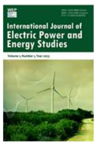
International Journal of Electric Power and Energy Studies
ISSN: 3006-2004 (Print), ISSN: 3006-0826 (Online) | Volume 3, Number 2, Year 2024
DOI: https://doi.org/10.62051/ijepes.v3n2.02
Journal homepage: https://wepub.org/index.php/IJEPES/index



Working Principle and Experimental Design of Hydraulic Wind Heating

Li Wan, Chengpeng Liu, SANGYONGLAMU, Wei Wang

Tibet Autonomous Region Energy Research Demonstration Center, Lasa 850000, China

ABSTRACT

The wind energy heating system studied in this article mainly consists of three parts: vertical axis wind turbines, heaters, and heat exchange devices. A liquid stirring heating experimental platform was built based on the heating principle. By using a heating experimental platform, the speed of the driving motor is controlled to simulate the input characteristics of the wind turbine under different speed conditions, so that the heater can reach a stable state from static state. Study the changes in temperature and efficiency during the start-up process. Finally, an economic evaluation was conducted on the investment cost throughout the entire lifecycle by comparing it with coal-fired heating and electric heating methods.

KEYWORDS

Wind Powered Heating; Heating Efficiency; Economic Evaluation.

1. INTRODUCTION

Energy is the most fundamental material guarantee in social and economic development, and it is also a necessary condition for human survival. After experiencing the oil crisis that broke out at the end of the 20th century, countries around the world have deeply realized the arrival of the energy crisis. Entering the 21st century, the development and utilization of renewable energy has gradually become one of the themes of energy development[1]. The effective development and utilization of renewable energy can to some extent alleviate a series of problems such as fossil fuel depletion and severe environmental pollution at present[2]. In recent years, China has made rapid progress in the development and utilization of clean energy resources such as solar energy, wind energy, geothermal energy, and ocean energy. Currently, solar photovoltaic power generation and wind power generation, which have high technological maturity, have entered the commercial operation stage[3]. Among them, the utilization of wind energy includes not only common wind power generation, but also wind powered water extraction and wind powered heating[4]. In Xizang, especially in the farming and pastoral areas, small and medium-sized urban residential areas and remote villages that have not yet been covered by the heating pipe network, small coal-fired boilers and the traditional way of burning cow dung are still used for heating, and a large number of environmental pollutants will be discharged during the winter heating cycle. If direct heating with wind energy is adopted in remote areas of Xizang to provide the residents in the above areas with the heat required for heating in winter, the emission of environmental pollutants will be significantly reduced, and domestic hot water will also be provided for residents in summer when heating is not required.

As an important part of distributed energy development, the research on direct heating technology based on wind energy in this paper can be used for winter heating, crop insulation, farming and animal husbandry of independent users in remote areas of Xizang. Therefore, it has important research value and social benefits in the fields of energy conservation and emission reduction, and improving energy utilization.

2. OVERVIEW OF WIND ENERGY HEATING

Wind energy heating can be converted into energy through the conversion pathway of "wind energy mechanical energy electrical energy thermal energy"[5]. The kinetic energy of wind is converted into mechanical energy by wind turbines, and then the mechanical energy is converted into electrical energy by generators. The electrical energy is then converted into thermal energy for users through electric heaters, as shown in Figure 1. In the above-mentioned wind energy heating system, although each energy conversion link has mature application technology [6], the equipment cost required for the power generation process is relatively high, resulting in high initial investment and long recovery cycle[6]. In addition, a higher number of energy conversions can also have a certain weakening effect on the energy utilization efficiency of the system, so the above factors limit the application and development of this heating method.

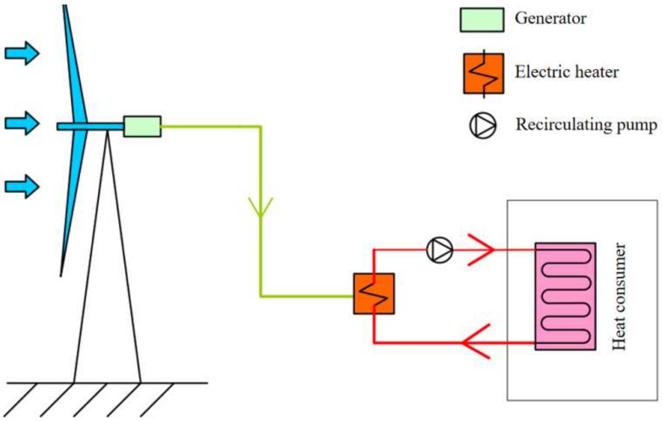


Figure 1. Schematic diagram of the conversion pathway of wind energy mechanical energy electrical energy thermal energy

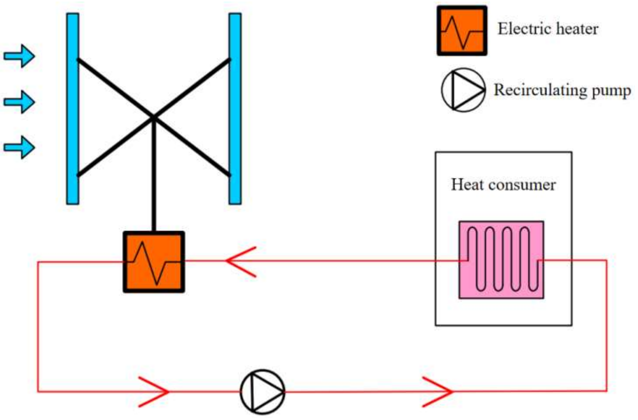


Figure 2. Schematic diagram of the conversion pathway from wind energy to mechanical energy to thermal energy

In addition to the energy conversion pathways mentioned above, wind energy heating can also obtain the thermal energy required by users through the "wind energy mechanical energy thermal energy" pathway[7]. The kinetic energy of natural wind is captured by wind turbines and converted into mechanical energy, which is then directly converted into the thermal energy required by users by heaters, as shown in Figure 2. Therefore, compared to the first type of energy conversion form, the latter conversion form eliminates the need for power generation equipment and reduces the number of energy conversions. This conversion method will further reduce the initial investment cost and significantly improve the energy utilization efficiency of the system, hence it is called a wind energy direct heating system. However, considering the conditions required for the installation of the heater, special requirements have been put forward for the structural form of the wind turbine.

The heater in the wind energy heating system refers to a device that directly converts the mechanical energy output by the wind turbine into thermal energy. According to different heating principles, it is mainly divided into the following categories[8-12]:

a) Liquid extrusion heating

The liquid extrusion heating device combines hydraulic components and damping valves to achieve the conversion of wind energy into thermal energy. The hydraulic components convert mechanical energy into pressure energy of the heating fluid. Afterwards, the high-pressure working fluid is ejected at high speed from the damping valve, converting the pressure energy of the working fluid into its kinetic energy. When the high-speed working fluid collides with the low-speed working fluid behind the damping valve, the molecules of the working fluid undergo violent movements of mutual impact and friction, thereby converting the kinetic energy of the hydraulic oil into thermal energy, causing the temperature of the working fluid to rise and achieving the heating effect.

b) Solid friction heating

The solid friction heating device mainly works based on the principle of frictional heat generation. It is mainly composed of friction blocks and heat generating bodies, and the friction blocks are installed on the input shaft of the device. In the static state of the device, the friction block does not come into contact with the heat generating body in order to reduce the starting torque of the device. When the device starts running, the friction block increases its radius of rotation under the action of centrifugal force, generating heat through friction with the heat generating body to achieve the heating effect. And the heating capacity of the device is positively correlated with the positive pressure of the friction block and the heat generating body, as well as the rotational speed of the device. Although the solid friction heating device has a relatively simple structure and low cost, the friction elements must be replaced regularly.

c) Compressed air heating

The compressed air heating device converts mechanical energy into thermal energy through an air compressor. The air compressor is driven by a wind turbine to compress gas, and the heat generated is exported to the heat user through a heat exchange structure to provide heat. When using a piston air compressor, compared to other types of air compressors, it has lower power consumption in any pressure range. However, due to the structural characteristics of piston air compressors, the overall vibration of the system is large, and there is a lot of loss during the heat transfer process, resulting in low economic efficiency.

d) Liquid stirring heating

The liquid stirring heating device is mainly composed of stirring blades and baffle plates, which realize the conversion from mechanical energy to thermal energy. When the stirring blades rotate, they accelerate the stirring of the working fluid in the device, causing eddy current motion between the stirring blades, the baffle plate, and the inner wall of the device. Through continuous impact and friction, the purpose of heating is achieved. In addition, the heating device has a simple structure, easy processing, low cost, high reliability, and no special requirements for materials and working fluids. Under the condition of achieving good matching with wind turbines, the heating effect is good.

e) Eddy current heating

Eddy current heating devices are usually composed of rotating magnets and stator heating elements, which realize the energy conversion process from mechanical energy to thermal energy. When the device is running, the magnet rotates together with the shaft, and the magnetic lines generated by the magnet cut the stator heating element. The stator heating element generates induced current according to the law of electromagnetic induction. Due to the structure of the stator heating element, the induced current exists in the form of eddy current in the stator heating element. Furthermore, it raises the temperature of the stator heating element, achieving the process of energy conversion.

3. THEORETICAL ANALYSIS AND EXPERIMENTAL DESIGN OF LIQUID STIRRING HEATING

3.1. Principle of Mixing Heating

During the operation of the stirring heating device, the torque generated by the wind turbine drives the stirring shaft to rotate. In the initial stage, the liquid working fluid has a certain amount of kinetic energy under the action of rotating blades, and presents a directional flow state in the mixing tank. The working fluid near the blade reaches the mainstream velocity first through friction and impact with the blade. The working fluid far away from the blades has not been disturbed and has formed a significant velocity gradient with the mainstream working fluid. Due to the viscous forces between the layers of the working fluid, collisions and friction also occur between the molecules in each layer. When a working fluid with a certain kinetic energy encounters a baffle, the molecules of the working fluid collide and rub against the wall of the baffle, and a vortex is formed in the space formed by the baffle and the wall of the mixing tank. The generation of eddy currents further exacerbates the degree of disorder of the working fluid molecules. Therefore, through the impact and friction effects between the working fluid molecules and between the working fluid molecules and various wall surfaces, as well as the eddy current effects generated in some areas, mechanical energy can be effectively converted into thermal energy of the working fluid. In this study, a four straight blade rotor was used as the stirring heating element, and the stirring rotor was arranged in a multi-stage staggered manner with a baffle plate.

3.2. System Structure of Experimental Apparatus

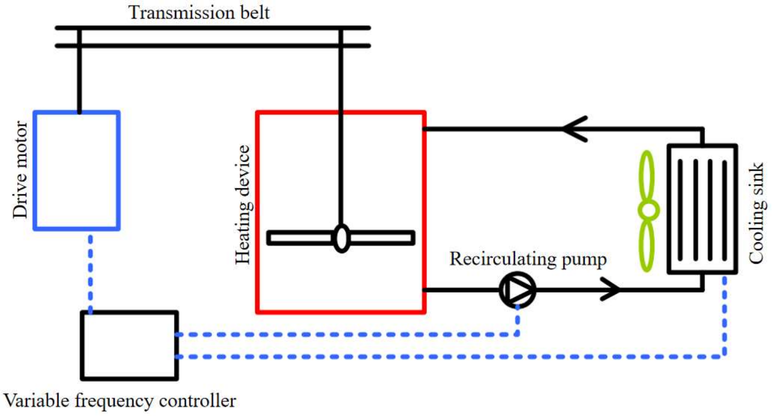


Figure 3. Schematic diagram of liquid stirring heating experiment

The liquid stirring heating experimental device mainly consists of a driving motor, a circulation system, a stirring heating device, and a variable frequency controller, as shown in Figure 3. The experimental setup is controlled by a variable frequency controller to drive the motor speed to meet the experimental requirements. The volume of the cooling water tank is $0.5m^3$, the maximum flow rate of the circulating pump is 7.5m³/h, the volume of the heater mixing drum is 0.15m³, and the mass of the working fluid is 150kg.

The body of the liquid stirring heater consists of a stirring bucket, a stirring shaft, stirring blades, a baffle plate, and an insulation layer. The mixing blades are made of four flat blades arranged in multiple stages in a staggered manner with the baffle plate. The circulating pump extracts the working fluid from the bottom of the mixing drum and sends it into the cooling water tank. The cooled working fluid enters the mixing drum through the inlet at the top of the mixing drum, completing the heat exchange cycle process.

3.3. Experimental Procedure

During the operation of the liquid stirring heater, as the speed increases, the stress on the stirring blades and baffle plates will increase, and the vibration of the device will also increase. To ensure the safety and reliability of the experiment, redundant power is no longer considered when selecting the drive motor. Based on the operating characteristics of the liquid stirring heater, the experimental process is determined as follows:

a) Determine the working flow rate of the circulation system, calculate the frequency value corresponding to the frequency converter of the circulation pump, start the circulation pump according to the preset value, and ensure that the liquid level of the heat dissipation water tank meets the experimental requirements when the working fluid is filled in the mixing tank. Ensure that all pipeline interfaces are securely connected without leakage;

b) Determine the required driving motor test speed for the experiment, calculate the corresponding frequency value of the motor frequency converter, and preset the frequency converter to the corresponding frequency value;

c) After the readings of each temperature measuring element and the flow meter tend to a constant value, start the driving motor and start data acquisition after reaching the preset speed;

d) To reduce the impact of experimental environment temperature on experimental results, measures such as controlling ventilation are adopted to maintain a basic constant laboratory temperature and ensure good insulation performance of the device;

e) After the settling test at a certain speed is completed, data collection is stopped, the cooling water tank starts to cool down the working fluid, and the circulation pump continues to work until all temperature measurement points are consistent with the initial state, and then the next operating condition test can be carried out.

4. THE VARIATION LAW OF OPERATING PARAMETERS AT 3 DIFFERENT SPEEDS

When the structural parameters of the liquid stirring heater are determined, the operating parameters mainly include the temperature of the working fluid inside the stirring tank and the heating rate. Experimental studies were conducted on five sets of operating conditions at speeds ranging from 300r/min to 500r/min to analyze the changes in operating parameters of the heating device during its transition from a static state to stable working conditions at various operating speeds.

4.1. Temperature Variation Law of Mixing Working Fluid

When the liquid stirring heater operates, the working fluid in the stirring drum moves under the action of the stirring rotor, and the working fluid also collides and rubs against the solid wall surface and the working fluid, heating the working fluid. The mechanical energy of the input device is converted into thermal energy through the interaction between the fluid molecules and the avoidance surface.

Part of this heat energy is absorbed by the metal of the device body, while the other part is used to increase the temperature of the stirring working fluid. Among them, the heat obtained from stirring the working fluid can be effectively utilized by users. Therefore, setting temperature measuring points on the wall of the mixing tank of the heater to measure the temperature of the circulating working fluid can effectively reflect the variation law of the heat generation of the working fluid. In order to ensure the accuracy of temperature measurement data and avoid accidental errors, three temperature measurement points are arranged from top to bottom along the axis of the mixing drum. Use the arithmetic mean of three temperature measurement points as the final measurement parameter.

Maintain the laboratory environment temperature at 17 ℃ during the experiment. Run for 60 minutes at different speeds and record the temperature changes of the stirring working fluid for each group. As shown in Figure 4, the experimental data shows that the temperature change of the working fluid is almost a linear function under different speed conditions of the heater. When the speed is 500r/min, the working fluid reaches 80 ℃ within 60 minutes, and the temperature is the highest. When the speed is 300r/min, the working fluid reaches 36 ℃ within 60 minutes, with the lowest temperature. From this, it can be seen that the different rotational speeds of the heater have a significant impact on the heating effect. In addition, it can be seen from the figure that during the initial start-up stage of the device, due to the high output power level of the experimental device, the absorption heat of the metal body of the device did not have a significant impact on the heating process. And due to the installation of a high-performance insulation structure for the heating device, the heat dissipation to the environment does not have a significant impact on the heating process when the stirring working fluid temperature is high. From this, it can be seen that optimizing the structure is the most effective way to improve the heating effect for a stirring heating device with a good insulation structure. In order to improve the heating effect, it is necessary to increase the degree of disorder and the frequency and intensity of irregular collisions of working fluid molecules in the mixing tank. Measures such as optimizing the structure of the stirring blades and replacing the thermal fluid with higher viscosity can be taken.

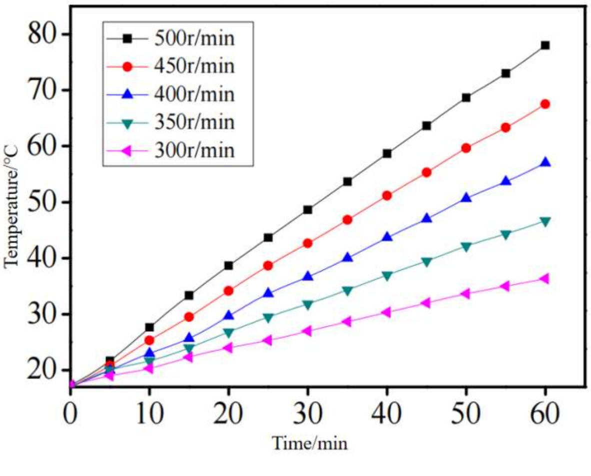


Figure 4. Temperature variation law of mixing working fluid

4.2. Variation Law of Temperature Rise Rate of Mixing Working Fluid

As shown in Figure 5, the temperature rise rate exhibits regular fluctuations at lower rotational speeds. This is due to the periodic impact of the mixing medium on the temperature measuring points set inside the mixing tank. The temperature measuring point is located between adjacent baffle plates inside the mixing bucket. Therefore, as the mixing blades rotate, the mixing medium impacts the temperature measuring point layout area in a regular manner, resulting in fluctuations in the data at the temperature measuring point. The fluctuation of data also proves the non-uniformity of temperature distribution inside the mixing tank from another perspective. In theory, the working fluid molecules near the end of the mixing blade and the intersection area between the blade and the baffle are most disturbed and generate the highest heat inside the mixing bucket. The working fluid molecules near the wall of the mixing bucket and the mixing shaft are less disturbed and generate less heat than the areas with larger molecular disturbances mentioned above.

As shown in Figure 5, the regularity of temperature rise rate change is affected to some extent under high-speed working conditions, mainly due to the intensification of turbulent flow inside the mixing bucket and the increase of device vibration with the increase of stirring blade speed, which breaks the balance relationship under low-speed working conditions. From this, it can be seen that the turbulent flow state of the working fluid in the stirred heating system intensifies under high-speed conditions, which will intensify the irregular vibration of the device and affect the service life of the stirring blades and baffle plates. Therefore, in the design process of the stirring heating device, the design speed should not be too high while meeting the heating effect.

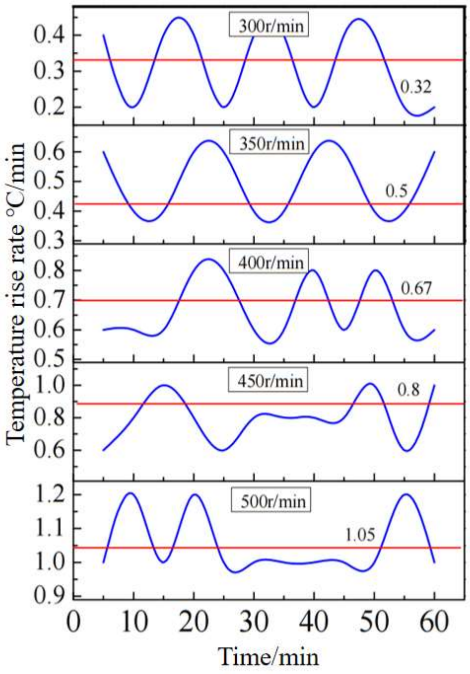


Figure 5. Variation law of temperature rise rate

5. ANALYSIS OF ECONOMIC FACTORS IN HEATING SYSTEMS

The economic factors of a heating system mainly include the total investment and the operating costs generated throughout the entire service life. Using different heating methods will result in significant differences in total investment and operating costs. In order to meet the heating demand of a 200㎡ independent house in Xizang in the example, 10kW heating equipment is selected and compared with coal-fired heating and electric heating. As shown in Tables 1 and 2.

a) Total investment. Assuming that the heating pipeline network has been determined, the total investment of the three different schemes in this example mainly considers the purchase and installation costs of heating equipment. The wind turbine in the wind energy heating device needs to be installed at a certain height above the ground, so the installation cost is relatively high.

b) Operating costs. For small coal-fired boiler heating methods, operating costs mainly include the cost of purchasing fuel during the annual heating cycle. For the heating method of electric boilers, the usage cost of electricity needs to be paid during the annual heating cycle. But for wind energy heating systems, there will be no additional operating costs.

Table 1. Total Investment and Annual Operating Costs of Each Scheme

Projects	**Option 1**	**Option 2**	**Option 3**
Total investment/yuan	4500	6500	45000
Operating cost/(yuan/year)	5780	37819	0

Table 2. Unit Kilowatt Cost of Heating Equipment

Heating equipment type	Yuan/kW
Small coal-fired boiler	380-450
Electrically heated boiler	580-650
Wind powered heating equipment	4300-5000

Through the analysis and comparison of different heating schemes for the heating demand of a 200 ㎡independent house in Xizang in the example, the initial investment cost and operating cost are compared. Based on the 15 year life cycle, it can be seen that compared with the coal-fired heating mode, the wind energy heating mode can achieve the same total cost of coal-fired heating in the seventh year because there is no fuel consumption in the later period. Not attractive for short-term use by users. In long-term use, it can effectively save operating costs and minimize heating costs.

6. CONCLUSION

The wind energy heating is an efficient, economical, and clean heating method that can effectively utilize wind energy resources. The following conclusions are drawn from this article:

a) This article provides a theoretical analysis of the working principle of the heating device and explains various factors that affect the heating effect of the heating device. The basic structure and parameters of each component of the liquid stirring heating device experimental platform were introduced, and the experimental process was described.

b) The liquid stirring heating device, under different rotational speeds of the stirring blades, closes the working fluid circulation system and starts running from a cold state for a certain period of time. After that, the temperature of the working fluid in the stirring tank shows a linear increase trend with time; When the temperature of the working fluid reaches 80 ℃, under the premise of good insulation of the mixing tank, the heat dissipated to the environment due to the temperature difference has no significant effect on the heating rate of the working fluid. Therefore, when the circulating working fluid of the stirring heater operates at parameters of 75 ℃ and above, it will not affect the heating efficiency due to significant temperature differences with the environment.

ACKNOWLEDGEMENTS

“Experimental Study on Hydraulic Wind Heating in Xizang”(XZ202201ZR0062G).

REFERENCES

[1] Chu S, Cui Y, Liu N.The path towards sustainable energy[J].Nature Materials, 2017, 16(1): 16-22.

[2] Nastasi B, Lo Basso G, Garcia DA, et al.Power-to-Gas Leverage Effect on Power-to-Heat Application for Urban Renewable Thermal Energy Systems[J].International Journal of Hydrogen Energy, 2018, 43(52): 23076-23090.

[3] Ali A, Tufa RA, Macedonio F, et al.Membrane Technology in Renewable-Energy-Driven Desalination[J]. Renewable and Sustainable Energy Reviews, 2018, 81:1-21.

[4] Wang Zuming, Wang Zumin, Wang Wenwei. Increasing research and development efforts on wind induced heating and energy storage technology Shanghai Energy Conservation, 2018, 1:9-12.

[5] Li Kai, Hu Yihuai, Zeng Cun, et al. Application of Eddy Current Method in Wind Induced Heating [J]. Scientific and Technological Innovation. 2018, 18:1-2.

[6] Zhao Jianzhu, Zong Yufeng, Wang Guoye, et al. Study on the Heating Efficiency of Layered Hydraulic Stirring Heating System [J]. Journal of Solar Energy, 2014, 35 (6): 1034-1039.

[7] Kou Peng, Li Yongguang. Direct mixing heating experiment powered by natural wind [J]. Journal of Shanghai Electric Power University. 2012, 28 (6): 521-524.

[8] Connolly D, Lund H, Mathiesen B V, et al.Heat Roadmap Europe: Combining District Heating with Heat Savings to Decarbonise the EU Energy System[J].Energy Policy.2014, 65: 475-489.

[9] Papaefthymiou G, Hasche B, Nabe C.Potential of Heat Pumps for Demand Side Management and Wind Power Integration in the German Electricity Market[J].IEEE Transactions on Sustainable Energy.2012, 3(4): 636-642.

[10] Marin. Research on Hydraulic Wind Energy Heating System [D]. Nanjing: Thesis from Nanjing University of Science and Technology, 2015.

[11] Ren Fei, Wang Cuntang, Xie Fangwei, et al. Simulation of Heating Characteristics of Throttle Valve in Hydraulic Wind Heating System [J] Fluid Transmission and Control. 2015, 3:1-6.

[12] Zhang Zuofu, Zhang Chao, Li Junrui et al. Maximum power matching design of a 5kW stirred wind energy heater [J]. Journal of Solar Energy, 2018, 39 (5): 1467-1474.