Research and application of a domestic system of wind power directly stirring heating---Taking northeast China as an example

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Abstract. In northeast China, wind in winter is strong and its energy has high sustainability, so this new type of household wind power stirring heating system focuses on stirring liquid(paraffin oil mixed with water according to the ratio of 1:1)by wind power directly, which eliminates the conversion of electrical energy and has high efficiency. The system causes energy saving and emission reduction and improves the conversion efficiency. In order to improve the situation where heating relies on coal burning or straw burning in rural areas in winter, based on the principle of energy saving, emission reduction, environmental protection and economical principles, we combine the wind energy and heating tactfully and it truly adjusts measures to local conditions.

Keywords: wind, stirring liquid directly, energy saving, emission reduction

1. Introduction

In northeast China, winter lasts for a long time, so long-term heating and traditional rural heating methods mainly rely on burning straw or coal are required to maintain the temperature. However, the coal burning has low calorific value and its heating cost is high. It is easy to cause carbon monoxide poisoning and environmental pollution if its waste is not purified but discharged directly, leading to the formation of haze.

Wind energy is a kind of clean renewable energy, and there is a lot of wind power research. At present, in order to make more effective use of wind energy, the United States and other Western European countries actively carry out wind heating work (Yuankai Wang, 1987) actively. The research and utilization of wind heating in China is at the beginning and has not received enough attention. Therefore, if the wind energy can be directly used to stir heating and generate heat for heating, the current heating situation will be greatly improved.
2. Design scheme of stirring heating system

The stirrer device and the electric heating rod are fixed in the tank, the electric heating rod is connected to the temperature control system which measures the temperature of water in the tank. The electric heating rod begins to heat when the temperature is below the set temperature. When the temperature meets the requirements, the relay module is disconnected and the heating rod stops heating.

2.1. Working principle and structure of temperature control system

The temperature control system is composed of a DS18B20 temperature sensor, single chip microcomputer, relay, liquid crystal display screen and adjusting button. Among them, DS18B20 temperature sensor is used to measure the temperature of water in the tank and sends the data to the SCM. The single chip microcomputer is connected with the liquid crystal display screen and the relay. The relay is connected with the microcontroller and the heating rod, controlling whether the heating rod is energized. The liquid crystal display screen is connected to the single chip microcomputer and the button. During the whole temperature control process, the real-time temperature of water in the tank and the set temperature will be displayed through the LCD screen for monitoring. We also design adjusting buttons, so it can be more convenient to change the setting temperature.

2.2. Working principle and structure of pipeline circulation system

The pipeline system consists of water pump, tank, pipe and cooling fin. The schematic diagram of its structure is shown in figure 1, 2 and 3.

2.3. Structure and principle of stirrer device

The reservoir has a stirrer device with double-layer structure, which together with a heat exchanger connecting the stirrer device and the reservoir. The inner layer of the stirrer device is filled with liquid (paraffin oil mixed with water according to the ratio of 1:1), and there is paraffin wax in the double-layer structure. The inner layer of the double-layer structure is aluminum alloy because of its strong thermal conductivity, and the feature makes it easy to melt paraffin wax for heat storage. The outer layer of the double-layer structure is polystyrene foam board whose thermal conductivity is poor, and it prevents the wax from exchanging heat with the water in the reservoir. The blades turn and stir to heat the liquid when the wind is enough, and some of the heat is used to melt wax while another part of heat is used to heat the water in the reservoir through the heat exchanging. When the wind is small, stirring speed slow, melting wax begins to solidify and dissipates heat, making the liquid stirrer device (paraffin
oil mixed with water according to the ratio of 1:1) heated and exothermic stably to ensure the continuous supply of heat.

3. Structure and principle of stirrer device

3.1. Selection and study of stirred liquid in stirrer device

Using wind agitation for heating, we carried out the experiment according to the relevant existing research experiments (Yu Guo & Ling Yang, 2019), and the following data could be obtained through quantitative calculation and analysis. On the basis of the data in the table 1, the 1:1 mixture of paraffin oil and water has the highest heat production efficiency, so the stirred liquid in the stirrer device is a 1:1 mixture solution of paraffin oil and water.

Table 1. Efficiency of working fluids at different speeds

| Working fluids            | Efficiency          |
|---------------------------|---------------------|
|                           | 1200/min | 1500/min | 1800/min | 2000/min |
| Water                     | 37.53%    | 38.11%   | 38.23%   | 38.22%   |
| Gravel turbid liquid      | 22.17%    | 25.12%   | 25.54%   | 26.83%   |
| Starch turbid liquid      | 34.47%    | 34.56%   | 34.89%   | 35.03%   |
| Machine oil               | 25.97%    | 26.72%   | 25.54%   | 24.83%   |
| Machine oil: Water <1:1  | 35.47%    | 35.04%   | 34.82%   | 35.33%   |
| Machine oil: Water =1:2   | 38.32%    | 38.52%   | 39.81%   | 39.86%   |
| Machine oil: Water >2:1   | 23.47%    | 23.80%   | 24.75%   | 25.07%   |
| Paraffin oil              | 22.15%    | 22.90%   | 22.25%   | 21.84%   |
| Paraffin oil: Water <1:1  | 45.24%    | 46.92%   | 49.13%   | 49.05%   |
| Paraffin oil: Water =1:2  | 41.31%    | 45.03%   | 45.79%   | 44.05%   |
| Paraffin oil: Water >2:1  | 38.77%    | 39.16%   | 39.96%   | 38.10%   |
| Saturated NaHCO₃ solution | 35.29%    | 34.70%   | 34.17%   | 35.03%   |
| Saturated NaOH solution   | 42.39%    | 42.70%   | 41.17%   | 39.59%   |
| 0.5% Iodine-velts solution| 29.83%    | 29.01%   | 28.49%   | 29.64%   |

Table 2. Thermal conductivity of different type of aluminum alloy

| Name of Material     | Type       | Thermal Conductivity \(\text{W/m·K}\) |
|----------------------|------------|---------------------------------------|
| Aluminium alloy      | 1050       | 209                                   |
| Aluminium alloy      | 1070       | 226                                   |
| Aluminium alloy      | 6061       | 155                                   |
| Aluminium alloy      | 6083       | 201                                   |
| Die-casting aluminium| ADC12      | 95.2                                  |
| Die-casting aluminium| A360       | 113                                   |
| Die-casting aluminium| A380       | 96.2                                  |
3.2. Study on inner layer material of double-layer structure of stirrer device

According to the requirements of the stirrer device, the inner layer of the double-layer structure is required to have good thermal conductivity, to ensure the supply of heat when the wind is insufficient. Metal is one of the most widely used thermal conductivity materials at present. Aluminum has the advantages of high intrinsic thermal conductivity and low density (Yuanchang Dong, 2019). Moreover, aluminum will produce a layer of dense alumina film to prevent continuous oxidation reaction after the reaction with oxygen. However, the hardness of pure aluminum is relatively low, so aluminum alloy is adopted as the inner layer material of the double-layer structure. The thermal conductivity of each type of aluminum alloy is shown in the table 2.

The hardness and chemical characteristics of all models of aluminum alloy can meet the requirements of making the inner layer of the double-layer structure. Therefore, 1070 aluminum alloy with large thermal conductivity is selected.

First of all, the total mass of water in the circulation system and the liquid stirred in the stirrer device is about 10 kg. The liquid stirred in the stirrer device is a mixture of paraffin oil and water at a ratio of 1:1, and the paraffin oil can be ignored in the calculation. The heat transfer between the stirrer device and the water in the tank occurs through a heat exchanger, whose efficiency reaches up to 96%. Therefore, the heat loss in this process is negligible.

In accordance with the experimental data, the heating power is 1870 W when the impeller rotation speed is 1800 r/min. When all heat generated by the wind is supplied to the liquid, 19 min is required. We suppose that the wind blows for 90 minutes, then the blade can generate 10098 kJ of heat, and about 9000 kJ will be supplied to the paraffin in the double-layer structure. The inner layer of the double-layer structure is similar to the envelop enclosure which is connected to the outside on all four sides. When there is no wind, the heat exchange is similar to the reverse heat dissipation process of envelope. At this point, the reverse formula of the basic heat consumption of envelope should follow the following formula:

\[ Q = \alpha FK(t_n - t_{wn}) \]

Where:
- \( Q \) -- basic heat consumption of envelop closure;
- \( \alpha \) -- Temperature correction coefficient of the envelope closure;
- \( F \) -- the area of the enclosure closure;
- \( K \) -- heat transfer coefficient of envelope closure;
- \( t_n \) -- temperature of the liquid;
- \( t_{wn} \) -- temperature of the paraffin;

During the cooling process, the liquid constantly exchanges heat with paraffin. However, due to the linear relationship between heat exchange and temperature, the problem can be equated to whether the paraffin can provide sufficient heat to the liquid when it cooling to a certain value.

\[ \text{Take } F = 2 \text{m}^2, \ \alpha = 0.4, \ K = 226 \text{[W/m}^2\text{K]}, \ t_n = 40 \degree C, \ t_{wn} = 70 \degree C \]
\[ Q = 5424 \text{ KJ. Less than 9000kJ, so it is enough for insulation.} \]

3.3. Research of the outer layer material of stirring device’s double-layer structure

The outer layer of the double-layer structure is a thermal insulation material, which can be classified into Grade A thermal insulation material and Grade B thermal insulation material. The material we used is immersed in water, so we consider to use Grade B material with better economic benefits.

Polystyrene foam board (Wei Li, 2019) is adopted as the insulation building material in China at present, which has a relatively high utilization rate in China’s construction industry. The apparent density of polystyrene foam board \( \geq 20.0 \text{kg/m}^3 \), thermal conductivity \( \leq 0.041 \text{ W/m} \cdot \text{K} \), water vapor transmission coefficient \( \leq 4.5 \), the parameter index is qualified. However, owing to its characteristic of being easily soaked by water, we need to cover a layer of waterproof film on the surface, which can achieve the ideal insulation effect.
4. Theoretical calculation and analysis

4.1. Calculation of house heat load

4.1.1. Establishment of house heat dissipation model. The national design standards for energy efficiency of public buildings and residential buildings with specific provisions on the heat transfer coefficient of envelop enclosure, exterior glass windows, balcony doors and skylights (China Academy of Building Research, 2012).

The thermal conductivity of the envelope should be calculated according to the following formula:

\[ K = \frac{1}{\alpha_n} + \sum \frac{\delta}{\alpha_x \lambda} + R_x + \frac{1}{\alpha_w} \]

Where:
- \( K \) -- heat transfer coefficient of envelope closure;
- \( \alpha_n \) -- heat transfer coefficient of the inner surface of the envelope closure;
- \( \alpha_w \) -- heat transfer coefficient of the outer surface of the envelope closure;
- \( \delta \) -- material’s thickness of each layer of envelope;
- \( \lambda \) -- thermal conductivity of materials of each layer of envelope;
- \( \alpha_\lambda \) -- correction coefficient of thermal conductivity of envelope materials;
- \( R_x \) -- thermal resistance of closed air layer.

The standard for ordinary house is \( 5 \times 4 \times 3 = 60 \) m³: the wall is 30-centimetre-thick solid wall. According to the standard, take \( \alpha_n = 8.7 \text{[W/(m}^2\text{°C)]}, \quad \alpha_w = 23 \text{[W/(m}^2\text{°C)]}, \quad \lambda = 0.7 \text{[W/(m} \cdot \text{K)}], \quad \alpha_\lambda = 1.15 \).

\[ K = \frac{1}{8.7 + \frac{0.3}{0.7} + \frac{1}{23}} = 1.88 \text{[W/m}^2\text{°C]} \]

The basic heat consumption of the envelop closure should be calculated according to the following formula:

\[ Q = \alpha FK(t_n - t_{wn}) \]

Where
- \( Q \) -- basic heat consumption of envelop closure;
- \( \alpha \) -- Temperature correction coefficient of the envelope closure;
- \( F \) -- the area of the enclosure closure;
- \( K \) -- heat transfer coefficient of envelope closure;
- \( t_n \) -- indoor calculated temperature in winter;
- \( t_{wn} \) -- outdoor calculated temperature for heating.

4.1.2. Solution of the model. Envelope closure of buildings in northeast area can be viewed as two sides connected to the outside environment and two sides connected to the non-heating house. According to the standard \( \alpha_1 = 1, \quad \alpha_2 = 0.4, \quad F_1 = 47 \text{m}^2, \quad F_2 = 27 \text{m}^2, \quad K = 1.88 \text{[W/m}^2\text{°C]} , \quad t_n = 22 \text{°C}, \quad t_{wn} = 5 \text{°C} \).

\[ \phi_1 = \alpha_1 F_1 K(t_n - t_{wn}) = 1502.12 \text{W} \]
\[
\phi_2 = \alpha_2 F_2 K (t_n - t_{\text{wn}}) = 345.17 \text{W}
\]
\[
\phi = \phi_1 + \phi_2 = 1847.29 \text{W}
\]

4.2. Selection of the cooling fin
We suppose that water inlet temperature of radiator is \(t_1\), water outlet temperature is \(t_2\), indoor temperature is \(t_3\), gravitational acceleration is \(g\), specific heat capacity of water is \(c\), density of water is \(\rho\), pipeline’s diameter is \(d\), kinematic viscosity is \(\nu\), Prandtl number is \(Pr\). Heat dissipation of cooling fin requires forced convection heat transfer between water and cooling fin, heat conduction of cooling fin itself and natural convection heat transfer between cooling fin and indoor air.

4.2.1. Establishment of model. (1) Interior flow
When the velocity of hot water flowing in the pipeline is \(v\), the Reynolds number is \(Re = \frac{vd}{\nu}\).

By the connection of Dittus-Boelter, we can know \(Nu = 0.023 Re^{0.8} Pr^{0.3}\).

Therefore, the surface heat transfer coefficient of the inner surface of the radiator is \(h_1 = \frac{Nu \lambda}{d}\) (\(\lambda\) is the thermal conductivity of water).

(2) Heat conduction of the cooling fin
By the Fourier’s law, the heat flow of cooling fin is \(q = -\lambda \text{grad}(t)\) (\(\lambda\) is the thermal conductivity of cooling fin).

(3) External heat dissipation of the cooling fin
The outer surface is approximately vertical plate natural convection heat transfer, then the Nusselt number can be determined by the connection of Dittus-Boelter
\[
Nu = C(Gr Pr)^n = C Ra^n
\]

The Grash of number is \(Gr = \frac{g \alpha v^4}{\nu^3}\).

The surface heat transfer coefficient of the external surface is \(h_2 = \frac{Nu \lambda}{d}\).

The total thermal resistance is \(R = R_1 + R_2 + R_3\).

So, the total heat transfer coefficient is \(k = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}\) (\(\delta\) is the thickness of the cooling fin).

4.2.2. Solution of model. According to the design code of heating ventilation and air conditioning for civil buildings, the radiator central heating system should be designed according to the thermal medium temperature of 75/50°C or 85/60°C continuous heating. So take \(t_1 = 65 \degree C, t_2 = 55 \degree C, room temperature t_3 = 20 \degree C, hot water flow rate is 0.6m/s\); Using steel radiator, thermal conductivity of steel is \(\lambda = 50 W/(m \cdot K)\), the inner diameter of tube is \(d = 19mm\), the thickness of tube wall is \(1.5mm\) ,the qualitative temperature of water is \(t_0 = 60 \degree C\), so the physical property of water \(is \rho = 983kg/m^3, \lambda = 0.659W/(m\cdot K)\), kinematic viscosity \(\nu = 0.478 \times 10^{-6} m^2/s, Pr = 2.99\); take the qualitative temperature of air is 40\degree C, so the physical property of air \(is v = 1.702 \times 10^{-5} m^2/s, \lambda = 0.02662W/(m \cdot K), Pr = 0.7225\). The radiator which is selected is 70cm in height and 18cm in width for each column. Take the obtained data into the established model, \(h_2 = 10.01(W/m^2 \cdot K)\). The total heat transfer coefficient of the cooling fin is \(k \approx h_2 = 10(W/m^2 \cdot K)\).

According to the selected radiator model, 11 columns are required.

5. Conclusions of system innovation and application prospect
First of all, this system uses wind power to stir liquid in order to generate heat directly, eliminating the intermediate conversion of electrical energy, converting wind energy directly into heat energy and improving the utilization efficiency.

Second, traditional wind turbine has the disadvantages of instability due to the influence of the wind. The system adopts double-layer structure device to stir. When the wind is sufficient, blades rotate and mix liquid to generate heat. Some of the heat is used to melt wax, the other part of heat through the heat
exchanger to heat the water in the reservoir. When the wind is relatively small, the stirring speed will slow down, and the melted paraffin wax will start to solidify and dissipate heat. The liquid in the stirrer device (paraffin oil and water are mixed in a 1:1 ratio) will be heated to make the stirrer device release heat externally stably, and to ensure the continuous and stable supply of heat.

This system can not only solve the problem of winter heating in rural areas of northeast China, but also solve the problem that household wind power is difficult to popularize. Northeast China has a vast territory and a large rural population. This system can solve the problem of winter heating in northeast rural areas and reduce the coal consumption due to heating, directly reducing carbon dioxide emissions. This will greatly improve the current situation of heating, energy saving and emission reduction, and protect the natural environment.

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