Experimental Exploration of Solar Photovoltaic and Thermal Integrated System

Qingqian Wang, Ye Cao

Zhejiang Fortune Energy Co., Ltd, Pinghu, Zhejiang, 314205, China

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Abstract: For the purpose of improving the use efficiency of solar energy and obtaining usable hot water and electric power at the same time, a small photovoltaic system structure for storing solar energy and a household flat-panel solar water heater can be integrated and formed, so that a photovoltaic cell device layer is arranged at a heat collecting plate of a flat-box aluminum alloy of the water heater, and a whole set of photovoltaic photo-thermal (PV/T) integrated system is formed. On the basis of expounding the principle of the experimental system, this paper carries out quantitative analysis on the calculation of its device efficiency, analyzes the integrated efficiency of photoelectric and photothermal devices, analyzes the construction of experimental equipment, and carries out experimental detection of the system performance in the cyclic mode environment under natural conditions in the S region. According to the experimental data, when the system is in a sunny or cloudy environment, the comprehensive performance efficiency index Ef is about 58%, which is obviously superior to the heating efficiency of the ordinary flat water heater. As for the efficiency of a single type of photovoltaic system, the efficiency is more obvious. In addition, after 24 hours of sunshine, most of the final temperature of the water exceeds 50℃, and even exceeds 60℃. Therefore, the system can sufficiently satisfy the user's need for hot water.

1. Introduction

About 99.98% of the energy people collect through the earth comes from solar energy. Based on relevant documents, it is shown that all radiant energy from the sun reaching the earth is about 177x1017kW, of which 30% is reflected into space through the form of light. Photovoltaic cells developed by solar energy are more and more popular among the people because the light sources they rely on are endless. However, in practical application, it is found that the efficiency of solar cell power generation is not constant[1]. When the external surface temperature of the battery meter increases, its efficiency becomes weaker instead. According to relevant experiments, the relative reduction ratio of electrical efficiency of the battery is 0.15% when the temperature of the battery increases by 1e. According to this, some scholars believe that the heat generated by increasing the temperature of the battery can be recovered and used, so that the temperature of the battery can be kept within a relatively low range, and an additional part of heat gain can also be obtained.In this context, the hybrid photovoltaic-thermal solar system, the PV/T system, has come out. Many scholars have carried out a lot of research on the types of emerging energy use systems[2]. This paper describes the experimental principle of the system under the premise of previous scholars' research. The quantitative research has been carried out, especially for the system of the system, that is, the relative power generation efficiency of the PV/T system has been systematically analyzed. Analyze the specific data under different environmental temperature conditions, and study the relative power generation efficiency of PV/T devices under the temperature environment at the inlet, in order to play a role in the future research of academic circles.

2. Principle of experimental system

The experimental system of PV/T system analyzed in this paper is shown in Figure 1 below. The system can not only generate electricity, but also provide daily hot water. Its principle is as follows: the heat-collecting circulating water pump sends out power to transfer the cold water in the water

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tank to the back plate of PV/T device at high temperature. The remaining heat is dissipated through the coil, then returned to the water tank, and heated circularly all the time to heat the water.Among them, F.M. in Fig. 1 represents an electromagnetic flowmeter, which synchronously supervises the flow data in the test operation. Correspondingly, additional cooling equipment has been added to the experimental system to simulate the user of the hot water demand. The heat can be drained in time by the heat pump and the air-cooled radiator, so that the water temperature in the water tank is in a sTable state, and the air-cooled radiator is mainly controlled by the frequency converter of the fan, thereby better controlling the constant temperature of the water.

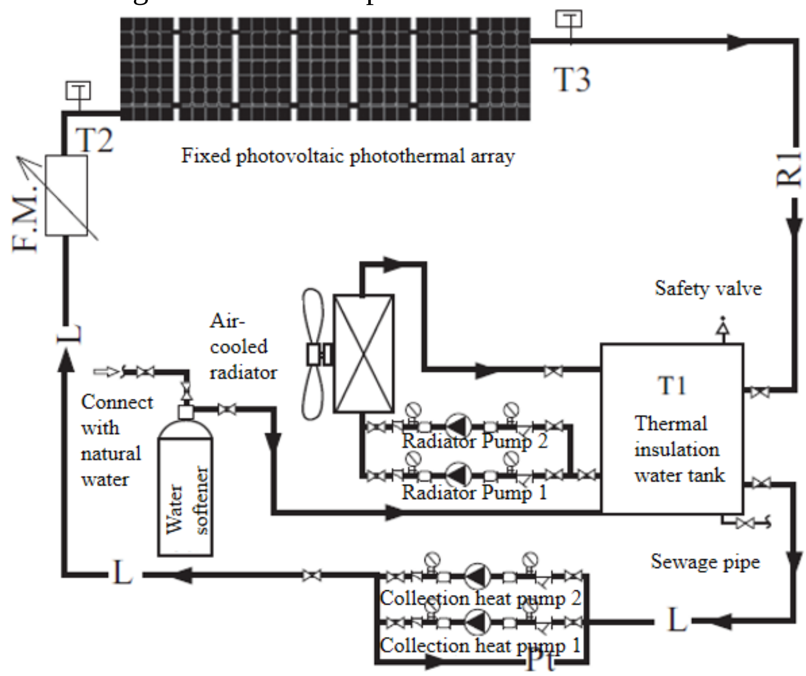

Fig.1. Schematic diagram of PV/T system

3. Analysis of experimental system and its operation

3.1 Calculation of Device Efficiency

The simplified model structure of PV/T device can be constructed as shown in Figure 2 below.

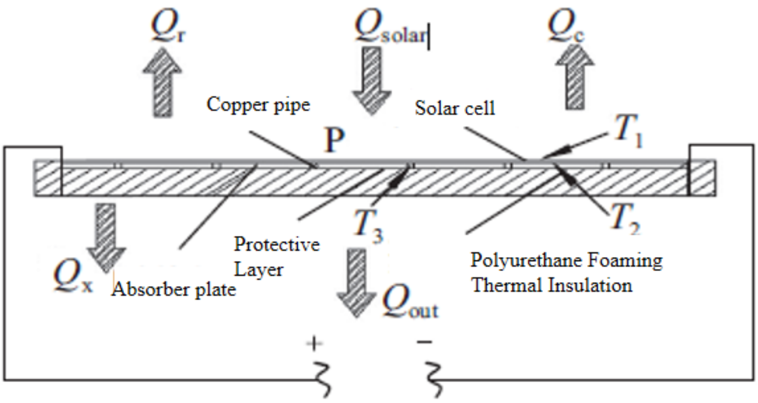

Fig.2. Simple Chart of PV/T Device Model

The function formula of solar energy absorbed by PV/T device is shown in the following (1):

$$Q_{solar} = q_{solar} A_c \quad (1)$$

Among them, Qsolar represents the heat (unit: W) obtained by solar PV/T devices. Qsolar represents the intensity of sunlight radiation received outside the device (unit: W/m2). Ac represents the area outside the device in m2.

Since the outside of the device is in direct contact with the air, convection heat transfer (expressed by Qc) will occur. In addition, it will also generate radiant heat exchange with the external environment (expressed by Qr), and the circulating water in the heat-collecting coil will obtain corresponding heat (expressed by Qx). Then, there is the following functional relationship between the above parameters:

$$Q_{\mathrm{x}} = \mathrm{mc_p}(T_{out} - T_{in}) \tag{2}$$

Among them, the back plate mainly plays the role of heat preservation. However, there is still a small amount of heat Qout escaping. Therefore, the solar energy function formula corresponding to this device is shown below:

$$Q_{\mathrm{solar}} = Q_{\mathrm{c}} + Q_{\mathrm{r}} + Q_{\mathrm{x}} + Q_{\mathrm{out}} + P \tag{3}$$

In the above formula, m represents the circulating water flow (unit: L/s). Cp represents the specific heat capacity of water (unit: $4.187\mathrm{kJ}(\mathrm{kg}\cdot\mathrm{K})$). Tout represents the temperature of water at the outlet of the device (in k). Tin represents the temperature (in k) of water at the inlet of the device. P represents the output power generated by the device.

The function of the thermal efficiency of the device is shown below:

$$\eta_{\mathrm{t}} = Q_{\mathrm{x}} / Q_{\mathrm{solar}} \tag{4}$$

Accordingly, the device's electrical efficiency function is as follows:

$$\eta_{\mathrm{e}} = P / Q_{\mathrm{solar}} \tag{5}$$

In the above formula, the power represented by P but obtained by the device is obtained by multiplying both the voltage and the current collected by the software.

3.2 Comprehensive Efficiency of Photovoltaic Thermal Devices

As far as PV/T system is concerned, there is no unified efficiency evaluation standard at present. Based on the first law of thermodynamics, if the radiation amount of the incident solar energy is constant, the electrical energy and thermal energy of the system must have an internal correlation with opposite existence. Many relevant scholars use the overall efficiency index of photoelectric and photothermal to evaluate the comprehensive efficiency of the system. The function formula is as follows:

$$\eta_0 = \eta_{\mathrm{t}} + \eta_{\mathrm{e}} \tag{6}$$

In the above formula (6), η0 represents the comprehensive efficiency of the device, and the value of the energy of the system is reflected by the numerical value. In terms of thermal energy, electrical energy is a type of higher quality energy. According to the relevant literature, the comprehensive performance function of photoelectric photothermal can be introduced as follows:

$$E_{\mathrm{f}} = \eta_{\mathrm{t}} + \eta_{\mathrm{e}} / \eta_{\mathrm{power}} \tag{7}$$

In the above equation (7), Ef represents the capability of the device to convert intercepted solar light energy into electrical energy and thermal energy. ηpower represents the power generation efficiency of conventional thermal power plants, and generally takes the value of 0.38. The formula represents the conversion of electric energy into equivalent thermal energy through the average power generation efficiency of the local power plant to perform calculation.

4. Experimental equipment

The experimental equipment of this paper is shown in Figure 3 below. Its main components include: heat pipe PV/T system, storage battery, PV system, water pump (fully intelligent micro hot water booster circulating pump), heat collecting water tank and rotameter.

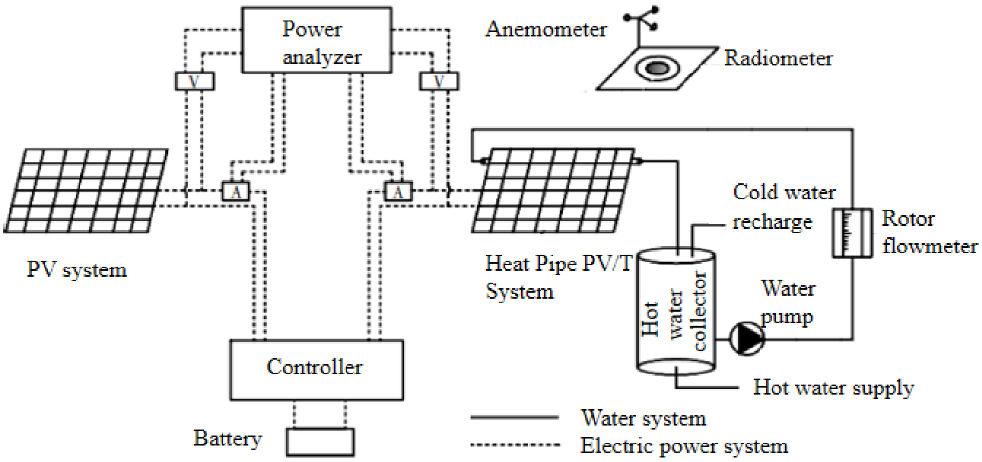

Fig.3. Graphics of the experimental system

For the structure and external structure of the inner boundary of the heat pipe type system, please refer to Figure 4 below:

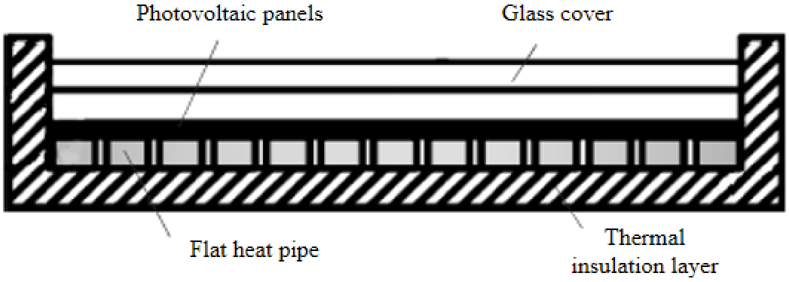

Fig.4. Diagram of the inner boundary structure of the heat pipe type system

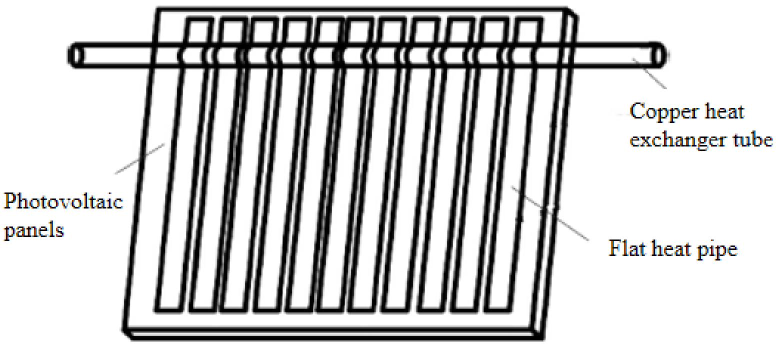

Fig.5. Diagram of the external structure of the heat pipe type system

As can be seen from the above figure, the heat pipe PV/T system is mainly composed of photovoltaic cell panels, flat heat pipes, copper heat exchange tubes, insulation layers (aluminum foil, rubber and plastic) and glass cover plates. As can be seen from fig. 3, for the heat pipe type PV/T collector, a plurality of flat heat pipes are laid on the back of the photovoltaic cell panel in parallel. The photovoltaic cell plate is in dry contact with the flat heat pipe, the flat heat pipe and the copper heat exchange pipe, and is coated with heat conducting silica gel to reduce the contact thermal resistance of the contact surface. In order to prevent heat loss from the back of the heat pipe PV/T system, a thermal insulation layer is pasted on the back of the heat pipe PV/T system.

The operation process of the heat pipe type PV/T system: the liquid fluid in the evaporation section of the flat heat pipe absorbs the heat of the photovoltaic panel and starts to vaporize; the steam in the flat heat pipe flows from the evaporation section of the flat heat pipe to the condensation section under the action of the pressure difference. And transferring heat to the circulating water in the copper heat exchange tube in the condensation section; after the steam in the flat heat pipe releases heat, it is recondensed into a liquid, and flows back to the evaporation section along the inner wall of the flat heat pipe under the action of gravity. Such a reciprocating cycle continuously transfers the heat of the flat heat pipe to the circulating water in the copper heat exchange tube.

5. Experimental scheme, results and discussion

Based on the national standard regulations for functional testing of domestic solar water heaters, the author carried out an 8-hour all-weather outdoor experiment in Area S. The main test indexes are: radiant energy R of the sun, temperature Tw of the water tank, external temperature Ts, working voltage Uw and its current Iw. Among them, the data collector collects the detected data every 5 minutes. After processing, please refer to Table 1 below:

Table 1 Experimental result

Time(2018)	Tin(Unit:℃)	ΔT(Unit:℃)	Tmax(Unit:℃)	Ts(Unit:℃)	R(Unit:MJ·m^{-2})	η_{th} (Unit:%)	η_e (Unit:%)	η_0 (Unit:%)	Ef(Unit:%)
7.10	31.4	6.5	37.8	35.24	3.66	28.1	9.66	38.32	54.3
7.11	35.5	9.1	47.5	33.75	5.98	28.4	9.27	37.42	50.2
7.12	32.1	21.3	53.5	36.34	11.98	34.8	9.26	44.26	60.3
7.13	32.5	25.7	56.7	35.12	17.88	25.4	9.27	46.13	59.7
7.14	31.6	27.2	56.9	36.41	14.72	42.1	9.91	49.32	66.8
7.15	30.5	20.4	52.3	33.41	12.87	31.4	9.46	41.42	56.3
7.16	36.4	15.4	50.1	31.34	6.22	40.1	9.36	46.32	63.5
7.18	37.5	32.4	63.2	36.31	20.41	42.4	9.41	49.41	64.5
7.20	35.7	20.3	63.5	35.18	12.93	39.8	9.33	48.24	60.5
8.01	30.1	30.5	64.6	34.89	20.13	44.5	9.34	53.46	66.6

Note: In Table 1 above, Tin represents the initial temperature of cold water at the inlet, ΔT represents the increase of water tank temperature after sunshine all day, and Tmax represents the highest temperature of water all day.

Many scholars evaluate the overall efficiency of the system by the sum of the thermal efficiency index (ηth) and the electrical efficiency index (ηe) (η0). In order to accurately evaluate the energy efficiency of the system and compare the performance of the system with the performance of previous water heaters and photovoltaic systems, this paper uses the following formula to evaluate the performance of the system:

$$E_f = \eta_{th} + \eta_e / \eta_{power} \tag{8}$$

Where ηpower represents the power generation efficiency of conventional power plants, and its value is 0.38.

As can be seen from Table 1 above, the efficiency index Ef of the integrated performance of the system is about 58%, which is obviously improved compared with the thermal efficiency of the general flat water heater. As for the efficiency of a single photovoltaic system, the efficiency is higher. Furthermore, after 24 hours of sunshine, the temperature of the last water mostly exceeds 50℃. If it is fine or cloudy, or even exceeds 60℃, it can be seen that the user's demand for hot water can be fully achieved.

6. Conclusion

This paper studies the PV/T system based on experiments. According to the experimental data, PV/T system can enhance the power generation efficiency of monocrystalline silicon battery to a certain extent. At the same time, the actual power generation efficiency of the system can be improved under the environment of good sunshine environment and low temperature of circulating water of the system. And the efficiency index Ef of its comprehensive performance is about 58%, which is significantly improved compared with the thermal efficiency of ordinary flat-plate water heater.Furthermore, based on the comparison, there is an inherent correlation between the relative power generation efficiency of the system and the temperature difference between the temperature at the inlet and the temperature of the environment. According to this, it can be considered how to effectively control the temperature of the water at the inlet, and the influent water with high temperature should be drained in time or transferred to other heat storage containers to ensure that the PV/T system is in Relatively high power generation performance status.

References

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