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Experimental study on heat transfer characteristics of composite thermosyphon radiator for CPU cooling

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Abstract. In order to meet the heat dissipation requirements of high-power CPUs and make data center servers more energy-efficient, this paper studies a composite thermosiphon radiator for 400WCPU. The cooling performance of the composite thermosiphon radiator and the degree of optimization compared with the ordinary heat pipes radiator are studied under different heat source power and different air volume conditions. The results show that the thermal resistance of the composite thermosiphon radiator is the lowest at 400W and it has little dependence on the air volume. Compared with the common heat pipe radiator, condenser has been greatly optimized, the evaporator needs to be further optimized. When the CPU power is 200W, the CPU core temperature is optimized by 6°C. It is estimated that when the CPU power is 400W, the CPU core temperature is slightly higher than the temperature spec.

1. Introduction

With the increasing integration of electronic component packaging, the amount of heat generated by electronic components has increased exponentially. Server CPU power consumption is increasing rapidly, and it will exceed 500W in the next two years, which is nearly four times of previous generations of platforms; CPU power consumption is getting higher and higher, but the maximum Tcase allowed by it is showing a downward trend, which has an higher and higher requirements of radiator thermal resistance[1]. Under the general configuration, due to space constraints, the standard radiator is close to the air-cooling limit, which cannot solve the future CPU cooling problem [2-4]. In order to make the data center server develop in the direction of safety, high efficiency, and energy saving, it is very important to develop a new type of low thermal resistance radiator.

Problem

The two-phase closed thermosyphon is one of the most effective heat transfer elements known at present. Its thermal conductivity exceeds that of any known metal. It has simple structure, light weight, low cost and excellent heat transfer performance [5]. Using the principle of closed thermosyphon to make a composite thermosyphon radiator is the current research hotspot in the field of electronic heat dissipation [6-8], such as the cooling of data center servers [9], fuel cells [10] and electronic equipment on commercial aircrafts[11]. Research by Rahimi et al. showed that after the thermosyphon adopts metal powder or capillary core sintering methods, its evaporation section and condensation section respectively show strong hydrophilicity and hydrophobicity, and the heat transfer performance is greatly improved [12].

novel
method
in lowering
heat

This paper proposes a composite thermosyphon radiator, which uses R134a as the heat transfer medium and is designed based on a 400W CPU. The composite capillary structure is set in the evaporator, and the relevant experiments are carried out according to the technical indicators of the radiator, compared with the ordinary heat pipe radiator, to evaluate the cooling capacity of the composite thermosyphon radiator to the CPU, and to obtain the performance parameters under

Papers
purpose

different working conditions at the same time. So that it can provide experimental basis for optimal design of composite thermosyphon radiator.

2. Experimental System And Experimental Method

2.1. Radiator design

Based on the high power consumption and heat dissipation problems faced by the current server CPU, a composite thermosyphon radiator is designed as shown in Figure 1. The radiator is composed of an evaporator, a condenser, an evaporator tube, a condenser tube and fins. The capillary structure is arranged in the evaporator, which increases the circulating power of the working fluid on the one hand, and on the other hand can assist in the gas-liquid separation in the evaporator. In the condenser, gas-liquid separation is carried out by means of microchannels, fin barriers, etc. The evaporating tube and the condensing tube are smooth tubes, which can reduce the flow resistance of the working fluid. When the composite thermosyphon radiator is working, the temperature of liquid working fluid will increase due to the heat absorption in the evaporator, and when the temperature reaches its boiling point, it will phase into high-temperature saturated steam. At this time, the pressure of the evaporator will increase, and the saturated steam will enter into the condenser through the gas tube under the action of pressure. The gas is cooled into a low-temperature liquid, the pressure becomes smaller, and then the liquid flows back to the evaporator under the dual action of gravity and capillary force, so as to continuously circulate.

Design of main system

Figure 1. Physical picture of composite thermosyphon radiator.

2.2. Experimental platform design

In order to accurately test the heat transfer performance of the composite thermosyphon radiator, the experimental system diagram is shown in Figure 2. To test the cooling performance of the composite thermosyphon radiator with the changing heat source power, and the simulated heat source is used to replace the real CPU. The experimental system includes a fan, a DC power supply, a composite thermosyphon radiator, a simulated heat source, and a data acquisition system. Three 4072 fans are used, and the fan voltage is 12V. In order to avoid air leakage, the air duct is constructed with a cardboard shell. The heating power of the simulated heat source can be adjusted through the DC power supply, and the size of the simulated heat source is 50*50mm. Thermocouples are used to measure the temperature of different parts of the radiator and the simulated heat source, including: T1 (simulated heat source shell temperature), T2 (bottom of evaporator), T3 (top of evaporator), T4 (evaporating end of evaporator tube), T5 (condensing end of evaporator tube), T6 (condenser left), T7 (condenser medium), T8 (condenser right), T9 (condensing end of the condenser tube), T10 (evaporating end of the condenser tube). Dig grooves on the surface of the simulated heat source to facilitate the placement of thermocouples, measure the shell temperature of the simulated heat source, and apply thermal grease between the simulated heat source and the radiator to reduce the contact thermal resistance.

Placement of every part in the experiment and its function

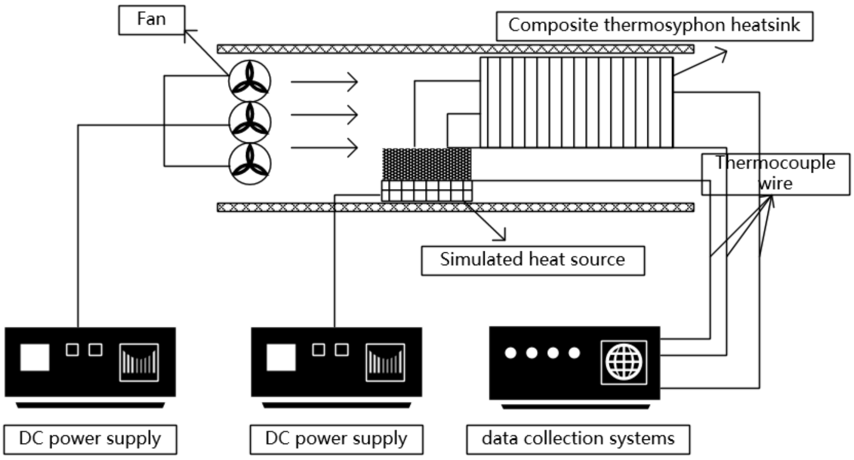

Figure 2. Radiator experimental test system diagram.

In order to accurately test the cooling performance of the composite thermosiphon radiator to the real server system and the degree of optimization compared with the ordinary heat pipe radiator, the composite thermosiphon radiator and the ordinary heat pipe radiator were installed on the server CPU for comparison tests, as shown in Figure 3. The server is placed in a constant temperature and humidity room, and the ambient temperature is maintained at 25°C. The server BMC system is used to read the CPU junction temperature, and the thermocouple is used to measure the temperature of each part of the radiator and the inlet and outlet air temperature of the radiator.

Sim.
Program
For CPU

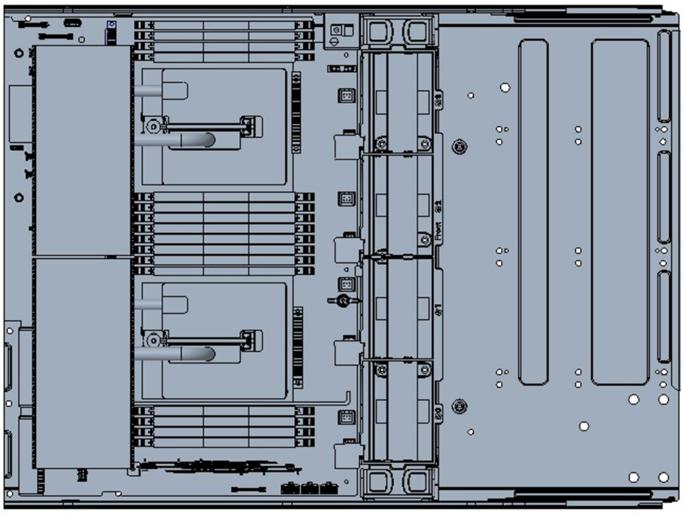

Figure 3. Schematic diagram of installation of composite thermosyphon radiator in the chassis.

3. Results And Analysis

In order to examine the working conditions of each part of the composite thermosyphon radiator and the internal heat transfer mechanism, the temperature of each position of the core part of the radiator was measured. The changes in the thermal resistance of the radiator under different heating powers are studied. In order to accurately test the cooling performance of the composite thermosiphon radiator adapted to the real server system, the composite thermosiphon radiator was systematically tested under different air volumes and different CPU power consumption, and the thermal resistance of each part was analyzed. Compare with ordinary heat pipe radiator, quantify the degree of optimization, and calculate whether this composite thermosyphon radiator can solve the target 400W CPU power consumption. The calculation formula of thermal resistance in this article is:

$$R = (Ta-Tb) / P$$

Among them, Ta and Tb are the temperatures at position a and b respectively, P is the power of the heat source, and R is the thermal resistance from position a to position b.

3.1. Analysis of the heat dissipation mechanism of the core part

Set the power of the simulated heat source to 400W, and measure the temperature distribution at each position of the core body when the ambient temperature is 13.5°C, as shown in Figure 4. It is inferred from the temperature of each position that the change of the working fluid inside the core is as follows: first, the liquid at the bottom of the evaporator absorbs heat and transforms into steam. When it flows upward to the top of the evaporator, the temperature of the steam decreases. When it continues to flow upward to the evaporating tube, due to the decrease in temperature, a small part of the gas working fluid will condense and release heat, making the temperature of the condensation end of the evaporating tube higher than the evaporating end of the evaporating tube. When the working fluid enters the condenser, it gradually becomes all the supercooled liquid state, and enters the evaporator from the evaporating end of the condenser tube. Therefore, after entering the condenser, the measured temperature basically shows a downward trend. The temperature at the condensation end of the condenser tube is slightly higher. It may be because a small part of the residual gas working fluid is condensed at this time, releasing heat, and at the same time losing the heat dissipation effect of the fins, causing the slightly rise of temperature. Through analysis, it is found that a small part of the gas working fluid in the evaporation tube will condense, which will affect the upward flow of the gas working fluid and needs to be optimized[13].

How the main system works ↗

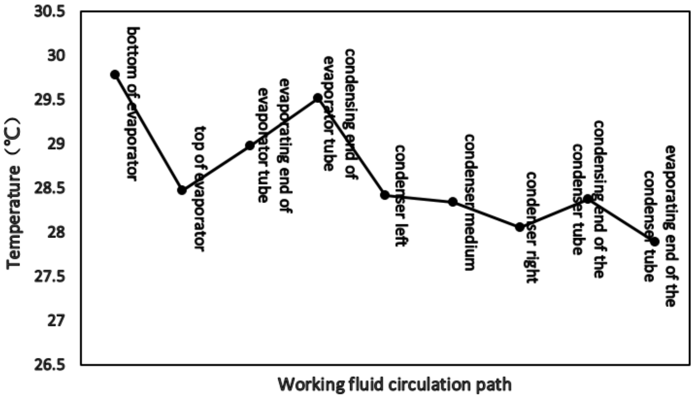

Figure 4. Temperature distribution curve at each position of the core part.

3.2. Research on the Influence of Different Heat Source Power on Heat Dissipation Performance

Keep the ambient temperature at 13.5°C, gradually increase the power of the simulated heat source from 50W to 750W, measure the temperature of the simulated heat source, and calculate the thermal resistance from the simulated heat source to the air, that is, the thermal resistance of the entire radiator. As shown in Figure 5, the test found that as the power of the heat source increases, the temperature of the simulated heat source gradually rises, and the thermal resistance of the radiator gradually decreases and stabilizes. After 400W, it starts to increase slightly. The reason may be: the radiator is filled according to the power consumption of the heat source of 400W, and there will be liquid plugging at low power. As the power consumption of the heat source increases, the liquid plugging phenomenon is alleviated. The thermal resistance reaches the lowest at 400W, indicating the liquid working fluid filling is accurate. When the power consumption of the heat source is greater than 400W, the evaporation changes from bubble-like flow to slug-like flow, more and more cavitation appears on the wall of the evaporator, and the heat transfer performance gradually deteriorates.

400W < x heat transfer is bad

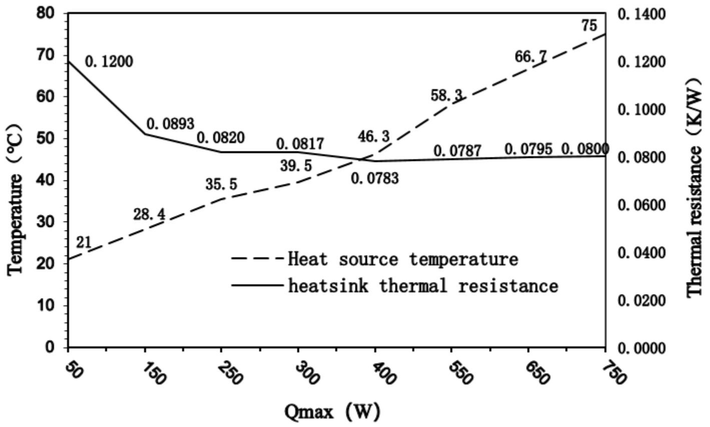

Figure 5. The curve of simulated heat source shell temperature and radiator thermal resistance vs. heat source power.

3.3. Comparison of heat dissipation performance between composite thermosyphon radiator and ordinary heat pipe radiator

3.3.1. Comparative Study on Heat Dissipation Performance of Different Air Volumes. In the real server system, the cooling performance of the composite thermosyphon radiator and the ordinary heat pipe radiator were tested under different fan duties. Select the CPU pressure mode, set the CPU power consumption to about 200W, and Rja is the thermal resistance value from the CPU junction to the air. As shown in Figure 6, the thermal resistance Rja of the composite thermosiphon radiator is lower than that of the ordinary heat pipe radiator under different fan duty. The thermal resistance of the two radiators decreases with the increase of air volume. The advantage of composite thermosyphon radiator at low air volume is greater than that of high air volume. It shows that this radiator is not very dependent on the air volume, and the cooling performance will not drop suddenly due to the decrease of the air volume.

Thermo. was better
than normal
heat pipe ->
thermo. is not
depen. on air volume

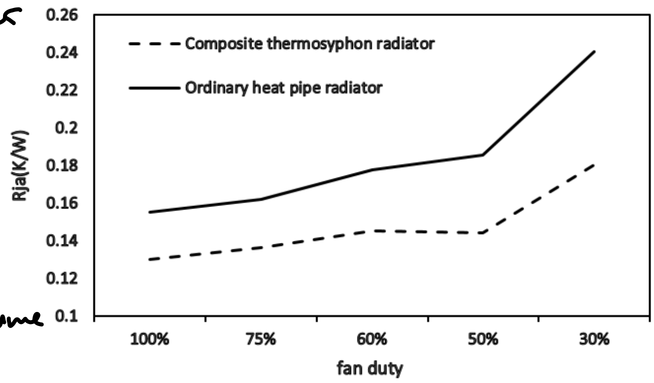

Figure 6. The curve of CPU junction-to-air thermal resistance vs. air volume.

3.3.2. Comparative study on heat dissipation performance of different CPU power. Fix the fan duty at 100% and test in two CPU pressure modes. The CPU power is 200W and 135W respectively. As shown in Figure 7, when the CPU power consumption is 200W, the CPU core temperature of the composite thermosiphon radiator is 6°C lower than that of the ordinary heat pipe radiator; when the CPU power consumption is 135W, the CPU core temperature of the composite thermosyphon radiator is 4°C lower than that of the ordinary heat pipe radiator. Therefore, when the CPU power consumption is 200W, the optimization effect of the composite thermosyphon radiator is more obvious, which

↑CPU power = ↓ temp. for thermo. compared to heat pipe.

verifies the curve of the thermal resistance of the radiator with the power consumption of the heat source. At 200W, the thermal resistance is smaller, so the optimization effect is more obvious.

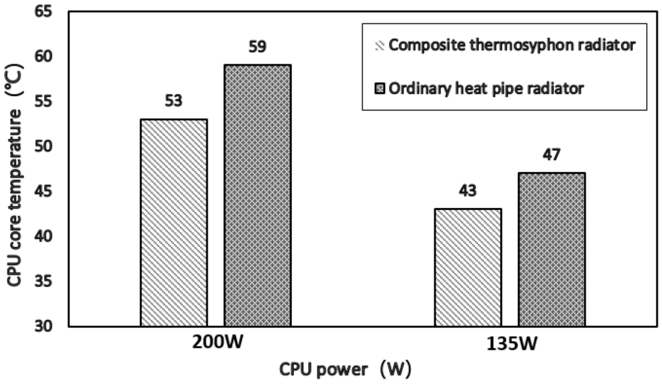

Figure 7. CPU core temperature with different CPU power.

3.3.3. Comparative study on the thermal resistance of each part of the radiator. In order to test the heat dissipation performance of each part of the composite thermosyphon radiator on the real CPU, and compare it with the corresponding ordinary heat pipe radiator, during the test, thermocouples are used to measure the temperature of each part of the two radiators, and the fan duty was set to 100% , Select the CPU pressure program, control the CPU power consumption at about 200W, the test data is shown in Table 1, including: T_{air}(Inlet air temperature) ,T_{et}(Evaporation tube temperature) , T_{fin}(Fin temperature) , T_j(CPU core temperature), R_{total}(Total thermal resistance) , R_{jt}(Thermal resistance from CPU core to evaporation tube), R_{con}(Condenser thermal resistance).

Table 1. Summary of temperature and thermal resistance at each position of the radiator.

Radiator project	CPU power （W）	Tair (°C)	Tet (°C)	Tfin (°C)	Tj (°C)	Rtotal （°C/W）	Rjt (°C/W)	Rcon (°C/W)
Composite thermosyphon radiator	198	27.17	31.27	31.43	53	0.13	0.11	0.02
Ordinary heat pipe radiator	200	27.97	40.49	33.25	59	0.16	0.09	0.06

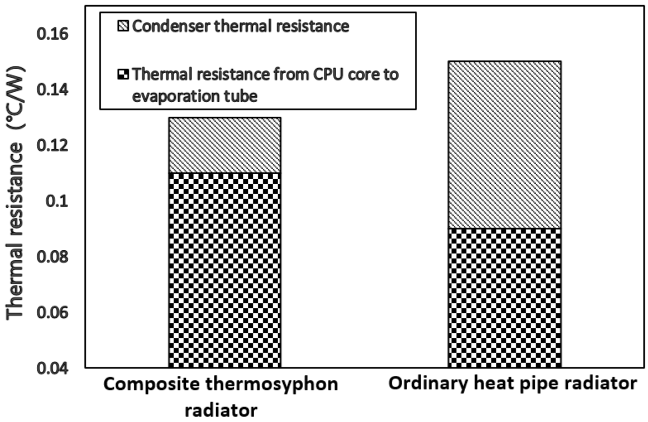

Figure 8. Comparison of the thermal resistance of each part of the radiator.

By comparing the thermal resistance of each part, it can be seen that the total thermal resistance of the composite thermosyphon radiator is lower, only 0.13°C/W. But the thermal resistance from the

CPU core to the evaporator tube is larger than that of the ordinary heat pipe radiator. When the thermal resistance of the CPU is constant and the same thermal interface material is used so that the thermal resistance of the interface is as consistent as possible, it indicates that the thermal resistance of the evaporator of the composite thermosyphon radiator is relatively large. Comparing the thermal resistance data of the condenser, it is found that the thermal resistance of the condenser has been greatly optimized. Therefore, the evaporator of the composite thermosyphon radiator needs to be further optimized, considering that the optimization direction may be the internal gas-liquid separation of the evaporator and the increase of the capillary structure force.

Thermo. has less heat resis.

3.3.4. 400W cooling result calculation. Since this server system lacks a real 400W CPU, based on the test data in Table 1 and the curve of the heat sink thermal resistance vs. heat source power consumption in Figure 5, simply calculate whether the composite thermosyphon radiator meets the 400W CPU heat dissipation requirements. According to Figure 5, the thermal resistance of the composite thermosyphon heat sink at 400W is about 0.008 lower than that at 200W. The calculation process is as follows:

$$Rja\ (400W) = Rja\ (200W) - 0.008$$
$$Tj = Rja\ (400W) * P + Ta$$

Among them, Rja (400W) is the thermal resistance from the CPU core to the air when the heat source power consumption is 400W; Rja (200W) is the thermal resistance from the CPU core to the air when the heat source power consumption is 200W; Tj is the CPU core temperature ; P is the power consumption of the heat source, which is 400W at this time; Ta is the inlet air temperature of the radiator. It is calculated that when the composite thermosyphon radiator is used and the ambient temperature is 35°C, the 400WCPU core temperature is 86.15°C. The CPU core temperature spec is 85°C, so although the use of a composite thermosyphon radiator can greatly improve the heat dissipation of the CPU, it still cannot meet the heat dissipation requirements at 400W, and further optimization is needed.

Thermo. can not work with 400W and needs optimization

4. Conclusion

In order to meet the future server CPU cooling requirement, this paper experimentally studied a composite thermosyphon radiator, and tested its heat dissipation performance, and the following conclusions were drawn: (1) When this radiator is working, a small part of the gas working medium will condense in the evaporation tube, which will affect the upward flow of the gas working medium. This needs to be further optimized. (2) The thermal resistance of the radiator decreases first and then increases slightly with the increase of the heat source power consumption. The thermal resistance reaches the lowest at 400W, and the filling quantity of the liquid working medium of the radiator is accurate.. (3) The total thermal resistance of the composite thermosyphon radiator is lower than that of the ordinary heat pipe radiator and there is no serious dependence on the air volume. (4) The optimization effect of the composite thermosyphon radiator at 200W CPU power is greater than that of 135W CPU power. The thermal resistance of the condenser has been greatly optimized. The thermal resistance of the evaporator is higher, and further optimization of the evaporator is required. (5) Using the composite thermosyphon radiator, the CPU core temperature is slightly higher than the temperature spec at 400W CPU power, and the radiator needs to be further optimized.

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