Air-Cycle Energy-Saving IH Rice Cooker Based on Phase Change Heat Storage

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Abstract. This device combines phase change heat storage with air circulation, and proposes a new three-dimensional honeycomb grid structure on the phase change material carrier structure. The reasonable use of steam residual heat and the use of a segmented electromagnetic coil structure reduce the heat loss and power consumption of IH rice cooker. Utilizing the hot steam generated in the heating stage of the rice cooker, the low-temperature waste heat is recycled in the low-temperature phase-change thermal storage module designed by the device. At the same time, the electromagnetic coil is segmented. Besides, the fuzzy control is used to determine the actual amount of rice to be cooked to determine the number of coil segments used in the heating stage to reduce power consumption.

1. Introduction
According to Zhongyikang, IH heating rice cookers have maintained a high growth trend. In the first half of 2015, the retail volume and retail sales reached 72.9% and 57.6% year-on-year respectively. IH rice cookers have been favored by more and more people because of the advantages of fast heating, uniform heating, easy temperature control, and the good taste of rice. More and more IH rice cookers have entered people's daily life.

The working process of the rice cooker mainly includes two stages of heating and heat preservation. IH rice cooker is a type of rice cooker that uses electromagnetic heating. It is superior to ordinary rice cookers in many aspects such as thermal efficiency. However, there are still problems in terms of heat loss and efficiency: 1) During the heating stage of the rice cooker, water absorbs heat and evaporates, producing a large amount of steam, which is directly discharged to the outside through the steam valve. This wastes a lot of heat energy. 2) IH rice cooker adopts three-dimensional heating method and timed heating method. Although the timed heating method can ensure the speed and quality of rice, the amount of rice cooked at a time is not fixed in actual use. And, if the rice is less cooked, the rice cooker will overheat. So the energy cannot be effectively used, which wastes electricity resources to a certain extent. Studying how to use the heat in the steam in the heating stage and how to improve the three-dimensional heating method to increase the working efficiency of the electromagnetic coil during heating has great prospects and application values in terms of energy saving and emission reduction.

This work uses phase change heat storage to collect the waste heat of steam generated during the heating process of the rice cooker and uses it to keep the power rice cooker warm. This reduces the power loss of the IH rice cooker. In addition, this work improves the three-dimensional heating
method. The fuzzy cooking control is used to determine the actual amount of rice cooked, and different electromagnetic coil heating is started to improve the working efficiency of the electromagnetic coil.

2. Design scheme
The device is composed of a low-temperature phase change heat storage module, an air circulation module, a three-dimensional heating module and a control module. The specific structure diagram is shown in the figure.

2.1. Low temperature phase change thermal storage module
The low-temperature phase-change thermal storage module is located at the bottom of the rice cooker, and is connected to the air circulation track through an air pipe. When the steam passes through the low-temperature phase-change thermal accumulator, the phase-change material attached to the carrier contacts the steam, absorbing the heat on the steam, and stores the heat on the carrier in the heating mode of the rice cooker. This phase change material can ensure that the phase change has occurred at the end of the heating phase when the temperature has reached above 65 degrees Celsius. When the airflow is reversed through the low-temperature phase change regenerator, the phase change material attached to the carrier is in contact with the airflow in the thermal insulation mode of the rice cooker. Once the temperature of the airflow is slightly lower than the temperature of the phase change material, energy will be released in the airflow. In this time a phase change will occur, and the temperature of the airflow will rise, which is used to heat rice in the rice cooker.

Figure 1. Overall view of the device.

Figure 2. Low temperature phase change heat storage module.

The inner wall is designed in an arc shape, which is conducive to the full contact of the air flow with the carrier structure in the container. The phase change reservoir is provided with three air ports, a, b, and c. When the rice cooker is in the heating stage, a and b are air inlets and c is an air outlet. The steam enters from a and b and passes through the phase change material through a certain pipe and is
discharged into the external environment. When the rice cooker is in the heat preservation stage, c is closed. a and b are an air inlet and an air outlet. The air flow passes through the phase change material and absorbs the heat stored by the phase change material to form an air flow cycle around the inner liner.

![Figure 3. Schematic diagram of the phase change storage container.](image)

2.2. Air circulation module

This device is designed with an airflow circulation structure to make the internal airflow circulate into the phase change heat accumulator for heat exchange. Through this structure, the heat of the steam generated in the heating stage is brought into the phase change heat accumulator for storage. The heat in the heat preservation stage is released from the phase change heat accumulator, and is used for heat preservation of the inner liner through air circulation. This module is composed of steam speed regulating valve, air circulation track and power fan. The air flow direction in the heating phase and the heat preservation phase is shown in Figure 4 and Figure 5.

![Figure 4. During heating phase.](image)

![Figure 5. During the insulation phase.](image)
2.3. **Three-dimensional heating module**
The three-dimensional three-dimensional heating module is composed of a multi-stage heating coil, a displacement sensor, and the like. When the rice cooker cooks less rice and the water level in the pot is low, the displacement sensor detects that the water level is low, and the auxiliary coil only selects the appropriate number of coil segments for heating. When the rice cooks more, the sensor detects that the water level is high. Segment auxiliary coils work at the same time, to reduce heating time and increase cooking efficiency. At the same time, the reasonable use of the coil can make the heating more uniform, the food taste better and extend the life of coil.

![Three-dimensional heating coil](image)

**Figure 6.** Three-dimensional heating coil.

2.4. **Control module**
The module consists of a displacement temperature monitoring system and a fuzzy controller. Based on the data transmitted by the detection system and the rice cooking process curve proposed by the rice cooking experts, the fuzzy controller formulated the optimal heating temperature, heating coil selection, and time control strategy through fuzzy reasoning. The fuzzy control can realize the reasonable use of the coil under different heating water levels. This detection system detects the water level. The displacement sensor detects the water level and performs hierarchical processing on the water level. Therefore, the system can control the number of coil operations through a preset program according to the water level. Before the rice cooker works, the height of the food in the inner container is detected by a displacement sensor, and the number of coils used to heat the food is intelligently selected by the fuzzy controller. This method can make full use of electromagnetic coils to heat food in the most energy-efficient way.

3. **Benefit analysis**

|                       | Electricity for heating | Electricity for thermal insulation | Total electricity consumption |
|-----------------------|-------------------------|-----------------------------------|------------------------------|
| **Rice cooker**       |                         |                                   |                              |
| New energy-saving IH  | 0.572kw.h               | 0.018kw.h                         | 0.590kw.h                    |
| rice cooker (3-stage |                         |                                   |                              |
| coil heating)         |                         |                                   |                              |
| New energy-saving IH  | 0.763kw.h               | 0.018kw.h                         | 0.781kw.h                    |
| rice cooker (4-section coil heating) |       |                                   |                              |
| New energy-saving IH  | 0.953kw.h               | 0.018kw.h                         | 0.971kw.h                    |
| rice cooker (5-section coil heating) |       |                                   |                              |
| Ordinary IH Rice Cooker | 0.953kw.h               | 0.100kw.h                         | 1.053kw.h                    |

Take one-cooking for example, the new energy-saving IH rice cooker and ordinary IH rice cooker cook the same amount of rice. In the heating stage, the heating power of the ordinary IH rice cooker is
1430W and the insulation power is 100W. Cooking time is about 40min. The holding time is about 1h. So the power consumption of the ordinary IH rice cooker in the heating stage is:

\[ Q_1 = 1.43KW \times \frac{2}{3}h = 0.953kw. h \]

Because the new energy-saving IH rice cooker requires electricity for small and medium-sized fans to work, the power of the small motor is 18W, and the motor only works during the heat preservation stage. The power consumption of the small motor during the insulation phase is:

\[ Q_2 = 0.018KW \times 1h = 0.018kw. h \]

If the new energy-saving IH rice cooker in the heating stage is heated with 3 coils, the power consumption of the new energy-saving IH rice cooker in the heating stage is:

\[ Q_3 = 1.43KW \times \frac{2}{3}h \times \frac{3}{5} = 0.572kw. h \]

If the new energy-saving IH rice cooker in the heating stage is heated by a 5-segment coil, the power consumption of the new energy-saving IH rice cooker in the heating stage is:

\[ Q_5 = 1.43KW \times \frac{2}{3}h = 0.953kw. h \]

The power consumption of ordinary IH rice cookers in the heat preservation stage is:

\[ Q_6 = 0.1KW \times 1h = 0.1kw. h \]

The new energy-saving IH rice cooker uses the heat stored in the heating stage for low temperature phase change thermal storage module, and the electromagnetic coil does not consume power during the heat preservation. Therefore, the electricity consumption of the new energy-saving IH rice cooker in the heat preservation stage is:

\[ Q_7 = Q_2 = 0.018kw. h \]

Therefore, for a new energy-saving IH rice cooker, the highest power consumption is 0.971 degrees for a single meal, and the minimum power consumption is only 0.590 degrees, while the ordinary IH rice cooker requires 1.053 degrees.

4. Conclusion
This project fully utilizes the excess heat generated in the heating stage to the thermal insulation stage by forming an air circulation system in the device. At the same time, the phase change material carrier adopts a spatial three-dimensional honeycomb grid structure design, which effectively expands the contact area with the air flow and increases the residence time of the airflow improves the efficiency of heat exchange. In addition, the electromagnetic coil is segmented, and the number of electromagnetic coils for heating is intelligently determined by the actual amount of rice cooked, which greatly reduces the power consumed during the use of the rice cooker. So the device has a good Energy saving and emission reduction benefits.

This project can be widely used in households, restaurants, canteens and other places where the use of rice cookers is large. It is expected to have good energy saving and emission reduction benefits, and has a broad application prospect.

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