1]air-cooled heat sinks can no longer meet the chip's heat dissipation requirements [5].

Various types of liquid cooling technology have been actively researched worldwide in recent years. The most currently used method of liquid cooling is cold plate cooling because of its lack of direct contact with the chip and its higher safety. Ahmed A.Y. improved the uniformity of chip temperature distribution and reduced the maximum temperature by adding subchannels [6]. Saad Ayub Jajja found through experimental studies that reducing the fin spacing and increasing the volume flow of cooling water through the heat sink reduces the heat sink's base temperature and thermal resistance [7]. Yogesh K. Prajapati numerically investigated the heat transfer and flow of rectangular microchannel heat sink with different fin heights and the results showed that increasing the fin height enhances the heat transfer of the heat sink and its heat dissipation effect will be weakened when the fins exceed a certain height [8]. The addition of ribs and notches in the microchannels can increase the heat transfer area and improve the heat transfer rate, but microscale ribs and notches lead to high pressure drop [9,10].

Most of the research nowadays is focused on chip cooling, while relatively little research has been done on server cooling. In a cold-plate server, the chip is cooled using a cold-plate heat sink and the air cools other heat-generating components, but an additional air conditioning system is required to cool the air coming out of the server to maintain a constant room temperature. In this paper, by studying a combined water-cooled and air-cooled heat sink, water cooling is used to cool the chips while air cooling is used to cool other heat generating components in the server, ensuring that the air inlet and outlet temperatures of the server are essentially the same and no excess heat is brought to the whole room, thus eliminating the need to set up an air conditioning system. This study provides a new idea for data center cooling to reduce energy consumption and simplify cooling system equipment.

2. NUMERICAL MODEL

The geometric and physical model of the water-air hybrid cooling heat sink was established using COMSOL software, as shown in Fig. 1, and the structure of the heat sink has been optimized. To simplify the problem, the following assumptions were made: Steady and laminar flow; no change in thermal properties of the material with temperature; incompressible, Newtonian, and viscous fluids; no slip at the walls. In all numerical calculations, some conditions will use a uniform setting: Fully developed flow at the inlet of the heat sink and pressure boundary conditions at the outlet. chip power of 500 W, 10 W per memory. The heat sink cooling water inlet temperature was 15 °C and the water mass flow rate is 1 L min^{-1}. The continuity, momentum, and energy equations are followed in numerically solving the conjugate heat transfer problem in the cooling process of the chip and the memory.

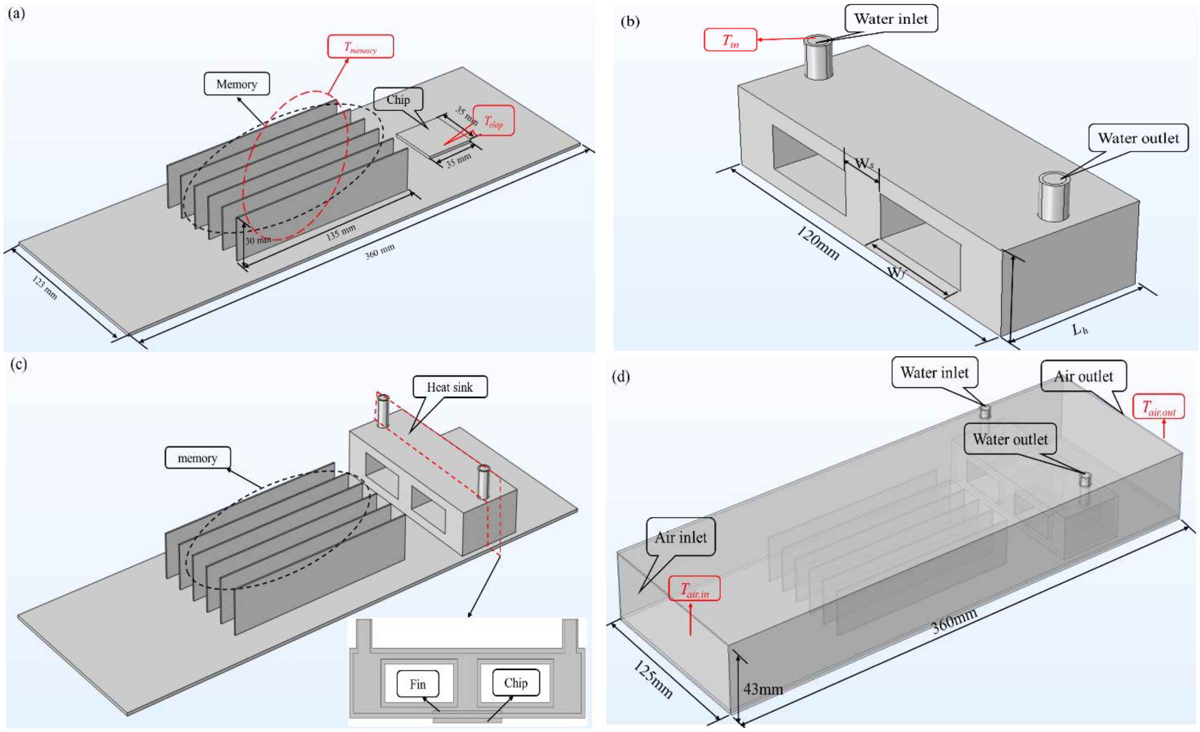

Fig.1 (a) Relative position of memory and chip, (b) Heat sink, (c) Internal structure of the model (d) Overall model of water-air hybrid cooling heat sink

3. RESULTS AND DISCUSSION

To optimize the structure of the water-air hybrid cooling heat sink, firstly, the number of air channels is changed under the fixed distance between air channels, and then the optimal number of air channels is determined; then, based on the optimal air channels, the width of the air channels is changed by fixing the spacing between air channels, and the heat sink air channel structure is determined. Based on determining the number of air channels and air channel structure, the length of the heat sink is optimized under fixed working conditions to determine the appropriate heat sink structure. The internal fin height Hf of the heat sink is an important parameter affecting heat dissipation. Based on the above optimization results, the fin height is optimized and the influence of the fin height on the heat dissipation performance of the heat sink is analyzed. Determine the appropriate fin height. Based on determining all the heat sink structures, analyze the optimal air speed required at an inlet temperature of 25 °C.

3.1 Optimization of the number of ducts and duct width

The optimal number of ducts is studied using numerical simulations with a fixed distance between the wind channels. Fig. 2 shows the chip, memory, and outlet temperature curves under different air channels and the pressure drop curve of the heat sink under different channels. Where $T_{air,in}$ is the air inlet temperature, $T_{air,out}$ is the air outlet temperature, T_{chip} is the chip temperature, T_{memory} is the memory temperature, and Δp is the heat sink pressure drop. The results show that the number of air channels has little effect on the outlet temperature and memory temperature. As the number of air ducts increases the heat sink structure becomes more complex and the internal flow resistance increases, resulting in a consequent increase in pressure drop. The chip temperature is lowest and the pressure drop is lowest when the number of ducts is 2. Therefore, 2 air ducts are selected.

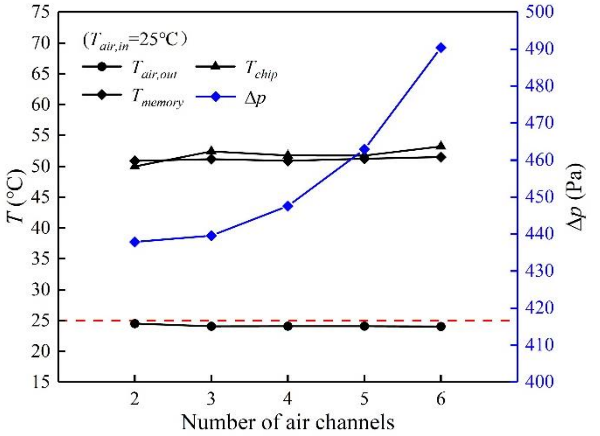

Fig. 2 Temperature curves and pressure drop curves for chip, memory, and outlet temperatures at different air channels.

Optimization of the air duct structure based on 2 air ducts. The duct width is changed based on the fixed duct spacing. Fig. 3, Fig. 4, Fig. 5, and Fig. 6 show the curves of air outlet, chip, and memory temperature and pressure drop with duct width at different duct spacing, respectively, where W_f is the duct width and W_s is the duct spacing. From the graph, it is observed that as the duct width increases the outlet temperature tends to rise, the chip temperature first falls and then rises, while the memory temperature and pressure drop fluctuate within a certain range. When W_f=35 mm and W_s=14 mm, the chip temperature is the lowest, while the memory and air outlet temperatures are not much different from other structures. On balance, the duct structure is better when W_f=35 mm and W_s=14 mm.

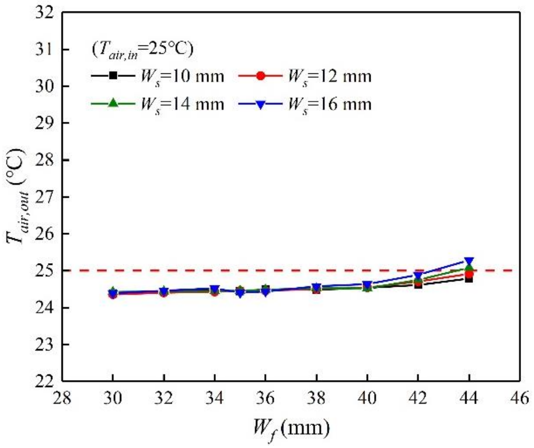

Fig. 3 Temperature variation of the air outlet at different W_f

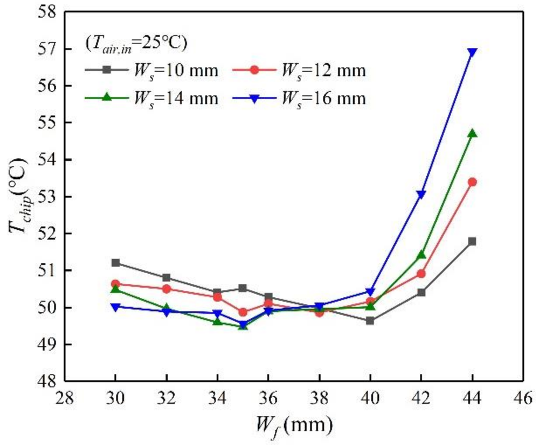

Fig. 4 Temperature variation of the chip at different W_f

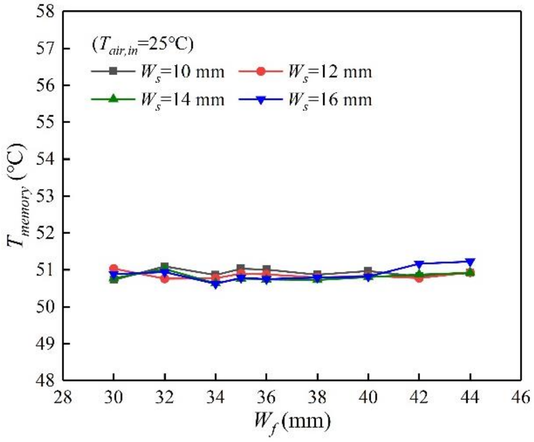

Fig. 5 Temperature variation of the memory at different W_f

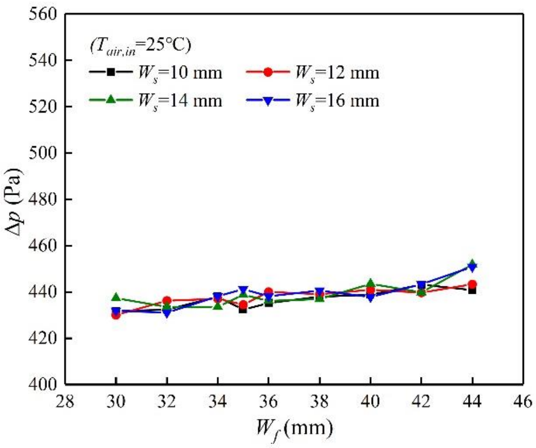

Fig. 6 Variation of heat sink pressure drop at different W_f

3.2 Optimization of the length of the heat sink

Based on the above optimization results, the length of the heat sink is optimized. Fig. 7 shows the variation of chip, memory, air outlet temperature, and heat sink pressure drop with heat sink length, where L_h is the length of the heat sink. It can be observed that with a fixed cooling water flow rate at the heat sink inlet, the chip temperature gradually increases as the length of the heat sink increases, thus causing a gradual increase in chip temperature, while the change in memory and air outlet temperature is minimal. The pressure drop of the heat sink decreases with the increasing length of the heat sink. Considering the cost, a heat sink length of 41 mm was chosen.

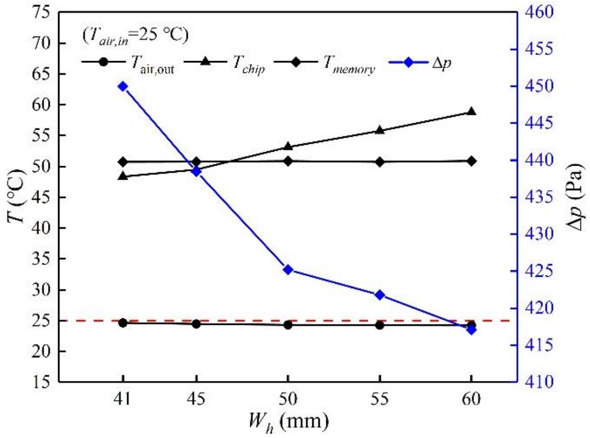

Fig. 7 The chip, memory, air outlet temperature, and heat sink pressure drop variation curves at different widths

3.3 Fin height optimization

The fin height is optimized based on the optimal number and structure of air ducts and the length of the heat sink. Fig. 8 shows the temperature variation and heat sink pressure drop variation curves at different fin heights under constant operating conditions, where H_f is the fin height, and it can be observed that the pressure drop of the heat sink increases with the fin height, while the air outlet temperature also increases. The chip temperature tends to decrease with the increase in fin height, but when the fins exceed a certain height, the heat dissipation effect decreases. When H_f=2.5 mm, the fins are in direct contact with the lower surface of the duct and conduct heat, resulting in enhanced heat transfer and lower chip temperature, while the air outlet temperature is slightly higher than the air inlet temperature. H_f=1.5 mm compared to H_f=1 mm, the air outlet temperature increases by 0.66 %, the memory temperature increases by 0.3 %, the chip temperature decreases by 2.66 %, and the pressure drop increases by 1.49 %. On balance, the fin structure with H_f=1.5 mm is chosen.

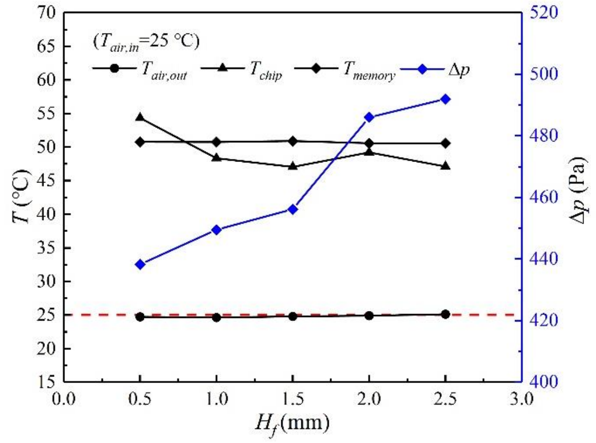

Fig. 8 Temperature and heat sink pressure drop for chip, memory, and outlet at different fin heights

3.4 Inlet air speed optimization

Based on the results of the optimization of the number and structure of the air ducts, the structure of the heat sink, and the structure of the fins described above. Under fixed conditions, the optimal water flow rate is analyzed when the inlet air temperature is 25 ℃. Fig. 9 shows the change in memory, chip, and outlet temperature and the change of inlet and outlet pressure drop curves at different air speeds, where T_{in} is the cooling water inlet temperature, q_v is the inlet water flow rate, and Δp_{air} is the air inlet and air outlet pressure drop. As observed in the fig, when the wind speed is 4 m s^{-1}, the outlet temperature is slightly lower than the inlet temperature, and the memory and chip temperatures are below70 °C, if the air speed is reduced, although the memory and chip temperatures are below 70 °C and the pressure drop will be lower, the outlet temperature is higher than the inlet temperature. Therefore, the optimum air speed required is 4 m s^{-1} when the inlet air temperature is 25 °C.

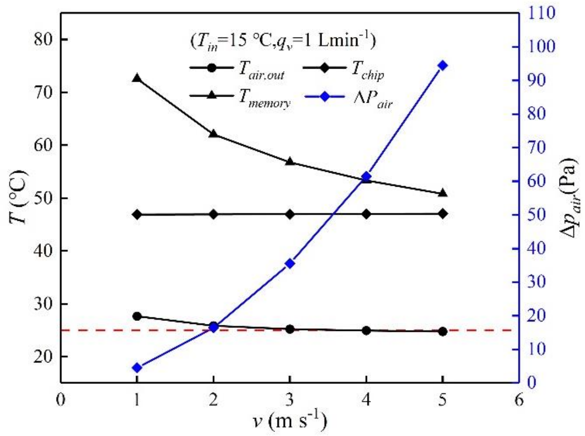

Fig. 9 Temperature and pressure drop variation curves of air outlet, chip, and memory at different inlet wind speeds

4. CONCLUSION

In this study, by constructing a water-air hybrid cooling heat sink, the number of air channels and the structure of air channels of this heat sink were optimized by numerical simulation. The main findings are as follows:

(1) The chip temperature is mainly influenced by the width of the air duct, the length of the heat sink, and the height of the fins. The structural parameters of the heat sink have a small impact on the memory temperature. The air outlet temperature is strongly influenced by the width of the air duct. The pressure drop is mainly influenced by the number of ducts, the length of the heat sink, and the height of the fins.

(2) The optimal number of ducts is 2, the optimal duct width is 35 mm, the optimal duct spacing is 14 mm, the optimal heat sink length is 41 mm, and the fin height is 15 mm. With these structural parameters, the heat sink can be made to obtain better heat dissipation.

(3) In optimizing the design of the heat sink structure, this study proposes a heat sink that meets the heat dissipation requirements of the internal heat generating components of the server. When the air speed is 4 m s^{-1}, the chip temperature is 47 °C, the memory temperature is 53.3 °C, and the air outlet temperature is 24.9 °C. Therefore, this study is feasible.

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