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Analysis of Influence Factors of Micro-heat Tube Array Solar Differential Temperature Power Generation Unit

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Abstract

In the paper, the influence factors of conversion efficiency are analyzed. Firstly, the thermoelectric unit is simulated in three dimensions, the temperature field and potential field are analyzed, and the influence factors of thermoelectric efficiency are considered. The output power of the thermoelectric unit is basically consistent with the increasing temperature difference, and the greater the temperature difference is, the greater the output power changes; With the increase of solar irradiance, the temperature at hot end increases rapidly; The cold end temperature increases slowly; Due to the increase of temperature difference, the conversion efficiency increases at a high speed and then gradually slows down; Under different temperature differences, the output power increases to a certain peak value with the load resistance, and then gradually decreases with the load resistance.

Keywords

Micro heat pipe array; Solar temperature difference power generation; D simulation; Influence factor.

1. Introduction

In energy consumption, most of the energy is consumed and wasted directly or indirectly in the form of heat energy. Moreover, due to the strong dispersion and low energy flow density of solar energy, it is easier for the temperature difference power generation system to obtain medium and low temperature heat sources. In the utilization of solar geothermal energy, there are three ways according to the temperature. The utilization of solar energy at 100 ℃ and below is classified as low-temperature utilization[1], the utilization of solar energy at 100~250 ℃ is classified as medium-temperature utilization, and the utilization of solar energy above 250 ℃ is classified as high-temperature utilization. Among them, the solar medium-low temperature photo-thermal utilization is the first known and utilized solar energy mode by human beings. It can be expected that the solar medium-low temperature utilization will be the top priority for the low-cost and large-scale application of solar energy.

In solar geothermal utilization, there is also a kind of thermal power generation technology. Solar temperature difference power generation technology is quite different from solar thermal power generation technology. The thermal power generation technology is a kind of high temperature utilization of solar energy. It uses the gathered high temperature steam to drive the steam turbine, and the steam engine drives the generator to generate electricity; Differential temperature power generation is to take solar energy as medium and low temperature heat source, form high temperature area at the hot end of semiconductor temperature difference power generation sheet, form temperature difference with the cold end of temperature difference power generation sheet, and then use the Saibeck effect of thermoelectric materials for power generation. The temperature difference power generation technology is limited by the characteristics of thermoelectric materials, and the hot end

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temperature is in the middle and low temperature range[2-3], so the solar energy temperature difference power generation technology belongs to the utilization of solar energy at middle and low temperature. This technology not only meets the needs of national policies, but also meets the requirements for the use of renewable energy.

In order to improve the efficiency of temperature difference power generation per unit area, a solar temperature difference power generation system based on micro-heat tube array is proposed in this paper. Essentially, this temperature difference power generation device comprehensively utilizes optical, thermodynamic, temperature difference power generation, control technology and other technologies, and uses non-concentrated solar energy utilization mode, so as to improve the number of power generation pieces per unit area[4].

2. Modeling and Simulation

2.1. Three-dimensional simulation of thermoelectric unit

Due to the limitation of experimental conditions, the analysis of the internal conditions of the temperature difference power generation fin can only be carried out by simulation. ANSYS simulation software is used to simulate and analyze the interior of the temperature difference power generation fin. Internal analysis of temperature field and potential field is carried out by dividing the internal thermoelectric unit into corresponding network, analyzing the internal state more accurately and changing the temperature difference[5]. Finally, the internal structure of the integral temperature difference power generation sheet is constructed, and the logarithmic influence of 1 pair, 2 pairs and 127 pairs of thermoelectric units is analyzed.

Because the thermoelectric material used in the experimental device in this paper is 127 pairs of thermoelectric units, the number is large, and the thermoelectric unit arrangement in the temperature difference power generation sheet is periodic, in the array, the device carries out modeling analysis on one thermoelectric unit, and focuses on analyzing the output power, temperature field change and electromotive force law of a single thermoelectric unit under different temperature differences. The structure of a single thermoelectric unit is shown in Figure 1.

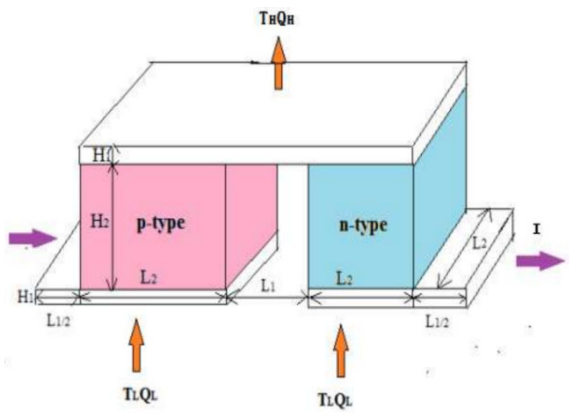

Figure 1. Schematic diagram of thermoelectric unit structure

In the model of a single thermoelectric unit, firstly divide the thermoelectric unit into network, then apply load to the divided thermoelectric unit, and finally divide the network of multiple units. The network division is shown in Figure 2, the corresponding load condition is shown in Figure 3, and the multi-unit network division is shown in Figure 4.

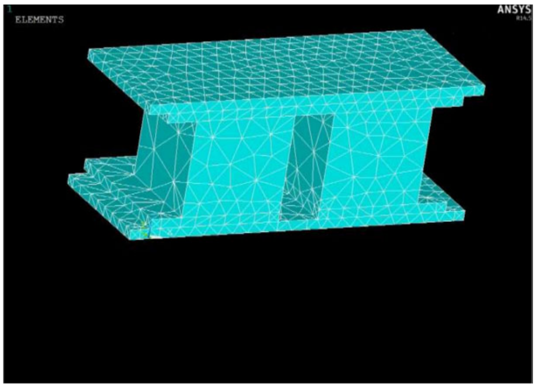

Figure 2. Junction network division of a single thermoelectric unit

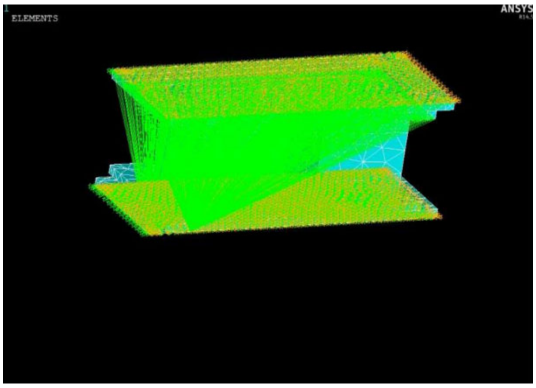

Figure 3. Applying a load

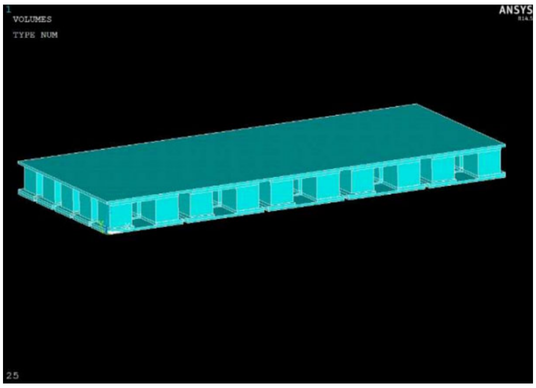

Figure 4. Multi-unit network partitioning

2.2. Distribution of temperature field and potential field

In order to analyze the influence of the pair of thermoelectric units inside the thermal power generation fin, the thermocouple analysis is used. Thermocouple analysis refers to the finite element analysis considering the cross action of two or more physical fields[6]. In order to compare the theoretical and experimental results, a coupled analysis of the thermoelectric unit is carried out by using simulation to analyze the output power under different short temperature of cold and heat.

When the hot end temperature of a single thermoelectric unit is 212℃, the cold end temperature is 34℃, and the external load is 0.22Ω, the temperature field distribution of a single thermoelectric unit is shown in Figure 5, and the corresponding potential field distribution generated is shown in Figure 6. It can be seen from the potential field distribution

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diagram that the output power changes by 0.024W with the change of temperature when the temperature decreases from 212℃ to 34℃ along the temperature gradient.

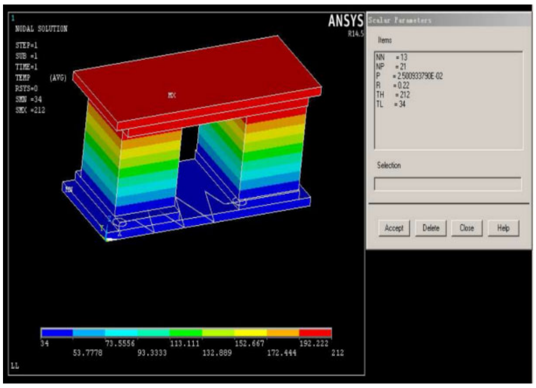

Figure 5. Temperature field distribution map

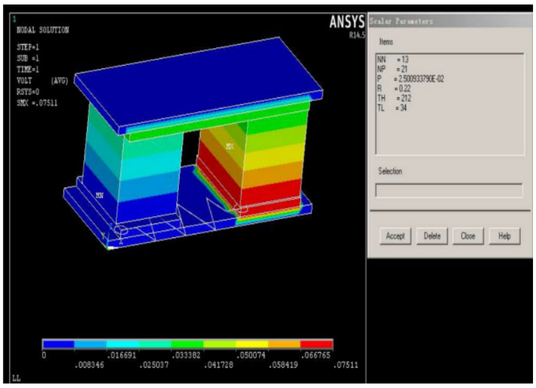

Figure 6. Potential field distribution map

The distribution of potential field and temperature difference vary in gradient. The potential of the lower right part of a single thermoelectric unit is the highest, 0.07511V, gradually decreasing from right to left until it is reduced to 0. The output performance parameters of other five representative groups with different temperature differences are shown in Table 1.

Table 1. Output performance under different temperature differences

Hot end temperature/K	Cold end temperature/K	Temperature difference/K	Output voltage/V	Output power/W
331	292	37	0.011	0.018
385	305	74	0.029	0.021
407	308	97	0.037	0.023
486	307	178	0.075	0.025
425	297	130	0.054	0.024

If the difference between the thermoelectric units is ignored, multiply the data of the individual thermoelectric units by 127 to obtain the simulation data of the temperature difference power generation fin[7]. As shown in Fig. 7, this figure shows the comparison between simulation data and actual test. In order to better see the difference, the simulation data is amplified by 10 times and compared with the series power of 10 temperature difference generators in this module. In the actual test, considering the heat loss and the influence of various external factors, the

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actual data and the theoretical data are quite different, but if the error is ignored, the correctness of simulation and test can still be verified.

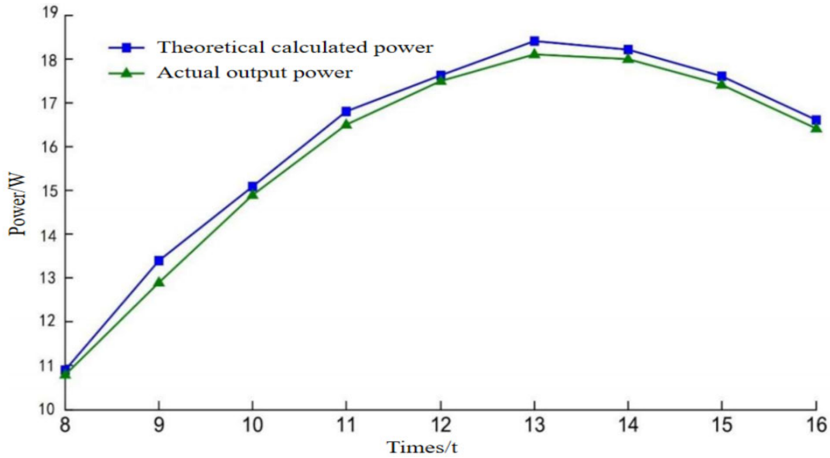

Figure 7. Theoretical and practical comparison

3. Factors Affecting Thermoelectric Conversion

3.1. Pairs of thermoelectric units

Due to limited laboratory instruments, the thermoelectric unit inside the temperature difference power generation sheet is analyzed by three-dimensional simulation. The temperature field inside the temperature difference power generation sheet is changed by software, and the thermoelectric unit of 1 pair, 2 pairs and 127 pairs are analyzed respectively, and then the change curve of output power and thermoelectric conversion efficiency with temperature difference is obtained after the simulation results are adjusted. As shown in Figure 8.

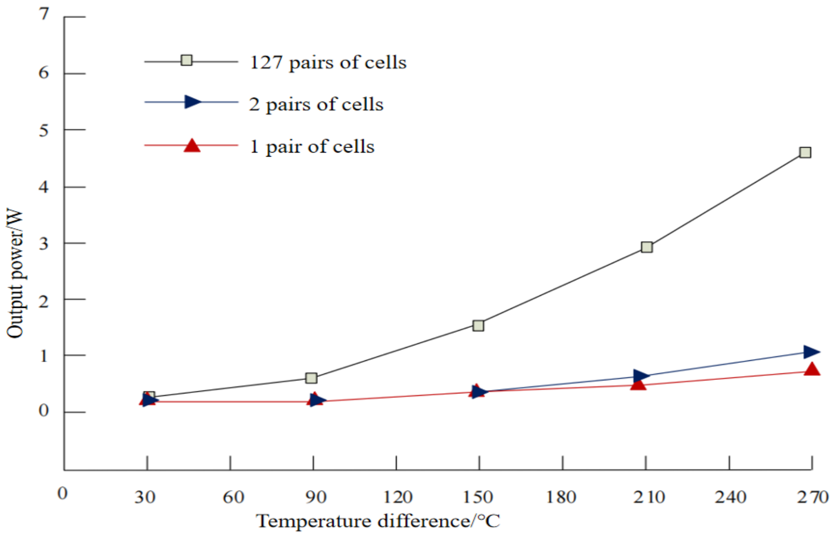

Figure 8. Curve of output power of thermoelectric unit with temperature difference

From Figure 8, it can be seen that the output power of the thermoelectric unit changes with the temperature difference. In general, the output efficiency of the thermoelectric unit of the differential temperature generator increases with the increase of the temperature difference, but a small number of thermoelectric units do not change significantly. It can be assumed that

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when the number of thermoelectric units increases to a certain extent, the change will be more obvious. At the same time, it can be seen from Figure 8 that the output power of pair 1 and 2 of thermoelectric units is basically the same even with the increasing temperature difference, especially when the temperature is below 160℃, there is no difference in the output power; When the temperature difference is over 160℃, there is a slight difference between the output power of pair 1 and 2 of thermoelectric units. From these two curves, it can be seen that the greater the temperature difference, the greater the change in output power. Compared with the curve of 127 pairs and 1 and 2 pairs of thermoelectric units in the figure, it can be clearly seen that the number of thermoelectric units has an impact on the output power under the same temperature difference. When the temperature difference is 30℃, there is basically no difference; When the temperature difference increases to 90℃, the output power of 127 pairs of thermoelectric units increases significantly; At above 90℃, 127 pairs of thermoelectric unit output power surges, and 1 and 2 pairs of thermoelectric unit output power basically has no change. In general, the output power of 1 and 2 pairs of thermoelectric units increases from 0.1W to about 0.5W with the temperature difference; Pairs, increasing from 0.1 W to 4.7 W with the same temperature difference growth.

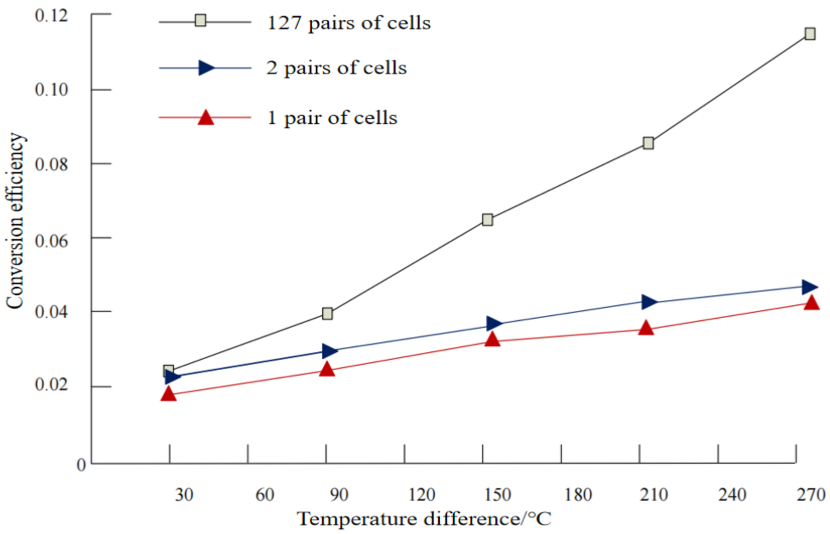

Figure 9. Curve of conversion efficiency of thermoelectric unit with temperature difference

FIG. 9 is a curve showing the conversion efficiency versus the temperature difference for different logarithms, and in general, the conversion efficiency is extremely low when the temperature difference is small. For example, at 30℃, the conversion efficiency of the thermoelectric units of pairs 1, 2 and 127 is basically similar, and there is basically no difference. As the temperature difference gradually increases, the difference becomes more and more obvious, especially 127 pair conversion efficiency increases faster and faster. Comparing the two curves of 2 pairs and 127 pairs of thermoelectric units, the conversion efficiency is 6.53% and 3.11% respectively when the temperature difference is 150℃, and 127 pairs of thermoelectric units are nearly 3 percentage points higher than 2 pairs of thermoelectric units. The number of thermoelectric units has a great impact on the output power and efficiency.

3.2. Temperature difference between cold and hot ends

In order to analyze the influence of the temperature difference between the cold and hot ends of the temperature difference power generation fin on the efficiency of the temperature difference power generation, the electrical parameters of the temperature difference power generation fin are measured. The measured electrical parameters of a single thermal generator blade are shown in Table 2.

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Table 2. Electrical parameters of thermoelectric power generation sheets

Temperature difference/℃	Open circuit voltage/V	Power generation current/mA
20	0.9	225
40	1.8	369
60	2.4	470
80	3.6	560
100	4.8	668

It can be seen from Table 2 that the actual efficiency of the TDP is not as high as the theoretical data even if the error of the test measurement is ignored. It can be seen that the efficiency of a single temperature difference power generation plate is obviously affected by the temperature difference. As a power generation system, the impact is even greater. The hot end temperature of the system is mainly obtained by absorbing solar energy heat. Analyze the influence of solar radiation and obtain the following figure 10.

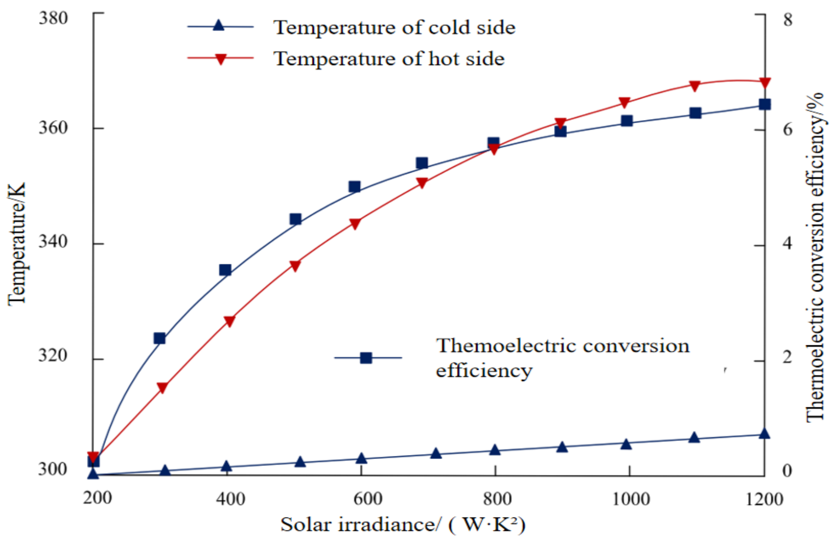

Figure 10. Temperature and thermoelectric conversion efficiency of thermoelectric power generation components as a function of solar irradiance

Figure 10 shows the curve of temperature and thermoelectric conversion efficiency of temperature difference power generation system with solar irradiance. In general, with the increase of solar irradiance, the temperature at hot end increases rapidly; The temperature at the cold end increases slowly; Due to the increase of temperature difference, the conversion efficiency increases at a high speed and then gradually slows down. The heat absorption coating is used at the hot end to absorb heat. The higher the solar irradiance is, the more the heat is absorbed. Meanwhile, the heat convection and radiation are reduced due to the heat insulation effect of the heat absorption coating on the inner part and the heat insulation effect of the insulation frame, the less the heat loss is, and the temperature at the hot end continues to increase. The cold end dissipates heat by means of air cooling or water cooling, and the temperature is basically kept at the ambient temperature. The cold end and ambient temperature rise slowly. The temperature rise at the hot end is fast while that at the cold end is slow, the temperature difference is gradually increased, and the thermoelectric conversion efficiency is gradually changed from 0.87% to 6.57%.

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3.3. Load resistance

It can be seen from the measurement of electrical parameters of the temperature difference generator blade that the open-circuit voltage and generation current of the generator blade are only 3.63V and 558mA even under the temperature difference of 80℃. The output power of the temperature difference generator blade assembly is extremely limited. If the resistance corresponding to the instantaneous power of the temperature difference generator is regarded as a linear resistance, it can be seen from the maximum power transmission theorem that when the output power is the maximum, the load resistance of the external circuit and the internal resistance of the temperature difference generator are equal. When the temperature difference between the cold end and the hot end increases, the output power of the temperature difference generator increases, and the corresponding load resistance also increases. In the temperature difference power generation system, by selecting different load resistances and controlling the temperature difference between the cold and hot ends of the temperature difference power generation blade, the actual measurement results in Fig. 11.

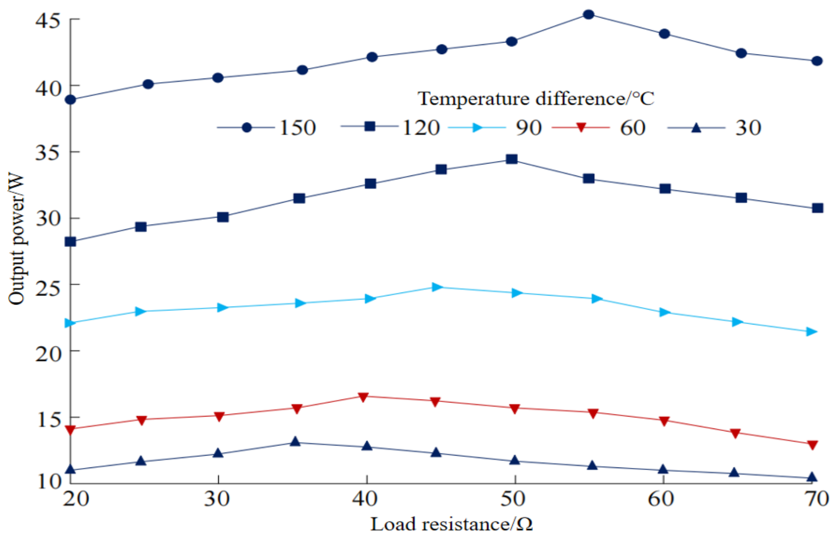

Figure 11. Output power versus load resistance

As shown in Fig. 11, the change curve of output power and load resistance under different temperature differences. Comparing the output power under different temperature differences in the figure, it is found that it always increases to a certain peak value with the load resistance, and then gradually decreases with the load resistance. It is easy to know from the maximum power transmission theorem that the load resistance corresponding to this peak value is equal to the internal resistance. When the temperature difference is 10℃ and 20℃, the output power is relatively gentle, although there is a peak value, the change is not obvious; When the temperature difference is greater than 90℃ (120℃, 150℃), the power changes obviously, and the load resistance corresponding to the peak value is 35Ω and 56Ω; The bigger the temperature difference is, the bigger the output power is. The initial output power is obviously different under the influence of temperature difference.

4. Conclusions

(a) The output power of the thermoelectric unit varies with the temperature difference. In general, the output efficiency of the thermoelectric unit of the temperature difference power generation sheet increases with the increase of the temperature difference, but a small number

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of thermoelectric units do not change significantly. Therefore, different numbers of thermoelectric units have a greater impact on the replacement of output power and efficiency.

(b) With the increase of solar irradiance, the temperature at hot end increases rapidly; The temperature at the cold end increases slowly; Due to the increase of temperature difference, the conversion efficiency increases at a high speed and then gradually slows down. At the same time, the temperature rise at the hot end is fast, the temperature rise at the cold end is slow, the temperature difference gradually increases, and the thermoelectric conversion efficiency will also gradually increase.

(c) The output power increases to a certain peak value with the load resistance, and then gradually decreases with the load resistance. The bigger the temperature difference is, the bigger the output power is.

Supported Project Name

2024 Xizang Natural Fund Project "Research on High Heat Flux Device Waste Heat Power Generation Device Based on Microheat Pipe Array" (XZ202401ZR0036)

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