Analysis of Experimental Data of Semiconductor Air-conditioning Garment

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Abstract. The semiconductor refrigeration technology was used to design a set of air-conditioning garment. It was movable by using a lithium battery so that people could wear it outside. The air-conditioning garment could afford 100-120W cooling power by using two pieces of semiconductors. The experiments were carried out at ambient temperature of 31°C and 36°C. There were two different heat-dissipating methods to remove the heat from the body at the hot-end of the air-conditioning garment. The feasibility of fan cooling for the hot-end of the semiconductor air-conditioning garment was proposed. There were also two different methods to transfer the cold from the air-conditioning garment to the human torso at the cold end. The cold-end was recommended to use the cold water to absorb the body heat through the capillary according to the experiment data because the cooling loss was so large if using air to absorb the body heat.

1. Introduction
In most parts of China, the temperature in summer was above 25°C, and in the southern cities was above 32°C. This paper mainly studied the cooling measures for the riders who are exposed outside for a long-term in summer. The data of the Meituan Research Institute showed that there were 2.7 million riders working for Meituan in 2018. It was estimated that the number would reach more than 5 million together in 2019. A wearable air-conditioning garment was studied which mainly analyzed how to absorb heat from riders when they are outside in summer. At present, the more mature air-conditioning garments were mainly military products in domestic and foreign markets which were characterized by heavy weight, large volume and high price. [1]For example, Natick Soldier Center, Aspen Systems, Foster-Miller, and PNNL National Laboratory have been conducting research on air-conditioning garments since the early 1990s. The Natick Single Soldier Center, Aspen Systems, and Foster-Miller were mainly developing micro vapor compression refrigeration systems, while the PNNL National Laboratory was mainly developing absorption refrigeration systems. So far, there have been prototypes of micro refrigeration systems applied successfully. The micro vapor compression refrigeration system developed by Foster-Miller has been used by the US military in the Iraq war. [2]Whether the semiconductor air-conditioning garment was feasible or not was analyzed, and how the heat transfer was performed between the cold-end and the hot-end of the semiconductor air-conditioning suit in these experiments.
2. Calculation of Human body heat dissipation

According to the book "Theoretical Analysis of Influencing Factors of Human Body Heat Dissipation" written by Wu Qingcai,[3] the total heat dissipation of human body was 12,540 KJ per day. Excretion and other heat taken away account for about 15.5% of the total heat dissipation of the human body. So the heat need to be transmitted was 10,596.3 KJ per day. They were calculated using the following formulas:

\[
W = \frac{P}{T} = \frac{10596.3 \times 1000}{3600 \times 24} = 122.6w
\]

(1)

According to "Experimental Study on the Influence of Wind Speed on the Heat Dissipation Characteristics of the Human Body" written by Wang Lijuan, the results show that the oncoming wind speed has a great influence on the convection heat dissipation of the human body.[4] Imagine that the ambient temperature was 33 °C. When the wind speed was more than 0.7 m/s during the riding, the 14.6 W convection heat dissipation should be subtracted when calculating the heat dissipation of the human body. As a result, the total heat transfer in the experiment was calculated as 108 w.

3. Methodology and instrumentation

The basic unit of semiconductor refrigeration chip was made by semiconductor thermocouple.[5] Composition material of the electric dipole was a P type semiconductor and a N type semiconductor (electronic). Take them as semiconductor refrigeration material was due to its strong Peltier effect. [6-7] It can exert obviously cooling effect in cold nodes. When the air-conditioning garment was working, the cooling generated by the cold-end was transmitted to the inner surface of the garment through a medium like air or water. As a result, the temperature of the human body surface was lowered. There was also an effective way to dissipate heat from hot-end to the outside of the system to allow the system operated continuously. The position of the instrument can be seen in figure1.[8]

![Figure1. Schematic diagram of the semiconductor air-conditioning garment.](image)

Based on the above calculation results, the detailed operating parameters of two semiconductor cooling chips of the same specification were as follows:

- Model: TEC1-122706
- Cooling power: 50-60 W
- Rated voltage: 12 V
- Working current: 4-4.6 A
- Maximum temperature difference: above 67°C
- Geometric size: 40*40*3.8 mm

4. Experimental data analysis of different hot end cooling methods

The experiment planned to use two cooling methods to cool the hot end. One was to use a fan and the other was to use cooling water. Data was obtained from the both methods.

4.1. Experimental data analysis of air-cooling method

In this experiment, the cast aluminum finned heat radiator was selected as shown in the figure2 below with a geometry of 80*80*35 mm and a mass of 0.25 kg. The selected cooling fan has a rated power of 8.4 W, a maximum speed of 4500 RPM, and a maximum air volume of 65 CFM/Min.
The temperature change of the heat radiators at two different ambient temperatures of 31.4 °C and 36 °C was compared. The results were shown in figure 3.

It can be seen from the figure 3 that during the operation of this section, higher ambient temperatures did not cause excessive load on the heat radiator, and the temperature of the radiator increased at a steady small increase. When the ambient temperature was 30°C, the temperature of the hot-end was 41.8°C after 30 minutes of operation. The difference between hot-end and ambient temperatures was 10.4°C. When the ambient temperature was 36°C, the temperature of the hot-end was 46.8°C after 30 minutes of operation. The difference between hot-end and ambient temperatures was 10.8°C. Obviously it didn’t exceed the limit temperature of the semiconductor. So the device was believed to operate normally in this high temperature environment.

4.2. Experimental data analysis of water-cooling method

In this experiment, a tube-and-belt radiator was used in combination with a fan to dissipate heat from the hot end of the system. The aluminum radiator with the same size of air cooling was used and the rated power of the fan was 4.2W. Considering the circulation of the water system during water cooling, a micro-small pump with a flow rate of 240L/h and a rated power of 3.6W was added to the hot-end system. The geometric volume was approximately 54*40*38mm. The expansion tank was selected to have a geometric volume of about 60*80*60mm, and the geometrical dimension of the aluminum water-cooled radiator was 40*80mm. The cooling water was pumped to the water-cooled radiator to absorb heat from the hot-end of semiconductor. In order to enhance the heat transfer effect, water was then passed through the tube-and-belt Radiator. figure 4 below was a schematic diagram of the physical connection of the hot end circulation system.

(1-Expansion Tank;2-Three-way Valve;3-Tube-and-belt Radiator; 4-Water-cooled Radiator;5-Semiconductor;6-Water Pump)

Figure 4. A schematic diagram of the water system at hot-end.
The experimental data was shown in figure 5 below when the ambient temperature was at 30 °C and 36 °C.

![Figure 5. The temperature of hot-end of semiconductor.](image)

As can be seen from the above figure, different ambient temperatures did not cause excessive load on the heat radiator. The hot-end temperature of the semiconductor tended to rise steadily from the 4th minute, but it was different at the 20th minute. When the ambient temperature was 30°C, the temperature of the radiator was 34.9°C after running for 30 minutes, and the difference between them was 4.9°C. When the ambient temperature was 36°C, the temperature of the radiator was 46.8°C after running for 30 minutes, and the difference between them was 10.8°C. Both situations did not exceed the thermal limit temperature of the semiconductor refrigerating sheet.

4.3. Summary
In this experiment, when the ambient temperature was 30°C, the temperature rise of the air-cooled radiator was 10.4°C, while the temperature rise of the tube-type water-cooled radiator was 4.9°C after operating for 30 min. When the ambient temperature was 36°C, the temperature rise of the air-cooled radiator was 10.8°C, while the temperature rise of the tube-type water-cooled radiator was 7.6°C after operating for 30 min. Compared with the aluminium based finned air-cooled radiator, the heat dissipation effect of the tube-and-belt type water-cooled radiator was more obvious than that of the air-cooled radiator when the ambient temperature was low. There was less influence of air-cooled radiator when the ambient temperature was lower. The next experimental data was based on the second cooling method.

5. Experimental data analysis of different cold transfer methods at cold-end
The experiment planned to use two methods to transfer cooling from the cool end. One was to use air to transfer the cooling and the other was water.

5.1. Cooling transfer through air
An aluminium heat radiator which was fixed on the cold end of the semiconductor was surrounded by a storage box. There was a cold air blower fixed on the outlet of the storage box to blow the cold air into the air-conditioning garment. The blower was selected as a 36W turbo blower and connected to the air-conditioning cloth with a hosepipe. It was expected that the human body would be cooled by rapid air flow. The temperature of the air in the storage box was shown in figure 6 at different ambient temperature.
The temperature drop was basically maintained at about 2 °C at both two different ambient temperatures. So, it was hard to achieve the cooling effect. The reasons were as follows: Firstly, the selected blower had higher wind pressure and larger suction air volume. So, the air which was drifted into the garment could not stably and efficiently to cool the human body. But lower pressure cold air blower couldn’t deliver cold air to the garment. Secondly, the cold amount was consumed during transportation especially in the storage box mostly.

5.2. Cooling transfer through water

Considering the thermal conductivity and ductility of the metal, the pipeline was made of copper tubes with diameters of 2mm and 10mm. According to the size of a man’s body, the appropriate length was chosen. Eight orifices were drilled in the 10mm pipe and the eight ends of four capillary copper tubes were welded at the eight orifices. The pump was chosen with flow rate of 240L/h and rated power of 3.6W. It was as shown in figure 7 below. The longer copper tube was the inlet pipe of chilled water and the two shorter copper tubes were the outlet of the chilled water.

![Figure 7. The schematic diagram of chilled water pipeline.](image)

The experimental data measured at two ambient temperatures of 31°C and 36°C were compared as shown below.
As can be seen from figure 8 and 9, the temperature change curve was similar at the ambient of 30°C and 36°C. The temperature of the chilled water dropped smoothly. The temperature of the outlet of chilled water at 36°C ambient temperature raised in the first 3 minutes. It was because the heat mainly comes from the environmental heat absorption while the cooling from the semiconductor had not timely remove that part of the heat. The temperature of chilled water at the inlet and outlet gradually decreased after 3 minutes. The mean temperature difference between the inlet and outlet chilled water was 5°C at 30°C ambient temperature while it was 4°C at 36°C ambient temperature. The ambient temperature was lower, the heat absorbed from human body was greater.

6. Conclusion and further discussion
Comparing the operation effects of the semiconductor air-conditioning garments at the ambient temperature of 30°C and 36°C, the two heat-dissipating methods of the hot-end of the semiconductor and the two cooling transfer methods of the cold-end were tested respectively. Through the data from the experiments, using air to remove the heat from the hot end was feasible because the operating limit of the semiconductor was still not exceeded after running at 36°C for 30 minutes. However, this experiment needs to be further completed. It can be started from two aspects to explore the operating limit of semiconductor by increasing the ambient temperature and running time. From the aspect of
heat dissipation performance, water-cooled heat dissipation performance was significantly better than air-cooled heat dissipation. But water-cooled heat dissipation was cumbersome and the system design was relatively complicated.

At the same time, the cooling methods were compared. If the air was used to transfer the cooling to human body, the cooling loss would be large and the cooling effect would not be obvious. Therefore, it was more sensible to choose water to transfer the cooling to human body. In this experiment, the capillary cooling tubes were used as the cooling conduit to significantly improve the cooling efficiency. In this experiment, a combination of four capillary tubes and two thick copper tubes were used. In the future, a more optimized arrangement of water-cooled pipelines can be simulated by CFD.

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