Study on Performance Test Method of Solar Assisted Gas Heating System

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Abstract. In this study, a test method for thermal performance of solar assisted gas heating system was taken as research object, basing on the existing relative test standards in China, test system was set up, and test parameters and test method for thermal performance of the heating system were put forward. Daily useful energy captured by solar collector, heat output of the gas boiler, heat loss rate and energy efficiency coefficient of system were proposed to analysis the thermal performance of the hybrid system.

1. Introduction

In view of the thermal performance test of solar assisted gas heating system, the relevant regulations and standards, available in China, were mainly concentrated in a single heat source or very few combined heating systems. Among them, for solar water heater, the relevant national and industrial regulations and standards were mainly related to the basic standards, technical conditions, performance evaluation standards, solar collector, water storage tank, supplementary heat source and so on, thereinto the main standards for performance test were shown in Table 1. For gas boiler, current performance test was carried out mostly according to the standards “Gas-fired heating and hot water combi-boilers” (GB 25034-2010) and “Minimum allowable values of energy efficiency grades for domestic gas instantaneous water heaters and gas-fired heating and hot water combi-boilers” (GB 20665-2015), principle product standards were shown in Table 2.

For solar assisted gas heating system, the existing standards were insufficient for the integrated test indexes and interaction between different heat sources can not be truly reflected. At the same time, in Europe energy labelling and ecodesign requirements for space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device were issued in 2013 [1-4], that provided a reference for the test of multi-energy hybrid heating system.

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Table 1. Principle test regulations and standards for solar water heaters in China.

Number of standard	Name of standard
GB 50495-2009	Technical code for solar heating system
GB/T 25966-2010	Specification of domestic solar water heating systems with electrical auxiliary heat source
GB/T 6424-2007	Flat plate solar collector
GBT 17581-2007	Evacuated tube solar collectors
GB/T 23889-2009	Specification of air source heat pump assisted domestic solar water heating systems
GB/T 4271-2007	Test methods for the thermal performance of solar collectors

Table 2. Principle test standards for gas water heater in China.

Number of standard	Name of standard
GB6932-2001	Domestic gas instantaneous water heaters
GB18111-2000	Gas storage water heater
GB25034-2010	Gas-fired heating and hot water combi-boilers
GB20665-2015	Minimum allowable values of energy efficiency grades for domestic gas instantaneous water heaters and gas-fired heating and hot water combi-boilers

2. Test system

The solar assisted gas heating system studied in this paper consisted of a solar heating unit and a gas heating unit. In order to carry out the test for thermal performance of the system, a solar assisted gas heating test platform was set up. The test devices and arranged test points were shown in Table 3 and the flow chart of test system in Figure 1.

Table 3. Test devices and test parameters.

Test devices	Test parameters
Electromagnetic flowmeter	Working mass flow of solar collector, L min^{-1};Water flow of domestic hot water, L min^{-1}; Water flow of space heating loop, L min^{-1};
Wet type flowmeter	Gas flow, m^3;
Temperature sensor	Return water temperature of solar heater, ℃; Supply water temperature of solar heater, ℃; Leaving water temperature, ℃; Tap water temperature, ℃; Supply water temperature of space heating, ℃; Return water temperature of space heating, ℃; Outlet hot water temperature of gas boiler, ℃; Inlet hot water temperature of gas boiler, ℃; Outlet water temperature of gas boiler in space heating loop, ℃; Inlet water temperature of gas boiler in space heating loop, ℃; Water temperature in the upper part of tank, ℃; Water temperature in the middle part of tank, ℃; Water temperature in the lower part of tank, ℃;
Electricity meter	Electricity consume of system, kwh; Electricity consume of gas boiler, kwh; Electricity consume of solar collector, kwh; Electricity consume of pump in space heating loop, kwh.

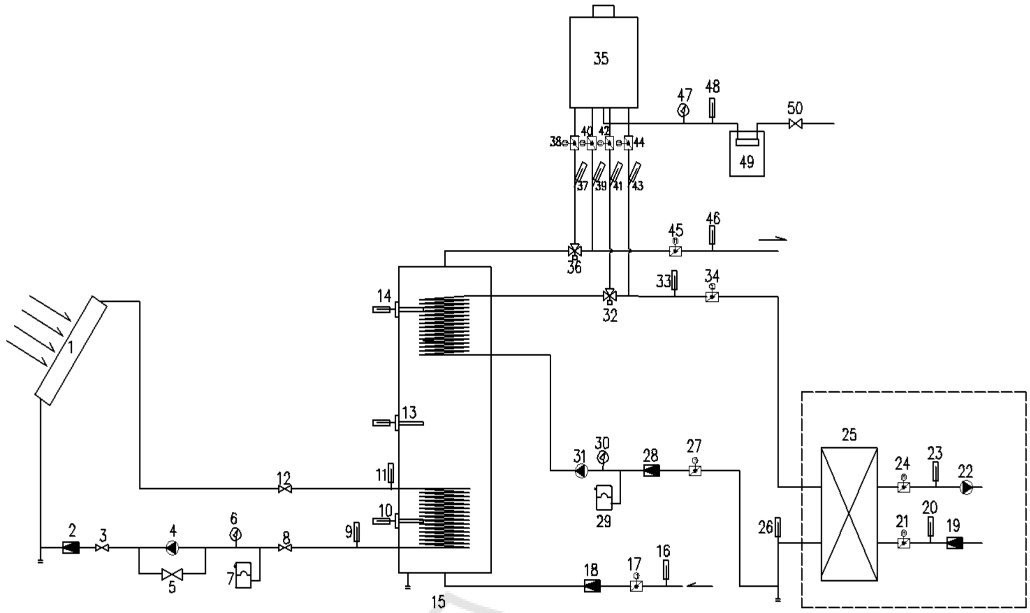

Figure 1. Test system 1-solar collector; 2,18,19,28- electromagnetic flowmeter; 3,5,8,12,50-regulating valve; 4,22,31-pump; 6,30,47-pressure gauge; 7,29-expansion tank; 9,10,11,13,14,16,20,23,26,33,37,39,41,43,46,48- temperature sensor; 15-water tank; 17,21,24,27,34,38,40,42,44,45- electromagnetic valve; 25-plate-type heat exchanger; 32,36-three-port valve;35-gas fired heating and hot water combi-boilers; 49-gas flowmeter.

3. Test conditions

Test should include at least 1 day to meet the following conditions: daily solar radiation was 10 MJ $m^{-2} \leq H \leq 25$ MJ m^{-2}; water temperature in the storage tank was $t_{b1}=15\pm2$ ℃ before test, and that was $t_{e1}=50\pm2$ ℃ after; average ambient temperature was 0 ℃$\leq t_{ad} \leq$39 ℃; reference gas was selected as test gas (15 ℃, 101.3kPa); and the ambient wind speed was $v\leq4$ m s^{-1}.

4. Test method

(1) Before the beginning of test, storage tank should be full filled with cold water of 15±0.5 ℃, and solar collector was covered with sun visor.

(2) At the beginning of the test, sun visor was removed, water temperature of storage tank and test time were started to be recorded; meanwhile outdoor ambient temperature t_{ad}, the humidity d and wind speed v were monitored in real time, and the electricity consumption N_1 and gas using amount V_{g1} were recorded at the same time, as well as the accumulated solar irradiation received by the solar collector.

(3) During the test, flow rate of medium in solar circulation system was set at a constant discharge between 6 L min^{-1} and 10 L min^{-1}, and the medium temperature at the entrance and exit of solar collector, t_{in1} and t_{out2}, were recorded at least every 15s.

(4) When the solar irradiation accumulated to 10 MJ m^{-2}, the combined operation of gas boiler and solar heater was started; water out from boiler was set at 60 ℃; storage tank was equipped with a mixing pump, water intake and outlet were placed at the bottom and the top of this tank respectively, mixing pump was run continuously during the whole period of test; when the water temperature in the middle part of tank arrived at 50 ℃, gas boiler was closed, the mixing loop was stopped, and the test was over.

5. Analysis of thermal performance

5.1. Daily useful energy captured by solar collector

$$Q_s = \frac{\sum_{i=1}^{n} c_m \times \rho_m \times \upsilon_i \times \tau_i \times \left(t_{ini} - t_{outi}\right)}{60} \tag{1}$$

In it, Qs was daily useful energy captured by solar collector, kJ; c_m was specific heat capacity of the solar cycle medium, kJ (kg ℃)$^{-1}$; ρ_m was density of the solar cycle medium, kg L^{-1}; υ_i was flow rate of the solar cycle medium, L min^{-1}; τ_i was measure interval, s.

Converted to the daily useful energy captured by solar collector, Q_{s17}, kJ, under daily solar irradiation of 17 MJ m^{-2}, calculated as formula (2),

$$Q_{s17} = 17 \times Q_s \times H_E^{\ -1} \tag{2}$$

In it, H_E was accumulated solar irradiation received during the test, MJ m^{-2}.

5.2. Heat output of the gas boiler

Under dry type flowmeter measuring, gas heat output was converted into gas heat input in the reference condition according to formula (3); When the wet type flowmeter was used, the gas density should be corrected by formula (4), and in it d was replaced by d_h.

$$Q_g = 1000 \times H_i \times V_{g1} \times \left(\frac{101.3 + p_g}{101.3} \times \frac{p_a + p_g}{101.3} \times \frac{288.15}{273.15 + t_g} \times \frac{d}{d_r} \right)^{1/2} \tag{3}$$

$$d_h = \left[d\left(p_a + p_g - p_s\right) + 0.622\, p_s \right] \times \left(p_a + p_g\right)^{-1} \tag{4}$$

In them, Q_g was heat output of the gas under 15 ℃, 101.3kPa and dry state, kJ; H_i was low caloric value of reference gas under 15 ℃ and 101.3kPa, MJ Nm^{-3}; V_{g1} was consumption volume of gas, m^3; p_g was gas pressure, kPa; t_g was gas temperature, ℃; d was relative density of dry test gas, dimensionless; d_r was relative density of reference gas, dimensionless; p_s was saturated vapor pressure at t_g, kPa; 0.622 was relative density of water vapor in ideal state, dimensionless.

5.3. Heat loss rate of system

$$\eta = 1 - \left(c \times \rho \times V \times \Delta t_{e1b1}\right) \times \left(Q_{s17} + Q_g\right)^{-1} \tag{5}$$

In it, η was heat loss rate of system, %; c was specific heat capacity of water, kJ (kg ℃)$^{-1}$; ρ was density of water, kg L^{-1}; V was volume of storage tank, L; Δt_{e1b1} was temperature rise of water in storage tank, $\Delta t_{e1b1} = t_{e1} - t_{b1}$, ℃.

5.4. Energy efficiency coefficient of system

$$CTP = c \times \rho \times V \times \Delta t_{e1b1} \times \left[\left(N_1 \times c_1 + V_{g1} \times c_2\right) \times Q_{tce} \right]^{-1} \tag{6}$$

In it, CTP was energy efficiency coefficient of system, dimensionless; N_1 was electricity consumption of system, kwh; c_1 was standard coal coefficient of electricity, kg tce kwh^{-1}; c_2 was standard coal coefficient of gas, kg tce m^{-3}; Q_{tce} was calorific value of standard coal, kJ (kg tce)$^{-1}$.

6. Conclusions

Through the study of test method for thermal performance of solar assisted gas heating system, it contributed to help consumers to specify the energy efficiency of hybrid heating system, and to understand the thermal performance of different types of water heaters more directly. Thermal performance of hybrid system was analysis, test method and test parameters were put forward in this research, so as to choose heating water equipment more better, and directly promote the energy efficiency of heating equipment and the application of renewable energy and energy saving technology.

7. References

[1] European Commission 2013 No.811/2013 *Energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device* p 77-81

[2] European Commission 2013 No. 812/2013 *Energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device* p 123-127

[3] European Commission 2013 No. 813/2013 *Ecodesign requirements for space heaters and combination heaters* p 156-159

[4] European Commission 2013 No. 814/2013 *Ecodesign requirements for water heaters and hot water storage* p 173-177