Self-heating incubator based on Fresnel lens and phase change energy storage

Jinyu Guo1,a, Yan Zhang2,a, Xu Chen3,a
1Wuhan University of Technology, Wuhan, Hubei, China
2 Wuhan University of Technology, Wuhan, Hubei, China
3 Wuhan University of Technology, Wuhan, Hubei, China
aemail: 287846@whut.edu.cn

Abstract: In recent years, with the continuous development of the Internet and catering industry, China's takeout industry chain has gradually improved, and takeout has become an important force in the domestic catering consumption market. But at present, there are some problems in the market, such as high energy consumption and unsatisfactory insulation effect. This work is mainly divided into four parts: Fresnel lens focusing module, light tracking module, phase change energy storage module and delivery box module. Fresnel lens concentrator module focuses sunlight and converts heat energy. The tracking module tracks the position of the sun and strengthens the capture of solar energy by Fresnel lens. Phase change energy storage module stores heat energy and releases heat energy when needed. The delivery box module determines the overall framework. Compared with similar products, this work has the advantages of less energy consumption, better heat preservation effect and lower delivery cost.

1.Introduction

1.1 Project’s research objectives
In this paper, a kind of energy-saving take-out thermal insulation distribution box based on traceable Fresnel lens and phase change energy storage module is studied. By using Fresnel lens to collect the solar heat energy, the heat preservation function of the delivery box and the heating of the cooled food can be realized. To a certain extent, it can reduce the demand of thermal insulation materials for take-out food, and effectively alleviate the problem of excessive packaging for take-out food. This paper mainly studies Fresnel lens focusing module, tracing module, phase change energy storage module and delivery box module. Through the joint action of four modules, the working process of collecting solar energy to heat the delivery box and store heat energy is realized. The overall schematic diagram of energy-saving and environment-friendly insulation box is shown in Figure 1.
2. Design scheme

2.1 Design ideas
The current market foreign sell tank insulation effect the demand is higher, in view of the current traditional take-out box does not have constant temperature function or need built-in disposable heat source or external power supply, energy, increase the cost of a single distribution problem, this project from the perspective of heat preservation and energy saving simultaneous, through a large number of data query, this paper proposes a using the spotlight Fresnel lens and a combination of phase change energy storage module. The plan is to use Fresnel lens to concentrate the sunlight into heat energy, and transfer the heat to the whole takeaway box through the metal heat conduction network built in the takeaway box, and supply the excess heat to the phase-change energy storage device at the bottom of the takeaway box for storage. Solar energy is used to heat and keep the boxes for sale, reducing the consumption of primary energy.

After the tracking module starts to work, the exact position of the sun is determined, and the attitude adjustment of the lens is completed by the steering gear, so as to realize the light alignment of the Fresnel lens. The Fresnel lens focuses the sunlight on the metal conductive plate and heats it up. The
metal heat conduction plate conducts the heat to the whole takeaway box through the heat conduction metal mesh, which plays the role of heating up. The phase-change energy storage device will store the excess heat energy when the temperature in the distribution box is greater than 60°C, and make the stored heat energy be able to release the heat energy when the temperature in the distribution box is lower than 60°C. The temperature sensor plays a role of temperature monitoring throughout the whole process. When the temperature inside the takeaway box is higher than 60 degrees, it will automatically transmit signals to the STM32 processor and adjust the Fresnel lens attitude by driving the motor to exit the focusing state.

2.2 Fresnel lens concentrating module

2.2.1 Fresnel lens mechanism

Compared with other lenses, the structure of Fresnel lens is simpler and more refractive. After being refracted and focused by Fresnel lens, the sunlight is concentrated on the metal heat conducting plate, which transfers heat to the connected heat conducting metal mesh and plays the role of heating up.

2.2.2 XY focusing positioning mechanism

XY focusing positioning mechanism is composed of inner ring, outer ring and steering gear. Fresnel lens is fixed in the center of inner ring, and outer ring, inner ring and Fresnel lens are kept horizontal. The first steering gear drives the outer ring to rotate to realize the rotation of the outer ring and inner ring in the Z-axis and Y-axis directions. The No.2 steering gear drives the inner ring to rotate to realize the rotation of the inner ring on the Z-axis and x-axis. Under the guidance of the light tracking module, the No.1 and No.2 steering gears operate orderly to realize the non-dead angle focusing of Fresnel lens in space. The position of XY focusing positioning mechanism is shown in Fig. 3.

![Fig. 3 position diagram of XY focusing positioning mechanism](image)

2.3 Light tracking module of gray camera

The tracking module can enhance the capture of solar energy by Fresnel lens and greatly improve the concentrating efficiency of Fresnel lens. The light tracing module of this project is mainly composed of Micron MT9V034 grayscale camera, photoelectric sensor, STM32 processor and stepping motor.

Micron MT9V034 grayscale camera takes pictures of the sky, and STM32 processor recognizes the grayscale images collected. The brightest point in the gray image is taken as the sun to obtain the exact position of the sun. Based on Fresnel lens as the origin of coordinates, the space coordinate system is established to accurately express the position of the sun, and then the included Angle between the sun and the lens is calculated. The STM32 processor adopts the high-performance STM32F103ZET6 single chip microcomputer. The processor accepts the data collected by the information acquisition system and calculates it. By checking the size of the preset Angle, it sends out THE PWM wave that controls the rotation of the servo motor, realizes the control of the steering machine turning up and down and the steering machine turning left and right, and completes the attitude adjustment of the lens. The whole
device USES 12V small volume and large capacity lithium battery with low energy loss. The workflow of the light tracking module of the gray camera is shown in Figure 4.

In order to improve the image contrast quality, the acquired gray images were processed with histogram equalization, and the results were shown in Figure 5b. The optimal threshold of the image was obtained through the Otsu algorithm, and then the image was segmented. The results were shown in Figure 5c.

2.4 Phase change energy storage module

Drawing on the design concept of plate heat exchanger, the project team designed a new type of high-performance flat-panel phase change energy storage unit with a specification of 500×400×5mm by comprehensively utilizing heat conduction enhancement technology, finalization and packaging technology of phase change energy storage materials. The function is to store the excess heat energy in the distribution box when the temperature is greater than 58°C, and make the stored heat energy be able to release the heat energy when the temperature in the distribution box is lower than 58°C. The energy storage unit is composed of high-performance phase change energy storage materials with high energy storage density and high thermal conductivity and its packaging materials. According to the principle that the best taste temperature of hot cooked food should reach 55°C, the project team selected paraffin C22~C45 as high-performance phase change energy storage materials. The sealing material is 0.3mm thick aluminum film, which has the advantages of light quality, easy to process, cheap and easy to get. The structure of phase change energy storage module is shown in Figure 6.
2.5 Delivery box delivery module

The delivery box is based on the existing large delivery box with the size of 570mm × 470mm × 470mm, and the original plastic framework design is cancelled. The heat conduction metal mesh made of 304 stainless steel is used as the support framework, which can transfer heat, heat evenly and support the framework.

A layer of reflective aluminum foil paper is laid inside the thermal conductive metal mesh to prevent food from directly touching the high-temperature metal mesh to cause damage, and further plays the role of heat preservation. The takeaway distribution box can be opened from the side, the metal mesh is removed at the opening side, and the aluminum foil + insulation foam + aluminum foil + Oxford cloth is designed. At the same time, it can be opened easily. The bottom of the takeaway box is aluminum foil + phase change energy storage module + insulation foam + aluminum foil + Oxford cloth, which plays the role of thermal energy storage while holding heat.

3. Feasibility analysis

Considering the simplicity, convenience and rapidness of the condenser system in installation, the following parameters are set: lens size 250mm × 250mm, F number (the ratio of lens focal length to aperture) 1.2, lens material PMMA refractive index 1.49, lens ring spacing 1mm, receiving surface area 10mm × 10mm. According to data consulting, the formula of concentrating light from any point of light source on the optical axis to a specific focal plane can be calculated as follows:

\[ \theta_f = \arctan \left( \frac{\sin u_i}{N \cos u_i} \right), \]

Where \( \theta \) is the height Angle of the pixel edge

Based on this formula, the basic parameters of each ring of Fresnel lens are calculated, and the solid model of Fresnel lens is established by SolidWorks software. After the solid modeling is completed, the TracePro optical software is imported to define the material properties, select the incident light source, ray tracing, and analyze the energy distribution and performance of the receiving surface at different receiving distances from the Fresnel lens.

According to the simulation results, the maximum irradiation energy of focal plane is \( 2.7545 \times 10^7 \text{W/m}^2 \), and the average irradiation energy is \( 1.1757 \times 10^5 \text{W/m}^2 \). The energy accumulation meets the expected requirements.

4. Conclusion

In this paper, a new energy-saving take-out thermal insulation distribution box based on traceable Fresnel lens and phase change energy storage module is designed. Fresnel lens is used to collect solar thermal energy, so as to realize the thermal insulation function of distribution box for external sale and heat the food after cooling. MT9V034 grayscale camera is used for directional tracking of sunlight and phase change energy storage is used for heat energy storage and release. The solar focusing effect meets the expected requirements. This device can reduce the demand of thermal insulation materials for
take-out food to a certain extent, and effectively alleviate the problem of excessive packaging for take-out food.

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