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EXPERIMENTAL STUDY ON POWER GENERATION PERFORMANCE OF THERMOELECTRIC MODULE IN LOW-TEMPERATURE ENVIRONMENT

Yifan Liang[1],Shixue Wang[1,2*],Zhaojun Liang[1],Yulong Zhao[3]
1 School of Mechanical Engineering, Tianjin University,Tianjin,300350,china.
2 Key Laboratory of Efficient Utilization of Low and Medium Grade Energy(Tianjin University),Ministry of Eduation,
Tianjin ,300350,China.
3 School of Energy and Environmental Engineering, Hebei University of Technology, Tianjin, 300401, China.

ABSTRACT

To study the power generation characteristics of a thermoelectric module under low temperature, a test system was built to measure the thermoelectric performance of semiconductor modules in low temperature environments, and the influence of the loading pressure and the hot and cold end temperatures of the temperature difference power generation module on the module performance is measured. The results show that the power generation performance of the module increases with the increase in the load pressure, but the rate of increase decreases gradually. The performance of the module under low-temperature conditions is much lower than that under normal temperature conditions. When the temperature at the cold end interface is –110 °C and the temperature difference between the hot and cold ends is 51.0 K, the maximum output power is 0.28 W, and the maximum efficiency is 0.38%. Compared with the room temperature power generation under the same temperature difference,the power is approximately 1W lower, and the efficiency decreases by 78%.

Keywords: Thermoelectric module; Cold energy utilization; Low-temperature performance; Load pressure;

1. INTRODUCTION

With the increasingly serious problems of energy and environment, natural gas has been used more and more because of its high efficiency and cleanliness.The state of natural gas transportation is mainly liquid by sea and compressed gas by land pipeline.[1]. At the receiving end of the LNG pipeline, LNG at a temperature of –162 °C must be converted into a gaseous state by pressurized gasification to be delivered to the user. During the gasification process, each ton of LNG can release 830–860 MJ of energy. If this portion of the cooling capacity can be converted into electric energy with 100% efficiency, it will yield 240 kW • h of electric energy [2].Therefore, the cold energy of LNG should be recycled to not only reduce energy wastage, but also produce considerable economic benefits. Cold energy power generation technology is a mature technology, that is divided into power cycle power generation [3] and temperature difference power generation [4]. Compared with other power generation methods, thermoelectric power generation requires no chemical reactions, no moving parts [5]. Therefore, it has the advantages of no noise, no wear, no medium leakage, small volume, light weight, convenient use, and long life[6].

At present, there are relatively few related studies on LNG cold energy temperature difference power generation Jia Lei et al [7] carried out an experimental study on the power generation performance of semiconductor thermoelectric materials at low temperature, and the relationship between performance and temperature was obtained. It was found that the material power generation performance is optimal at a certain cold junction temperature when the temperature at the hot end remains constant. Wei S [8] performed numerical analysis on a pair of PN junctions, and the thermoelectric conversion efficiency reached 9% at a temperature difference of 160 K. Karabetoglu S et al. [9]used liquid nitrogen as a cold source to examine the physical properties of monolithic thermoelectric modules in the temperature range of 100–375 K. Chung D Y [10] developed a thermoelectric material that can be used in low-temperature conditions, with a figure of merit of 0.8 at a temperature of 225 K .

Hitherto, there have been no systematic studies on the effects of assembly pressure on modules in low-

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temperature environments and changes in overall module performance. Low-temperature cold energy recovery is currently commonly used in commercial modules, and its optimal operating temperature range is above 0 °C, whereas its low-temperature performance is not clear. To address this problem, this study builds an experimental system to test the low-temperature performance of thermoelectric modules, and the effects of loading pressure and heat flux at low temperature on the power generation performance of thermoelectric modules were measured. This could provide a reference for future designs of LNG cold energy temperature difference power generation systema.

2. EXPERIMENTAL SYSTEM

The experimental system is shown in Figure 1. It consists of a thermoelectric power generation module, cold-end heat exchanger, heater, dewar, load pressure regulator, heat flow density measurement module, pressure sensor, and thermal insulation material. The thermoelectric module is a TEHP-24156-1.2 module, and the heat flux density measurement module is a stainless steel block with dimensions of 56 mm × 56 mm × 30 mm. The rib of the cold-end heat exchange device is a copper column of 10 mm × 10 mm × 200 mm, which is 5 × 5 in total. The dewar is a THERMOS D-6001 stainless steel jar with a capacity of 6 L. The pressure sensor is an MIK-LCLY spoke type pressure gauge with a range of 0–2.2 MPa. The end insulation material is a PTFE gasket (tetrafluoro gasket) with a diameter of 160 mm and a thickness of 15 mm.

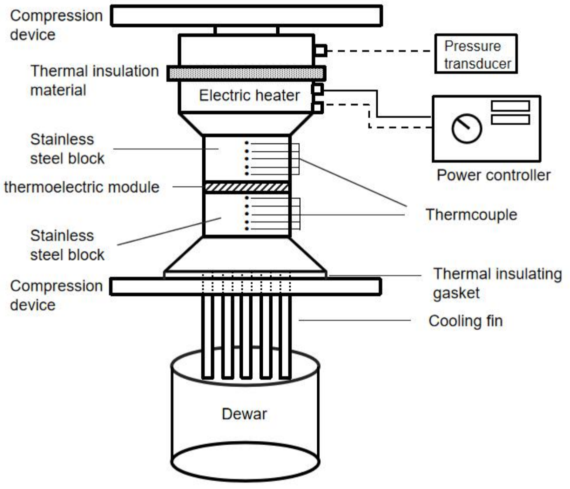


Figure 1 Diagram of experimental system

The heat flux density measuring module is positioned on both sides of the thermoelectric module, and five holes with a diameter of 0.6 mm and a depth of 28 mm are arranged from top to bottom in 5 mm intervals The axial temperature distribution of the module is measured by a K-type thermocouple with a diameter of 0.5 mm. Based on this, the heat flux density can be calculated and the temperature at the contact interface of the hot and cold ends of the thermoelectric module can be derived. The liquid nitrogen is contained in the dewar, and the heat exchange fins are immersed in this liquid nitrogen for heat exchange so that the cold end of the thermoelectric module maintains a low-temperature state. The electric heater can heat the hot end of the thermoelectric module to change its temperature. The pressing device and the gasket cooperate to adjust the loading pressure of the thermoelectric module, and the pressure sensor is used to measure the loading pressure of the thermoelectric module. The upper part of the heater is covered with insulation material to ensure that most of the heat of the electric heater is transmitted to the thermoelectric module.

To reduce the heat dissipation of the entire system to the environment, the experimental device is covered with 8 mm of insulation cotton, and the heat flux density is measured at both ends of the thermoelectric module. The result is shown in Figure 2. The cold end heat flux density q_L is significantly higher than the hot end heat flux density q_H, and the average is approximately 8%. In fact, although insulation measures had been implemented in the experimental device, the temperature difference between the device and the environment is almost 100 K, indicating that the external environment still has heat inflow. The thermal measurement error of the entire system is primarily derived from this, and the maximum error is within 15%.

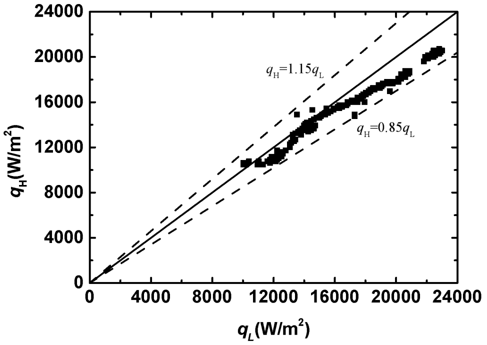
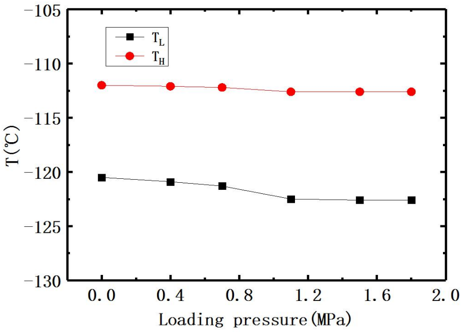


Figure 2 Comparison of heat flow density at the hot and cold ends

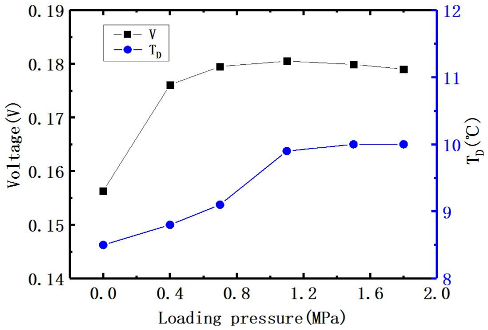
3. RESULTS AND DISCUSSION

3.1 Influence of loading pressure

Loading pressure is an important parameter to be considered in the assembly of thermoelectric modules. If the loading pressure is too small, the interface contact will not be tight, and the interface thermal resistance increases, which affects the power generation performance of the thermoelectric module. If the loading pressure is too large, it is easy to damage the thermoelectric module. To obtain the influence of load pressure on the performance of the thermoelectric module at low temperatures, this study first measured the influence of load pressure on the cold and hot end temperatures and circuit voltage of the thermoelectric module when the heat flow density is 13600 W/m^2; the results are shown in figure 3. The figure indicates that as the loading pressure increases, the temperature of the cold end (T_L) decreases, while the temperature of the hot end (T_H) decreases slightly but remains essentially unchanged, and finally stabilizes at –123 °C and –113 °C, the temperature difference between the cold and hot ends gradually increases with the increase in loading pressure, and this increase gradually slows down. When the pressure reaches 1.1 MPa, the temperature difference between the cold and hot ends is essentially stable at 10 K, and the increase is approximately 2 K. The increase in pressure can make the contact between the thermoelectric module and the heat flux measuring device closer, so as to reduce the contact thermal resistance and the interface heat transfer temperature difference. Therefore, when the heat flux remains unchanged, the temperature difference between the cold and hot ends will gradually increase with the increase in the contact pressure. Figure 3 (b) also shows that, the same as the change of the temperature difference (T_D) between hot and cold ends, the open-circuit voltage of the thermoelectric module increases with the increase in loading pressure. This is because although the module interface reduces the temperature difference between hot and cold ends, owing to the closely fit contact, the contact thermal resistance is reduced, the temperature difference between the cold end and the hot end of the module increases,because the open-circuit voltage is proportional to the temperature difference between the hot and cold ends when the physical properties of the module do not change much, thus, the open circuit voltage also increases with the increase in load pressure and reached a maximum at approximately 1.1 MPa and remained stable.



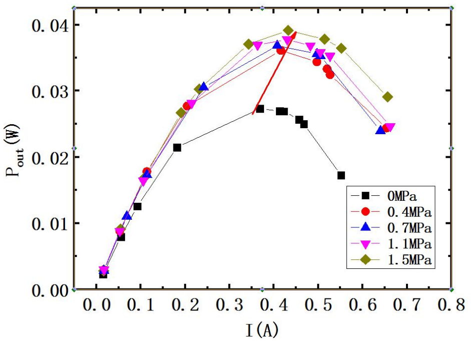
(a) Hot and cold end temperature



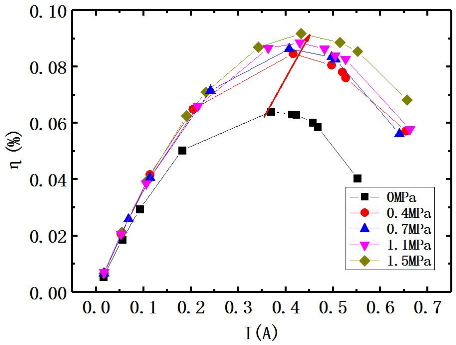
(b) Temperature difference and open circuit voltage

Fig. 3 Changes of cold and hot end temperature, temperature difference and open circuit voltage with loading pressure when q_H is 13600 W/m^2

Figure 4 shows the output power and efficiency as a function of current for different loading pressures. The figure also shows that the loading pressure increases from 0 to 1.5 MPa, the maximum output power increases from 0.027 to 0.039 W, and the maximum efficiency increases from 0.06% to 0.09%. In addition, the output power and efficiency gradually decrease with the increase in loading pressure. When the loading pressure exceeds 1.1 MPa, the influence of the loading pressure on the output power and efficiency is negligible. This is because the increase of load pressure will reduce the contact thermal resistance between the cold and hot ends of the thermoelectric module and the heat flow measurement device, inducing increases in the open circuit voltage of the thermoelectric module and the output power and efficiency. However, the pressure is increased to a certain value, and the contact thermal resistance is already small. Even if the loading pressure is increased, the effect on the contact thermal resistance is very limited, so the performance of the thermoelectric module cannot be improved further. Therefore, we can conclude that the loading pressure of the thermoelectric module at a low temperature should not be lower than 1.1 MPa.



(a) Output power

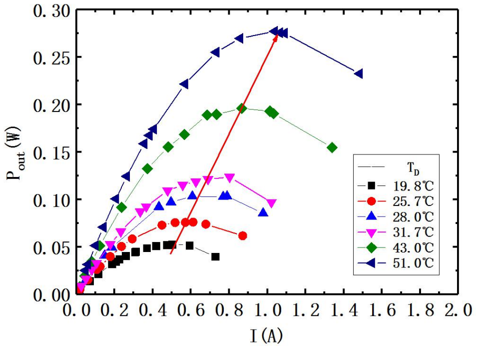


(b) Efficiency value

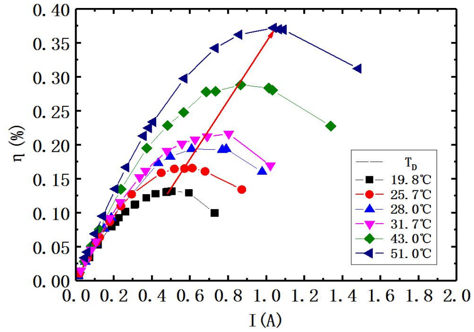
Fig. 4 Changes of Output power and efficiency with current under different loading pressures when q_H is 13600 W/m^2

3.2 Influence of Temperature

As mentioned above, when the loading pressure reaches 1.1 MPa, the power generation performance of the module is essentially stable, and subsequent experiments are conducted at 1.1 MPa. To further examine the low-temperature thermoelectric characteristics of the module, Figure 5 indicates that the temperature difference between the hot and cold ends has a great influence on the output power and efficiency of the thermoelectric module. First, as the temperature difference between the hot and cold ends increases, the output power and efficiency will increase to different degrees, and the larger the temperature difference, the greater the increase. This is because the temperature difference between the hot and cold ends of the thermoelectric module increases, and the open circuit voltage of the module increases. Therefore, both the output power and the efficiency increase. When the temperature difference reaches 51 K, the output power can reach a maximum of 0.28 W, and the efficiency can reach a maximum of 0.38%. Compared with the normal temperature power generation at the same temperature difference, the power is approximately 1 W lower, and the efficiency is reduced by 78%. Second, as the temperature difference between the hot and cold ends increases, the peak value of the curve, that is, the maximum output power and current value corresponding to the highest efficiency, will increase accordingly. This is because the increase in the temperature difference will induce an increase in the open circuit voltage. When the resistance value of the external circuit does not change, the peak value of the output power and the power generation efficiency shift to the right.Finally, at the same cold junction temperature, the smaller the temperature difference between the hot and cold ends, the lower the performance of the thermoelectric module; that is, the low temperature greatly degrades the module performance, because the physical properties of the thermoelectric material at a low temperature are significantly changed.



(a) Output power



(b) Efficiency value

Fig. 5 TL is –110 °C , Changes of the output power and efficiency with current under different temperature differences

4. CONCLUSION

In this study, a performance test device for a low-temperature temperature-difference power generation module is built. The effects of loading pressure and the temperature of the hot and cold ends on the performance of the thermoelectric power generation module are measured in a low-temperature environment. The results show that the following:

(1) Increasing the loading voltage of the thermoelectric module at a low temperature can improve the performance of the thermoelectric module. As the loading pressure increases, the output power and open circuit voltage increase gradually, but the rate of increase decreases. When the loading pressure reaches 1.1 MPa, it continues to increase. The large loading pressure has negligible effect on the thermoelectric module.

(2) The increase in the hot end temperature of the thermoelectric module can significantly improve the performance of the thermoelectric module. When the temperature difference between the hot and cold ends reaches 51.0 K, the maximum output power can reach 0.28 W, and the maximum conversion efficiency can reach 0.38%.

ACKNOWLEDGEMENTS

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