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Experimental Study on Micro Heat Pipe Array Radiator in High Altitude Area

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Abstract

Aiming at the problem of poor heat dissipation of photovoltaic inverter in high-altitude areas, which affects its actual performance and service life, this paper plans to adopt micro heat pipe array technology and use the phase change heat transfer mechanism to study the temperature rise characteristics of micro heat pipe array radiators with different shapes at different liquid filling rates, and separately study the effects of different liquid filling rates on the total thermal resistance and each segment thermal resistance of flat micro heat pipe array radiators. The experimental results show that when the liquid filling rate is 50% ~ 70%, both flat and cylindrical micro heat pipe array radiators can reach thermal equilibrium; Under the same working medium and liquid filling rate, the thermal response speed of flat plate is better than that of cylindrical, and the thermal response time is shortened by about 20s; Considering the factors of heat balance and thermal resistance, the liquid filling rate of micro heat pipe array radiator should be between 50% ~ 60%.

Keywords

High Altitude Areas; Micro Heat Pipe Array; Liquid Filling Rate; Thermal Resistance.

1. Introduction

With the rapid development of Tibet's economy, solar distributed photovoltaic power station, as a convenient, inexhaustible and pollution-free clean energy, has become the energy choice of more and more farmers and herdsmen. With the increasing installed capacity of photovoltaic power station, wider application range and higher requirements for power supply quality, the capacity of inverter as its core key equipment is also increasing, and the requirements for comprehensive performance are also higher and higher. However, with the development of high frequency, high power and high integration of photovoltaic inverter [1], the heat flux density per unit area is higher and higher, especially the IGBT module as the main heating component. The heat dissipation problem has become the main factor directly affecting the operation reliability and stability of photovoltaic inverter [2]. At present, the solution to the heat dissipation problem of photovoltaic inverter is mainly external heat dissipation, which is divided into: (a) forced heat dissipation by air convection; (b) Phase change material (PCM) is used for phase change heat dissipation; (c) Cooling with liquid (water, refrigerant, etc.) for cooling and heat dissipation; (d) Heat pipe cooling, phase transformation and convective heat dissipation at the same time. Among them, air convection forced heat dissipation has the advantages of simple structure, easy maintenance and low cost, but it has long heat dissipation time and high energy consumption; PCM phase change heat dissipation mode has the advantages of good heat dissipation uniformity and great potential, but the thermal conductivity is low and the phase change latent heat is relatively small; The liquid cooling and heat dissipation mode has the advantages of large convective heat exchange and good temperature uniformity, but the additional heat dissipation accessories take up a large space

[3]; The heat pipe heat dissipation method has the advantages of simple structure, high heat exchange efficiency and no risk of leakage and short circuit.

At present, experts and scholars at home and abroad have carried out research on the heat dissipation performance of heat pipes in all walks of life, and obtained a series of research results. Burban et al. [4] applied the circular pulsating heat pipe to the heat dissipation of hybrid electric vehicles. Its filling media are acetone, methanol, water and n-pentane respectively. It is obtained that the circular pulsating heat pipe can operate normally under different inclination angles, and the working thermal resistance decreases with the increase of power and air flow rate; Tran et al. [5] studied the heat dissipation performance of the battery module by using the flat plate capillary core heat pipe. Through the experiment, the flat plate capillary core heat pipe can make the battery module have good heat dissipation performance, and the average temperature is maintained below 50 ℃; Zeng Jian et al. [6] designed a tubular capillary core heat pipe heat dissipation module according to the temperature rise characteristics of lithium battery during charging and discharging, and obtained through experiments that the heat pipe heat dissipation module can control the maximum temperature of lithium battery within 40 ℃; Zhou haikuo et al. [7] studied the feasibility of heat management based on intelligent control algorithm under low-power fan by using the designed integrated combination of flat heat pipe + fin + heat collection module in high-power lithium battery box.

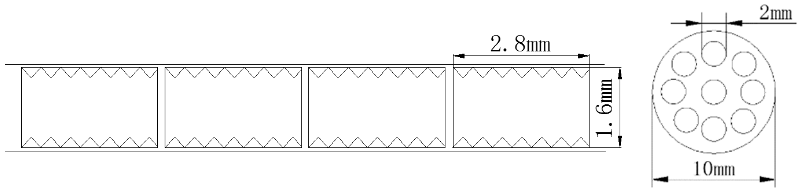
Aiming at the current situation of poor heat dissipation effect of existing photovoltaic inverters in high-altitude areas, combined with the heat dissipation characteristics of micro heat pipe array, this paper experimentally studies the effects of different shapes and different liquid filling rates on its heat transfer performance, and explores the relevant heat transfer mechanism of micro heat pipe array radiator, so as to provide basic theoretical basis and optimization design support for the heat dissipation of photovoltaic inverter based on micro heat pipe array.

2. Test Pieces and Devices

2.1. Micro Heat Pipe Array Test Piece

In this paper, two kinds of micro heat pipe arrays with different shapes are specially made: flat and cylindrical. They are made of aluminum alloy (the thermal conductivity of the shell is 163W/ (m · K)), and their dimensions are flat 900 mm × 50 mm × 3 mm (Long × wide × Thickness) and cylindrical Φ 10mm and 900 mm (diameter and length), and the real object is shown in Figure 1. The two kinds of micro heat pipe arrays are composed of multiple independent micro channels with capillary structure, and the size of a single micro channel is: the size of a flat plate is about 2.8mm × 4.8mm × 1.6mm (Long × wide × Thickness), the wall thickness is about 0.7mm, and the overall width section has a total of 8 micro channels; The cylindrical dimension is about Φ 2mm, 4.8mm (diameter and length), and the wall thickness is about 0.7mm. The gap in the middle of the micro channel is fixed with a diaphragm, and its overall circular section has a total of 9 micro channels. The micro channel dimensions of the two micro heat pipe arrays are shown in Figure 2. The working medium of the above two micro heat pipe arrays is acetone, and the liquid filling rates are 30%, 40%, 50%, 60% and 70% respectively.

Fig 1. Physical diagram of micro heat pipe array

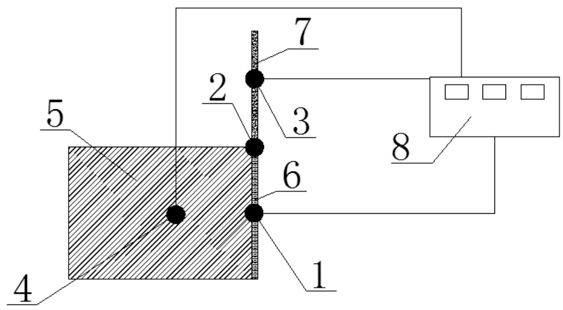


(a) Flat (b) cylindrical

Fig 2. Micro channel size diagram of two kinds of micro heat pipe arrays

2.2. Experimental Device and Steps

The experimental device system is shown in Figure 3. The flat and cylindrical micro heat pipe array radiators are in close and effective contact with the IGBT module shell with high-performance thermal conductive silicone grease, and temperature measuring points 1 ~ 4 are set to test the hot-side temperature, middle section temperature, cold-side temperature and core component surface temperature of the micro heat pipe array radiator respectively. Both micro heat pipe array radiators are filled with acetone working medium, and the liquid filling rate is 30% ~ 70%. When the hot end of the micro heat pipe array radiator receives the temperature of the core components, the heat source uses the heat conduction method to transfer the heat to the working medium at the hot end of the micro heat pipe array through the heat conductive silicone grease. After the acetone absorbs heat and vaporizes, it flows to the cold end under the action of differential pressure. After the acetone is exothermic and liquefied, it flows back to the hot end under the action of gravity. In this way, the heat is transmitted to the heat sink to achieve the purpose of heat dissipation of the core components. In the experiment, the data acquisition cycle is 30s, the temperature test adopts K-type thermocouple, the correction error of the thermocouple is 0.2K, and the heat transfer process is approximately simplified to one-dimensional steady-state heat conduction. The experimental steps are as follows: (a) select the flat plate micro heat pipe array radiator with liquid filling rate of 30% and stick it closely to the shell of IGBT module; (b) Collect the data of temperature measuring points 1 ~ 4 through thermocouples; (c) When the temperature of the flat micro heat pipe array reaches thermal equilibrium or changes periodically, stop data acquisition; (d) Replace the flat plate micro heat pipe array radiator with other liquid filling rate and repeat data acquisition; (e) Replace with cylindrical micro heat pipe array radiator, repeat the above steps, and complete the experiments of micro heat pipe array radiator with different shapes and different liquid filling rates.



1 - hot end temperature acquisition point; 2 - intermediate section temperature acquisition point; 3 - cold end temperature acquisition point; 4 - surface temperature collection points of core components; 5 - core components; 6 - hot end of micro heat pipe array; 7 - cold end of micro heat pipe array; 8-data collector

Fig 3. Experimental device

3. Result Analysis

3.1. Influence of Different Liquid Filling Rate

Based on the existing PV Inverter in normal operation, two different shapes of micro heat pipe array radiators are designed: flat plate shape 900 mm × 50 mm × 3 mm (Long × wide × Thickness) and cylindrical Φ 10mm and 900 mm (diameter and length). Under the condition of filling acetone working medium, the filling rates are 30%, 40%, 50%, 60% and 70% respectively. By measuring the temperature of temperature measuring point 2, the temperature rise characteristics of micro heat pipe array radiators with different shapes under different liquid filling rates are studied and analyzed. As shown in Fig. 4 and Fig. 5, when the liquid filling rate is 30%, both flat and cylindrical micro heat pipe array radiators are in a thermal imbalance state, and the temperature in the middle section of micro heat pipe array increases linearly with time. This is because there are relatively few working fluids in the micro heat pipe array. After the gaseous acetone releases heat at the cold end, it continues to absorb heat and evaporate before returning to the hot end. The acetone working fluid is approximately considered to be in the vaporization state all the time. The heat transfer performance of the whole micro heat pipe array is similar to that of aluminum alloy, and it is almost in the heat conduction state as a whole. When the liquid filling rate is 40%, they are in wave equilibrium. The temperature of flat plate micro heat pipe array tends to fluctuate periodically after 90 s and cylindrical micro heat pipe array after 110 s. This is because when steam acetone flows through the middle section, the convective heat transfer capacity is poor and its temperature increases. When liquid acetone flows through the middle section, the convective heat transfer capacity is strong and its temperature decreases. Due to the alternating flow of acetone working medium in different states, the temperature of micro heat pipe array fluctuates periodically. When the liquid filling rate is 50% ~ 70%, it can reach the thermal equilibrium state. The temperature changes first rise rapidly, and then the flat shape is in the thermal equilibrium state after about 90s and the cylindrical shape is in the thermal equilibrium state after about 110s. At this time, the temperature fluctuation range is within 1 ℃ and remains basically unchanged. At the same time, by comparing Fig. 4 and Fig. 5, it can be seen that under the condition of the same liquid filling rate, the thermal response speed of the flat micro heat pipe array radiator is better than that of the cylindrical radiator, and its thermal response time is shortened by about 20s. This is because the contact area between the cylindrical micro heat pipe array and the shell of core components is smaller than that of the flat radiator. On the basis of ensuring the thermal insulation measures, the heat flux transferred from the shell of core components to the hot end of micro heat pipe array is only about 1 / 3 of that of flat plate, resulting in the overall thermal reaction speed being slower than that of flat plate. Therefore, under the experimental conditions, considering the heat balance state, the liquid filling rate of micro heat pipe array radiator should be between 50% ~ 70%.

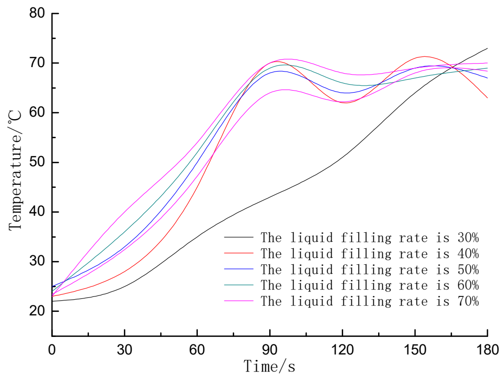


Fig 4. Temperature change of flat plate micro heat pipe array at different liquid filling rates

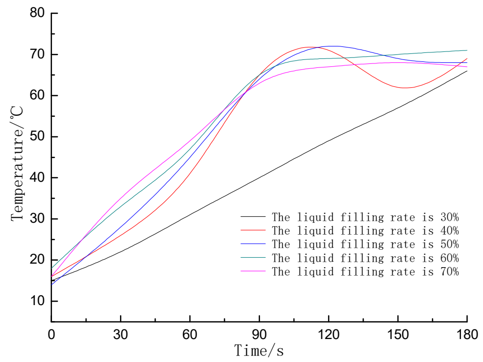


Fig 5. Temperature change of cylindrical micro heat pipe array at different liquid filling rates

3.2. Thermal Resistance Comparison

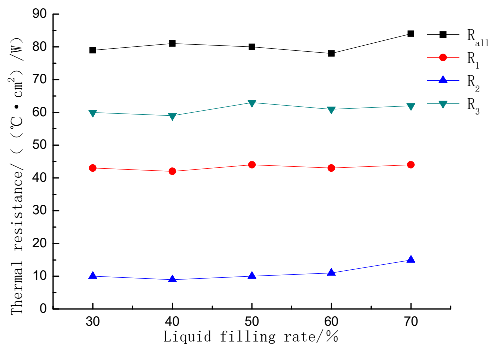


Fig 6. Comparison of thermal resistance under different liquid filling rates

For size 900 mm × 50 mm × 3 mm (Long × wide × Thickness) Under the condition of uniformly filling acetone working medium, the total thermal resistance and each segment thermal resistance of flat plate micro heat pipe array radiator under different liquid filling rates are compared and analyzed, and the effects of different liquid filling rates on the total thermal resistance and each segment thermal resistance of flat plate micro heat pipe array radiator are studied. As shown in Figure 6, when the liquid filling rate is ≤ 60%, the total thermal resistance is basically unchanged, maintained at about 80 ℃ cm^2/W, and is the smallest when the liquid filling rate is 60%. When the liquid filling rate reaches 70%, the total thermal resistance begins to increase rapidly. This is because the thermal resistance between the hot end and the cold end of the micro heat pipe array radiator increases rapidly when the liquid filling rate reaches 70%, resulting in the increase of the total thermal resistance. The thermal resistance between the core components and the hot end of the micro heat pipe array radiator and between the cold end of the micro heat pipe array radiator and the outside air is between 30%~70%, and the value is basically unchanged. This is because the heat transfer between the core components and the hot end of the micro heat pipe array radiator is one-dimensional steady-state heat conduction, and its thermal resistance is related to the thickness and thermal conductivity of the thermal conductive silicone grease, but not to the liquid filling rate; The heat transfer between the cold end of the micro heat pipe array radiator and the outside air is convective heat transfer, and its thermal resistance is related to the convective heat transfer coefficient and has nothing to do with the liquid filling rate. Therefore, it remains basically unchanged under the same experimental environmental conditions. The thermal resistance between the hot end and the cold end of the micro heat pipe array radiator begins to increase significantly when the liquid filling rate is > 60%. This is because with the increase of acetone working medium, the driving temperature difference of the internal environmental flow increases, the growth of acetone bubbles is restrained, and the gas-liquid convective heat transfer is mainly in the micro heat pipe array. Therefore, under the experimental conditions, considering the influence of total thermal resistance and each segment thermal resistance, the liquid filling rate of micro heat pipe array radiator should be ≤ 60%.

4. Conclusion

This paper introduces the structure and operation principle of flat and cylindrical micro heat pipe arrays, analyzes the flat and cylindrical micro heat pipe array radiators filled with acetone working medium through comparative experiments, studies the temperature rise characteristics of different shapes of micro heat pipe array radiators with different liquid filling rates, and separately studies the effects of different liquid filling rates on the total thermal resistance and each segment thermal resistance of flat micro heat pipe array radiators. Through the above contents, the conclusions are as follows:

(a) When the liquid filling rate is 30%, both flat and cylindrical micro heat pipe array radiators are in thermal imbalance state; When the liquid filling rate is 40%, they are in a fluctuating equilibrium state; When the liquid filling rate is 50% ~ 70%, it can reach the thermal equilibrium state, and the flat shape can reach this state after about 90s and the cylindrical shape can reach this state after about 110s.

(b) Under the experimental conditions of the same filling medium and the same filling rate, the thermal response speed of flat plate micro heat pipe array radiator is better than that of cylindrical radiator, and its thermal response time is shortened by about 20s.

(c) Under the experimental conditions, considering the heat balance state, the liquid filling rate of micro heat pipe array radiator should be between 50% ~ 70%; Considering the influence of total thermal resistance and sectional thermal resistance, the liquid filling rate of micro heat pipe array radiator should be ≤ 60%. Therefore, considering comprehensively, the liquid filling rate of micro heat pipe array radiator should be between 50% ~ 60%.

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