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Heat Pipe Solar Water Heater System Based on Heat Pipe Technology

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Although traditional solar water heaters bring great convenience to people's life, there are still shortcomings such as slow start-up speed and poor thermal conductivity. Therefore, in order to improve the performance of solar water heaters, this paper designs a heat pipe solar water heater system based on heat pipe technology, and uses experiments to analyze the heat transfer performance of glass-water/ZGM thermosiphon at room temperature. According to the experiment results, this paper fabricates a copper-water/ZGM thermosiphon, and based on this, it designs a siphon heat pipe vacuum solar water heater. The research results show that the optimal liquid filling rate of the glass-copper thermosiphon is about 14%. Compared with water, for thermosiphon with ZGM as the working medium, the temperature of each point is about 2°C higher. The glass-water/ZGM thermosiphon has good isothermality and thermal conductivity, and the start-up temperature is low, about 14°C. The research results of this paper have important guiding significance for the improvement and optimization of solar water heater systems.

1. Introduction

As a necessity for production and life, energy is the foundation of human social activities (Taylor, 2010). With the development of society, people's demand for energy is also growing rapidly. In the future, energy will become a bottleneck restricting the economic development of countries around the world. The various energy sources such as wind energy and hydropower that humans use today are directly or indirectly converted from solar energy (Tarasova and Makarova, 2013), and solar energy has received wide attention from people due to its advantages of pollution-free, regenerative and long-lasting (Huang et al., 2015), but the solar energy is thin and intermittent, and is affected by natural conditions (Chun et al., 1999). Therefore, how to convert solar energy into conventional energy that can be used on a large scale has become the focus of research by experts and scholars.
Humans have used solar energy for more than 3,000 years, mainly in the form of photoelectric conversion and photothermal conversion (Akyurt, 1984). The era of large-scale development and utilization of solar energy by human dates back to the first solar house built in 1939. The earliest research on solar energy focused on the basic theory of solar energy and the endothermic coating. Black nickel selective coating has laid the foundation for the development of high-efficiency heat collectors (Pei et al., 2012). The oil crisis triggered by the Middle East War in 1973 set off a new wave of solar energy development in various countries. The United States uses solar energy to generate electricity and produce hot water. Japan has subsidized households to install solar water heaters and power generation systems through financial subsidies. From 1980 to the present, US, Denmark, Germany and other countries have made considerable progresses in solar energy utilization such as solar heating and solar power generation. Although there are still some gaps between China and other countries, the use of solar energy in China has also been continuously strengthened, and our country has become a major producer of solar water heaters. Until now, the development of solar water heaters has experienced three generations of solar water heaters, the batch water heater, the flat-plate water heater and the vacuum tube water heater (Hanson, 1985), however, there are still various shortcomings such as damage of a single-pipe can lead to overall failure, and poor impact resistance. Heat pipe technology invented the heat pipe heat transfer components by applying the principle of heat transfer, which has the advantages of good isothermality, high thermal conductivity, reversible heat flow direction, variable density,

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etc. Therefore, it is hoped that the advantages of the heat pipe can be used to improve the solar water heater. The requirements for the development of the fourth generation of solar water heaters, namely the heat pipe solar water heaters, were proposed.

Based on the above analysis, this paper collates references related to solar water heater systems and heat pipe technology at home and abroad, proposes a heat pipe solar water heater system based on the heat pipe technology, analyzes the experimental process and results of glass-water/ZGM thermosiphon in detail. Based on this, it also introduces the production process and fabrication method of copper-water/ZGM thermosiphon in detail, analyzes the efficiency of solar water heater and designs a siphon heat pipe vacuum solar water heater.

2. Experimental study on solar heat pipe technology

2.1 Experiment objective and equipment

2.1.1 Experiment objective

The thermosiphon is a kind of heat pipe, but has the advantages of reliable heat transfer performance, low price, simple structure and convenient manufacture compared to ordinary heat pipes, and it's a kind of high-efficient heat transfer component among various heat transfer devices. However, its heat transfer performance is greatly affected by the dip angle, the physical and chemical properties of the liquid working medium and the liquid filling rate (Nuntaphan et al., 2009). Therefore, this paper uses experiments to analyze the heat transfer performance of glass-water/ZGM thermosiphon at room temperature, and fabricates a copper-water/ZGM thermosiphon based on this.

2.1.2 Experimental equipment

The glass-water/ZGM thermosiphon experimental equipment is shown in Table 1 below.

Table 1: Glass-water/ZGM thermosiphon experimental equipment

Name	Model	Quantity
Quartz glass tube	Φ30*2，total length 990mm	One
Temperature Sensor	——	Three
Rotary vane mechanical pump	——	One
Vacuum gauge	——	One
Electric constant temperature hot bath	0~500 watts adjustable power	One
Measuring cup	500ml	Two
Measuring cylinder	500-100ml	1 each
Thermometer	Minimum scale 0.2℃	Two
Three-way valve	——	One
Rubber stopper	——	One
Rubber hose	——	Several
Iron stand	——	One

2.2 Glass-water/ZGM thermosiphon experiment process and results analysis

2.2.1 Experiment process

Before the experiment, the thermosiphon was cleaned and dried. In order to obtain the optimal liquid filling rate of the thermosiphon, the liquid filling rate (distilled water) was set to be less than 5%, 14% and more than 20%, and the angle with the horizontal direction was set to 90°, when the vacuum gauge pointer is pointing at 0.09Mpa, the vacuuming is stopped, and the condensation section is condensed by natural convection cooling (indoor air is 5°C). Under the same conditions, the working medium is changed from water to SGM and then perform the experiment, separately record the temperature change of the hot water bath under the two kinds of working media, and the temperature change of the evaporation section, the adiabatic section and the condensation section with time in the thermosiphon, the results are shown in Figures 1-3.

2.2.2 Analysis of experimental results

When the liquid filling rate of the heat pipe is higher than 20%, during the temperature rise of the hot water bath from 43°C to 77°C, the boiling inside the thermosiphon is changed from indirect to high frequency, while the temperature of the evaporation section rises from 26°C to the final 55°C, and the final temperature of the condensation section is only 50°C, indicating that the liquid filling amount is too large, resulting in unstable thermal conductivity and poor heat transfer effect. When the liquid filling rate is less than 5%, during the process of raising the temperature of the hot water bath from 45°C to 65°C, the liquid in the evaporating pool changes from indirect boiling to basically dried, and the temperature of the evaporation section rises from 28°C to the final 38°C. When the temperature rises to 75°C, the evaporation section of the thermosiphon reaches the dry limit and is completely dried, so the liquid filling rate of the heat pipe should not be lower than 5%. When the liquid filling rate is 14%, the heat transfer of the thermosiphon is relatively stable. It can be seen from Figures 1-3 that the temperature difference between the condensation section and the evaporation section of the thermosiphon is less, and the temperature-time curves of the adiabatic section and the condensation section are basically coincident, indicating that their isothermal and thermal conductivity are good. In the course of the experiment, the final temperature of the working medium ZGM is about 2°C higher at each point compared to water, indicating that the thermal conductivity is better.

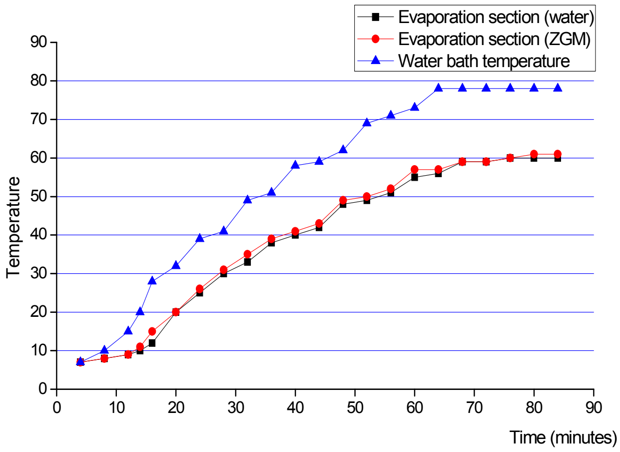

Figure 1: Superposition of temperature-time curve and hot water bath temperature time curve of evaporation section

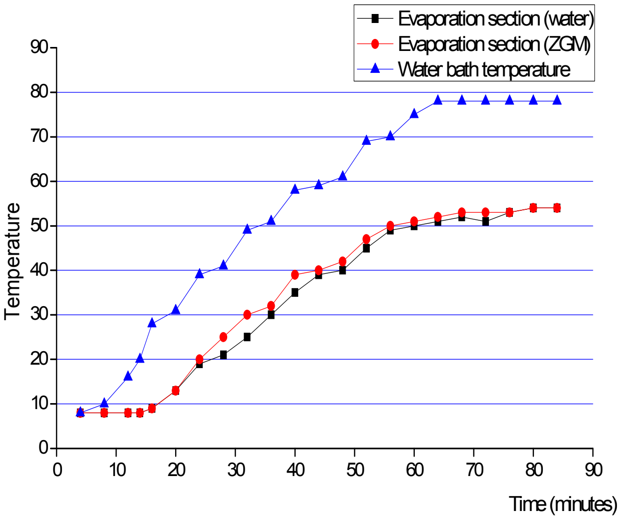

Figure 2: Superposition of temperature-time curve and hot water bath temperature time curve of adiabatic section

2.3 Production of copper-water/ZGM thermosiphon

2.3.1 Production process

The fabrication method of thermosiphon is the key factor affecting its quality. Figure 4 shows the flow chart of the production process of copper-water/ZGM thermosiphon, including mechanical processing and cleaning of the tube shell, assembly and welding, vacuum leak detection, vacuuming and liquid filling, sealing and cutting, and other processes (Morrison et al., 1999).

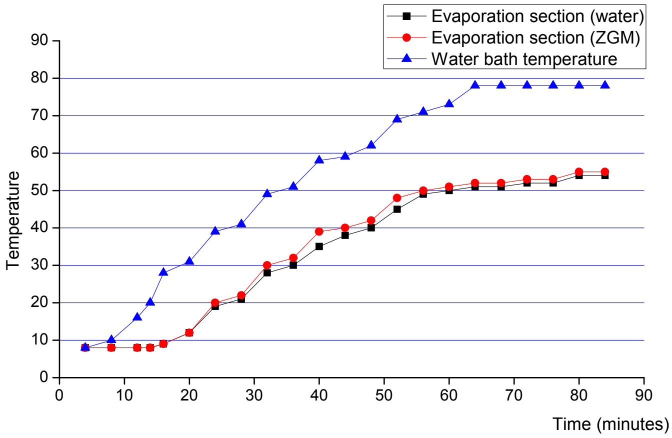

Figure 3: Superposition of temperature-time curve and hot water bath temperature time curve of condensation section

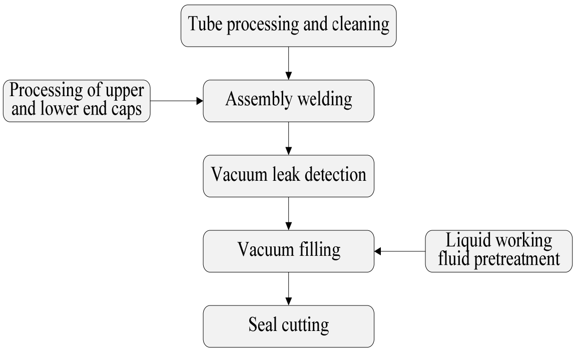

Figure 4: Copper thermosiphon production process flow chart

2.3.2 Production of copper-water/ZGM thermosiphon

(1) Cleaning of copper pipes

In order to avoid the influence of various impurities on the weld quality and the discharge of non-condensable gas to affect the vacuum degree of the tube, before fabricating the thermosiphon, the pipe shell, liquid filling pipe and the end cap shall be cleaned by phenol washing or acyl washing. In this paper, the copper pipe was cleaned by dilute ammonium nitrate with a volume ratio of 1:1 and a concentration of 50%, and dilute sulfuric acid with a volume ratio of 1:1 and a concentration of 55%.

(2) Main points of liquid filling process

Before filling liquid into the thermosiphon, firstly, the liquid working medium should be degassed by vacuuming or heating and exhausting (this paper takes the vacuuming method) to ensure the vacuum degree of the thermosiphon after filling the liquid. Secondly, a part of the air in the thermosiphon is discharged by heating the shell to save the time for vacuuming in the next step.

(3) Welding and sealing technology

In order to ensure the sealing performance of the thermosiphon and improve its impact resistance and pressure resistance, this paper uses the spot-welding electrode to internally weld the flattened liquid filling pipe, and cut the fused part with the cutting tool. The specific process is shown in Figure 5.

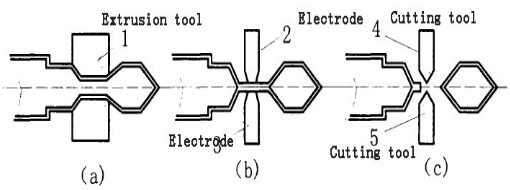

Figure 5: Pipe sealing diagram

3. Heat pipe solar water heater system based on heat pipe technology

3.1 Efficiency of heat pipe solar water heater

3.1.1 Working principle of a single heat pipe vacuum heat-collector

Figure 6 is a schematic diagram of the operation of a single heat pipe vacuum heat-collector. The copper heat pipe receives the solar heat energy transformed by the selective absorption coating, according to the heat pipe principle, the heat transfer medium is heated and vaporized to carry the heat to the condensation section, where the steam releases the heat and condenses to liquid, and the liquid flows back to the heating section at the bottom, this cycle is continuously repeated so as to achieve the transformation process from solar energy to thermal energy (Omara et al., 2013).

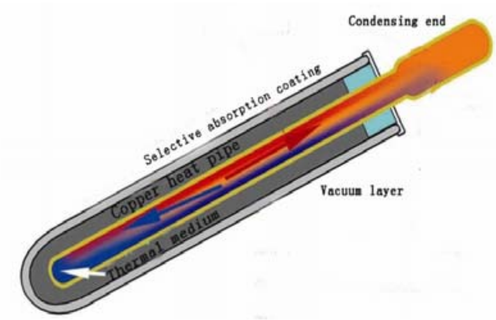

Figure 6: Schematic diagram of a single heat pipe vacuum heat-collector

3.1.2 Basic equation for heat transfer of heat pipe vacuum heat-collector

In order to facilitate the heat transfer analysis, it is assumed that the steam of the heat transfer medium is uniform, the contact thermal resistance between the heat transfer plate and the heat pipe evaporation section, the air convection and conduction heat loss in the vacuum tube are negligible, the total heat loss coefficient and heat transfer coefficient U_I are h_{g-a} constants.
(1) Total heat loss coefficient $\boldsymbol{U_I}$ of the vacuum tube heat-collector:

$$\left(\rho_L - \rho_G\right)\cdot g \cdot V_B = \pi a^2 \frac{\rho_L U_0^2}{2} \cdot f \tag{1}$$

Where, U_b and U_i are the heat loss coefficients of the heat preservation box and the vacuum tube, respectively.
(2) Instantaneous efficiency $\boldsymbol{n}$.

$$\eta = \frac{A_p}{A_s}\left[\left(\tau a\right) - U_I \frac{T_p - T_a}{I}\right] \tag{2}$$

Where, A_p and A_s are the area of the heat absorbing plate and the vacuum tube, respectively; T_p and T_a are the temperature of the hot plate and the temperature of the air outside the tube, respectively; a is the absorption rate of the absorption coating, τ is the transmittance of the outer glass.
(3) Efficiency factor of heat pipe vacuum tube:

$$\eta_2 = \left(\frac{A_p}{A_g}\right) F_1 \left[\left(\tau a\right) - U_I \frac{T_h - T_a}{I}\right] \tag{3}$$

Where, A_g is the area of the outer glass tube, T_h is the average temperature during operation of the copper thermosiphon and F_1 is the efficiency factor of the heat-collector.

3.2 Overall design of heat pipe vacuum solar water heater

In order to improve the start-up speed of the solar water heater, and to make up for the disadvantages of traditional solar water heater such as some hot water in the tube cannot be used, the inside of the vacuum tube is easy to scale, damage of a single-pipe can lead to overall failure, and the poor impact resistance. Based on these, this paper applied the vacuum layer insulation principle, diffuse reflection secondary heat collection principle and the working principle of heat pipe, and designed a siphon heat pipe vacuum solar water heater, as shown in the figure.

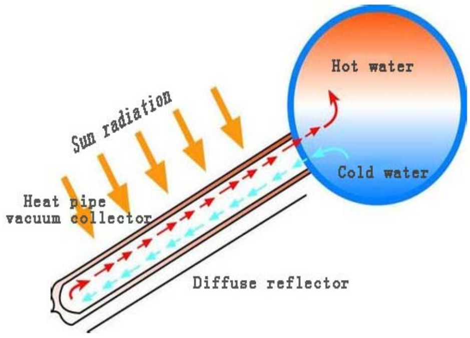

Figure 7: Siphon heat pipe solar water heater

4. Conclusion

In order to improve the shortcomings of traditional solar water heaters, such as slow start-up speed and poor thermal conductivity, this paper introduced heat pipe technology to study the heat pipe solar water heater system based on heat pipe technology. The specific conclusions are as follows:
(1) The experimental results of glass-water/ZGM thermosiphon show that the liquid filling rate of the thermosiphon shouldn't be lower than 5%, or higher than 20%, the best liquid filling rate is 15%, and the temperature difference between condensation section and the evaporation section of the thermosiphon is less, indicating that its isothermality and thermal conductivity are better, and the working medium ZGM has better thermal conductivity than water.
(2) Based on the experimental results of glass-water/ZGM thermosiphon, the fabrication process and method of copper-water/ZGM thermosiphon were analyzed.
(3) Based on the glass-water/ZGM thermosiphon experiment and the fabrication of copper-water/ZGM thermosiphon, a siphon heat pipe vacuum solar water heater was designed.

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