High-Efficiency and Energy-Saving Thermostat Combining Peltier Effect and Air Vortex Characteristics

Fei Song*, Chenglong Yang and Lin Zhou
School of Mechanical and Electrical Engineering, Wuhan University of Technology, Wuhan 430070, China

*Corresponding author: S_F_1@whut.edu.cn

Abstract. This project uses the Peltier effect to optimize the temperature control system of the thermostat, uses semiconductors to generate temperature differences, and then forms a heat pump, uses the conversion between high and low taste energy to replace the compressor for refrigeration and temperature adjustment, and at the same time uses the gas vortex characteristics to exchange gas and Adapt and improve the heat dissipation and other aspects. The incubator designed in this project is more excellent in terms of energy saving, low noise and service life, and improves the utilization of energy and resources. At the same time, the temperature control of the incubator has the advantages of stability and accuracy, which can effectively solve the problem of food and medical the deterioration and loss of supplies.

Keywords: Transportation thermostat, Peltier effect, eddy current characteristics, heat pump, temperature control.

1. Introduction
In modern society, in order to obtain accurate experimental data and maintain a constant temperature environment, the market has very strict requirements for the stability of the internal temperature of the incubator and temperature control.

In today's market, there are many kinds of thermostats, most of which use compressor refrigeration or resistance energization for temperature control. Take the most important compressor thermostat as an example. The problem of insufficient temperature control accuracy and uneven internal temperature [1].

Take the FYL-YS-50L laboratory 18-23℃ constant temperature box as an example. The relevant parameters are shown in the table below. The temperature deviation is ±5 ℃ and the accuracy is 1℃. Today many laboratories required accuracy required 0.5 C for even smaller, such temperature control box gradually unable to fully meet the requirements.
### Table 1 Some parameters of FYL-YS-50L thermostat

| size          | temperature range | Operating Voltage | Cooling / heating power |
|---------------|-------------------|-------------------|--------------------------|
| 430*480*510mm | 4~48 °C           | 220V              | 85/120W                  |

Based on this background, this project designed a thermostat based on the Peltier effect and eddy current characteristics. The thermostat has many advantages such as accurate and rapid temperature adjustment, energy saving, and low noise.

2. **Project mechanical model design**

The device is mainly composed of four parts: heat exchange module outside the box, thermoelectric reactor, heat exchange module inside the box and temperature difference control module.

![Figure 1](image1.png)

**Figure 1** box appearance and temperature regulating device structure (enlarged)

2.1. **Tank external heat exchanger module**

The device utilizes the combined action of heat pipe radiator and fan to forcibly dissipate heat, and utilizes the Kangda effect and the turbulent airflow characteristics to perform heat dissipation treatment on the hot end. The heat pipe is connected to the heat conducting plate of the thermoelectric stack, and the heat is transferred through the heat pipe. At the hot end of the heat pipe, an array of heat sinks is installed to increase its heat dissipation area. The middle part of the heat sink is hollowed out to provide a path for the airflow of the cooling fan and reduce the use of materials.

The middle fan blows air, provides high-speed gas, and forms a low-pressure zone between each layer. As a result, the air near the radiator enters between the radiating fin layers under the action of atmospheric pressure, pushing the gas between the layers to escape, accelerating the air flow between the layers, improving the distance between the fins, resulting in greater air viscosity and small air flow, is not conducive to heat dissipation.

![Figure 2](image2.png)

**Figure 2** The structure of the heat dissipation module outside the box

At the same time, according to the design of each heat sink, drawing on the golf ball surface pit design, the heat sink surface is designed with pits (not shown in the model), so that when the airflow
passes through, due to the existence of airflow viscosity at the pits, A clockwise vortex will be formed in the pit. The vortex will stay in the pit for a long time and make the laminar flow between the fins turbulent, so that the part of the airflow layer that is far away from the boundary layer can conduct heat closer to the surface of the heat sink. Exchange is conducive to the airflow to carry the heat dissipation. At the same time, the pits make the contact area of the heat sink larger and heat dissipation more quickly.

Since the diameter of the heat pipe has a great influence on its heat conduction efficiency, when the diameter of the heat pipe is too large, its thermal resistance will increase sharply. This device uses a heat pipe group, which is bundled by multiple heat pipes in parallel to form a heat pipe bundle. The transfer of heat. The diameter of a single heat pipe used in this device is 6 mm, and this heat pipe has a better heat conduction effect.

**Figure. 3 Heat pipe bundle model diagrams**

2.2. *Inside heat exchanger module*

Since the inside of the box belongs to the active area, the heat exchange inside the box can be carried out directly through the heat sink and natural heat exchange.

**Figure. 4 Heat exchange modules in the box**

Considering the heat exchange of the unilateral fins, the small gas flow in the box, the slow adjustment of the temperature inside the thermostat and the unbalanced temperature distribution in the box, this project draws on the aileron design of the wing lift module to carry out circulating heat exchange. In the box, air is supplied close to the top and bottom, and a vortex generator is formed by setting baffles of a certain shape and inclination on the upper and lower tops, so that a return vortex is generated in the box, and the airflow forms a vortex close to the baffle. As a result, effective guidance of airflow can be achieved. At the same time, the air vortex can quickly exchange heat in a wide range in the thermostat, making the temperature inside the thermostat closer.
Figure 5 Schematic diagram of circulating heat transfer in the box

2.3. Thermoelectric module stack effect
Since the semiconductor single-stage refrigeration efficiency is generally about 20 W, and the temperature difference is less than 50 °C, the device uses the semiconductor group multi-stage refrigeration to increase its power. Through multi-stage refrigeration, the temperature difference that can be reached is larger and the power is higher, but due to the current control of each semiconductor group, the efficiency is controlled at about 20W, so as to ensure the best cooling efficiency, that is, the best temperature regulation efficiency.

Figure 6 Single semiconductor working element

Figure 7 Thermoelectric reactors

Thermally conductive plates are used on both sides of the thermoelectric stack to allow heat to be dissipated, and its heat transfer coefficient is 25-200 times that of air cooling, and there is also a fan for air cooling Heat dissipation can realize rapid heat conduction and reduce the influence of heat accumulation on the operation of the semiconductor stack.

Figure 8 Thermopile and heat dissipation space layout outside the box
2.4. Temperature control feedback module
This module uses sensors to measure the temperature of the outer end of the semiconductor box and the outdoor temperature in real time through closed-loop feedback. When the temperature difference between the two is too large, the fan speed is controlled to speed up the heat dissipation. When the temperature at the outer end of the box fluctuates, the internal temperature is stabilized by the insufficient fluctuation of the temperature difference variable.

3. Project mathematical model establishment and analysis

3.1. Establishment of device model
This device uses a $Bi_2Te_3$ semiconductor material design [2].

3.2. Performance parameter setting
N-type semiconductor resistivity [3][4]

$$\rho_n = 1.98 \times 10^{-10} \times T^2 - 6.02 \times 10^{-9} \times T + 5.76 \times 10^{-7} \ (\Omega \cdot m)$$

(1)

P-type semiconductor resistivity

$$\rho_p = 8.69 \times 10^{-10} \times T^2 - 2.51 \times 10^{-7} \times T + 2.82 \times 10^{-5} \ (\Omega \cdot m)$$

(2)

N-type semiconductor thermal conductivity

$$\lambda_n = 2.36 \times 10^{-5} \times T^2 - 0.015 \times T + 3.806 \ (W/m/k)$$

(3)

P-type semiconductor thermal conductivity

$$\lambda_p = 3.21 \times 10^{-5} \times T^2 - 0.022 \times T + 4.949 \ (W/m/k)$$

(4)

Total resistance of thermocouple

$$R = \sum S \rho$$

(5)

Total thermal conductivity of thermocouple

$$k = \sum S \lambda$$

(6)

Peltier coefficient of this semiconductor junction

$$\pi = \alpha \cdot T$$

(7)

In the above formula, $S$ is the cross-sectional area of the semiconductor arm, $L$ is the length of the semiconductor, $a$ is a material Seebeck coefficient (whichever here. 300 K at a temperature of Seebeck coefficient, its value $200 \mu V / k$) [4], $T$ is the absolute temperature. The physical parameters of the material in the above formula are the fitting equations of its parameters obtained by consulting the literature [5].
3.3. Basic assumptions of the model

(1) This device is applied to a small oven, the temperature control range of not more than 100 K, has little effect on the thermal conductivity and the thermal resistivity of the material, the temperature range is also small, negligible, whichever absolute the temperature is 300K;
(2) The ambient temperature outside the box remains constant;
(3) When working, only the resistance, thermal resistance of the semiconductor part, the thermal resistance of the heat conduction part is considered, and the bracket, welding part, etc. are not considered;
(4) It is assumed that the semiconductor reactor is in a steady state working state and the Thomson effect is not considered;
(5) The work of each semiconductor junction does not affect each other, and the work of the heat pipe bundle does not affect each other.

3.4. Model Solution

A single semiconductor junction can be analyzed by hypothesis. Its various parameters can be obtained by formula (1) ~ (7)

The total resistance is
\[ R \approx 1.49 \times 10^{-4} \Omega \]
Total thermal conductivity
\[ k \approx 0.06 \, W/k \]
The Peltier coefficient of the material is
\[ \alpha \approx 0.06 \]

(1) Semiconductor thermoregulation performance parameters

The cooling capacity for a single semiconductor group is
\[ Q_c = nI - \frac{1}{2} I^2 R - k \times \Delta T \quad (8) \]

Voltage drops across thermocouple
\[ V_S = \alpha \times \Delta T \quad (9) \]

The voltage difference across the semiconductor
\[ V = V_S + I \times R \quad (10) \]

Then from the formula (9) (10), we can get:

Input power of a single semiconductor
\[ P = V \times I \quad (11) \]

Then the cooling efficiency of the device can be obtained
\[ \eta_c = \frac{Q_c}{P} = \frac{n - \frac{1}{2} I^2 R - K \times \Delta T}{\alpha \times \Delta T + I \times R} \quad (12) \]

It can be seen that the current I and the temperature difference \( \Delta T \) affect each other and jointly affect the cooling efficiency; In addition, from the principle of conservation of system energy, the heat dissipation of the hot end is
\[ Q_h = Q_c + P \]  

Available, the heating performance coefficient of the device

\[ \text{cop} = \frac{Q_h}{P} = \eta_c + 1 > 1 \]  

It is proved that the device can constitute an energy-saving heat pump, which can achieve the effect of heat transportation, can use less electric energy to achieve a large amount of heating, and has a better energy-saving effect when cooling in winter.

(2) Calculation of maximum power and maximum efficiency

For formula (8), a binary analysis is carried out, since the temperature difference is always non-negative, that is

\[ \Delta T > 0 \]

Then we can get formula (8)

\[ \pi I - \frac{1}{2} I^2 R > k \times \Delta T > 0 \]  

(15)

The value is available, the maximum power of the device

\[ Q_{\text{max}} = 12.2W \]

It can meet the power needs of the thermostat.

Vertical joint (9) (10) (11), by the formula (15) corresponding to the current calculated maximum power the I, substituting the simultaneous equations is calculated to give:

\[ P = 10.13W \]

Substituted into the formula (12), the refrigeration efficiency is

\[ \eta_c = 1.2 \]

For maximum efficiency, from (. 1 2) and (. 1. 4 can be obtained, the cooling efficiency and heating efficiency of the monotonicity of the same). Analyze the refrigeration efficiency and find the derivative in the formula (1 2) (assuming that the current has nothing to do with the temperature difference), namely:

\[
\frac{d \eta}{d(\Delta T)} = \frac{d \left( \frac{\pi - \frac{1}{2} I R \times K \times \Delta T}{\alpha \times \Delta T + I \times \Delta T} \right)}{d(\Delta T)}
\]

Make, \[ \frac{d \eta}{d(\Delta T)} = 0 \]

For simplicity, the order \[ b = I \times R \times c = \pi - \frac{1}{2} I R \times d = K / I \]; calculated:

\[ c - d=0 \]

It shows that current has an effect on efficiency. At this time, given the general temperature difference required by the work \[ \Delta T = 30K \], back to c and d, the parallel vertical type (8) can be obtained:

\[ Q_c = -20 < 0, \text{invalid} \]

Therefore, when the best efficiency is reached, the working needs of the device cannot be met, and the device cannot work at the best efficiency.

In the above FYL-YS-50L Comparison incubator model, available to achieve the same heating effect, this means the actual input electric power is required 100W, which is more energy efficient.
3.5. Heat transfer simulation

This project uses finned natural convection heat transfer and heat pipe forced convection heat transfer. In order to verify the stability and accuracy of heat transfer, this project uses a NSYS steady-state thermal convection analysis module to simulate the heat transfer effect. Perform statistical analysis on the average heat transfer temperature, the maximum temperature difference and the heat convection vector cloud diagram at different temperatures.

3.5.1. Fin natural convection simulation. Pair of fins simplified model, the model size. 400 *400 mm, a thickness of the fin. 1 0 mm, provided the material is made of aluminum fins, specific pretreatment parameters as follows:

| Table. 2 Pre-processing parameter settings for fin simulation |
|---------------------------------------------------------------|
| Heat transfer method | Material thermal conductivity | Air heat convection coefficient | Ambient temperature setting |
| Natural heat convection | 170W/ m *k | 4.0W/ m² *k | 295k |

The model is meshed. Because the model is relatively simple, a hexagonal mesh is used for division, which improves the efficiency and speed of result analysis.

Set the boundary conditions, set the heat source power to 100W, and simulate the temperature and thermal convection of the fins. The results are shown in Figure (9) (10).

![Temperature simulation results at various locations of the fin](image1)

![Thermal convection vector cloud diagrams](image2)
By analyzing the maximum and minimum temperatures everywhere, the following data is obtained:

**Table. 3** Analysis of fin temperature simulation results

| Maximum temperature (℃) | The lowest temperature (℃) | Average temperature (℃) |
|--------------------------|-----------------------------|--------------------------|
| 22.75                    | 21.983                      | 22.351                   |

It can be obtained that the temperature difference in the box can be controlled within 1 ℃, and the heat convection cloud diagram shows that the heat transfer is stable under the condition of natural convection, which has a positive effect on temperature stability.

3.5.2. *Heat pipe cooling simulation.* The simulation results of temperature and thermal convection in various places are as follows:

Analyzing the simulation results, the statistical temperature conditions are as follows:

**Table. 4** Simulation data analysis of heat pipe temperature

| Maximum temperature (℃) | The lowest temperature (℃) | Average temperature (℃) |
|--------------------------|-----------------------------|--------------------------|
| 24.48                    | 23.655                      | 24.02                    |

The temperature difference is also controlled within 1 ℃. The analysis of the heat convection vector cloud diagram shows that the concentrated heat flow is at the boundary, and the forced heat dissipation by the fan can promote the heat dissipation speed of the boundary and take away the heat.
4. Conclusion
This project uses the Peltier effect to create a temperature difference to form a heat pump, realizes the transfer and exchange of high and low taste energy, and improves the heat transfer ratio. At the same time, the temperature difference is used to control the temperature inside the incubator, and the Peltier semiconductor temperature difference is controlled by voltage.

In the thesis, some preliminary conclusions were obtained by using model design, theoretical calculation, and experimental simulation. In the subsequent project, we will combine the experimental results to further analyze the project. However, it can be concluded from the existing research that the device has certain feasibility. The current market for cold chain transportation needs and have a good ability to meet prospects.

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