Renewable Energy 86 (2016) 257–261

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Experimental investigation of a domestic solar water heater with solar collector coupled phase-change energy storage

H. Sheng Xue

Jiangsu Provincial Supervising and Testing Research Institute for Products Quality, 5 East Guang Hua Street, Nanjing, SU 210007, China

ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form
6 August 2015
Accepted 7 August 2015
Available online xxx

Keywords:
Constant flow rate
Exposure
Thermal energy storage
Domestic solar water heater
All-glass evacuated tubular solar collector
System efficiency

ABSTRACT

Phase change materials (PCMs) have good properties such as high thermal capacity and constant phase change temperature. Their potential use in solar energy storage is promising. Tests of exposure and constant flow rate are performed to investigate the thermal performance of a domestic solar water heater with solar collector coupled phase-change energy storage (DSWHSCPHES). Due to the low thermal conductivity and high viscosity of PCM, heat transfer in the PCM module is repressed. The thermal performance of the DSWHSCPHES under exposure is inferior to that of traditional water-in-glass evacuated tube solar water heaters (TWGETSWH) with an identical collector area. DSWHSCPHES also performs more efficiently with a constant flow rate than under the condition of exposure. Radiation and initial water temperature have impacts on system performance; with the increase of proportion of diffuse to global radiation and/or initial water temperature, system performance deteriorates and vice versa.

1. Introduction

PCM is characterized by high thermal capacity and constant phase change temperature. It has the promising potential of eliminating the mismatch between supply and demand, reducing storage volume, lowering cost, lengthening nocturnal service time, and intensifying thermal performance. Extensive researches about the application of PCM in integrated collector storage solar systems and domestic solar water heater components—collector, tank, and heat transfer loop, for example—have been undertaken. Both beneficial impact and undesired effects have been presented in works of scholars, making the introduction of PCM into solar storage systems a controversial issue.

For an integrated collector storage solar water heating system, the use of PCM leads to a decrease of thermal efficiency [1,2]. The improvement of insulation enhances solar energy accumulation, lengthens nocturnal service time, and boosts water temperature [3,4]. The system efficiency increases incrementally with the thermal conductivity of PCM and of the water flow rate; outlet temperature fluctuation decreases if the heat transfer pipes are placed deeper in the storage material [5,6].

The research results on PCM coupled solar collectors are contradictory. It is observed that the use of PCM decreases thermal loss and thus system efficiency improves by up to 11% [7]. Thermal performance factors such as useful energy and nocturnal service time are intensified [8–10]. However, annual performance is penalized by low efficiency during the winter season [11]. Researchers argue that traditional collectors perform better than ones coupled with PCM due to their low thermal conductivity and high viscosity [12].

The exploitation of PCM in water tanks enhances its thermal energy density and capacity, compensating the increase of heat loss. Investigations show that introduction of PCM results in extension of the period of higher temperature water storage, volume reduction of the required water tank, and leveling the mismatch between energy supply and demand [13–23]. But experiments and mathematical optimization show a magnified fluctuation of water tank temperature, stratification degradation, and increased nocturnal heat loss. Thermal performance improvement is not relevant [24,25]. This can be remedied by carefully selecting the thermal PCM parameters, parametric intensification, and optimal design of the water tank [26–29].

Extra energy may also be stored in a PCM module installed in the heat transfer solar loop with a modified control system. Parametric

Abbrevations: PCM, phase change material; DSWHSCPHES, Thermal performance of domestic solar water heater with solar collector coupled phase-change energy storage; TWGETSWH, traditional water-in-glass evacuated tube solar water heaters.

E-mail address: 10408027@zju.edu.cn.

http://dx.doi.org/10.1016/j.renene.2015.08.017
0960-1481/© 2015 Elsevier Ltd. All rights reserved.

analysis shows that the solar fraction of a solar water heater with a water tank volume of 0.01 m^3 can be significantly improved from 42.4% to 48.5% by introducing a PCM module with a volume of 0.02 m^3. Moreover, water tank volume obtains a 40% reduction while maintaining a high solar fraction [30].

Comprehensive investigation and laborious works are still needed to clarify the feasibility of introducing PCM in domestic solar water heaters. In light of this, exposure and constant flow rate tests are performed upon a DSWHSCPHES to probe its thermal performance.

2. Experimental procedure

Thermal performance tests of the solar collector are conducted on the test rig, which is schematically illustrated in Fig. 1. It consists of a water tank, a solar collector, piping, and a data acquisition system. The solar collector is of an all-glass evacuated tubular type, and its area is 1.272 mm^2. The core component of the solar collector, the collector tube, is 1800 mm long. The outer diameter of the tube is 58 mm. On the outer surface of the inner glass tube, Cu/Al/stainless steel is magnet-sputtered as solar selective coating. There are 10 tubes in the collector. Inside each collector tube, PCM storage unit is built in. The diameter, wall thickness, and length of the unit are 42.16 mm, 1.53 mm, and 1.720 mm, respectively. The main part of the PCM is $Ba(OH)_2 \cdot 8H_2O$. A small amount of $BaCO_3$ is used as nucleant (Figs. 3–5). The thermal properties of the PCM are summarized in Table 1. Solar energy is absorbed by the solar selective coating. Via conduction and convection and radiation, it is transferred to the PCM unit. Then, fusion of the PCM occurs inwardly. A U-shaped copper tube with a diameter of 8 mm and a wall thickness of 0.8 mm is embedded in the PCM (Fig. 2). The heat transfer fluid, water, flows through the copper tube and converges at the manifold with a diameter of 15 mm and a wall thickness of 1.0 mm. Energy transfer is relayed by water flow in the embedded copper tube to the water tank with a volume of 90 L.

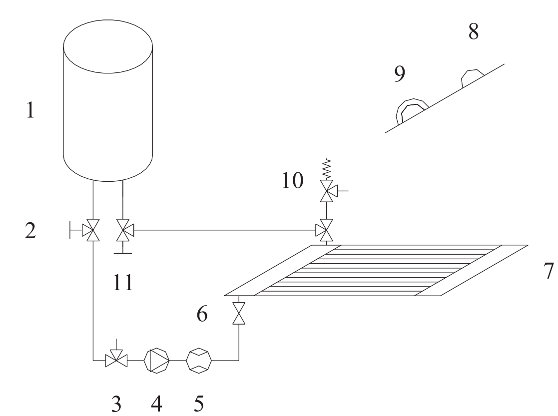

Fig. 1. Schematic diagram of the test rig. (1. Water storage; 2,11. Temperature sensor; 3. Three-way valve; 4. Pump; 5. Flow meter; 6. Valve; 7. All-glass evacuated tubular solar collector; 8. Pyranometer; 9. Shaded pyranometer; 10. Safety valve).

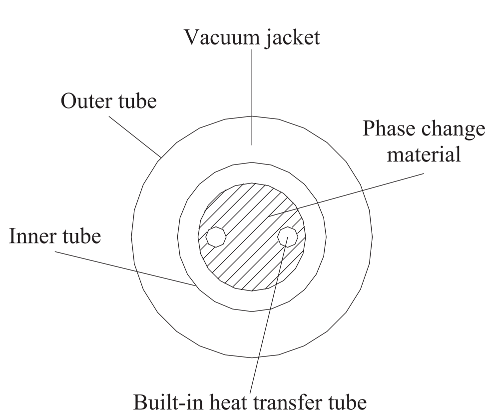

Fig. 2. Schematic diagram of thermal energy storage unit using $Ba(OH)_2 \cdot 8H_2O$ as PCM.

Preconditioning of the test rig is performed prior to each performance test. The solar collector is shaded from the solar beam. Valves at the locations of 2 and 11 are turned off. Water flows at a constant temperature in the pipeline from three-pass 3 across the solar collector till water temperature is equal at valves 6 and 10. The exposure test starts at 8:00 am by removing the shade from the solar collector. Radiation is logged by a data acquisition system. The exposure test ends at 4:00 pm. The valves at the two ends of the manifold are turned off. Three-passes 2, 10, and 11 are turned on, and the water tank is filled through three-pass 3. When the water tank is full, three-pass 3 and valve 10 are shut down. The valves at the two ends of the solar collector manifold are turned on. The pump is started, and water is circulated through the test rig. The flow rate of the heat transfer fluid is regulated to a value of 1.53 L/min. When the temperature at locations 2 and 11 stabilizes, the temperatures are tabulated.

The constant flow rate test starts by preconditioning the test rig with a constant flow rate of 0.02 kg/(m^2 s) with the solar collector shielded. When the whole system obtains a uniform temperature, the shade over the solar collector is removed. The test is run from 8:00 am to 4:00 pm.

The thermal performance of the solar system is evaluated by the useful energy obtained and system efficiency, which are formulated below.

$$Q_u = CM\Delta T = CM(T_o - T_i) \quad (1)$$

$$\eta = \frac{Q_u}{G} \times 100\% \quad (2)$$

3. Results and discussion

The energy efficiency variation of the TWGETSWH vs. the ratio of tank volume to collector area is demonstrated in Fig. 6. The typical water heater is characterized by tank volume/collector area of 50–54 kg/m^2, daily useful energy of 7.5–7.7 MJ, and efficiency of 44–45%. Also, it is shown that as the ratio of tank volume to collector area increases, the system energy efficiency improves.

With regard to this work, the ratio of the tank volume to collector area amounts to 70 kg/m^2. For a TWGETSWH, the energy efficiency could amount to about 52%. However, the daily useful energy, maximum efficiency, and average system efficiency obtained by exposure test are 6.4 MJ, 41%, and 37%, respectively. As for the constant flow rate test the parameters mentioned above are 10 MJ, 59%, and 57% (Table 2). Compared to the TWGETSWH, the thermal performance of the one with PCM under exposure is inferior. However, when the solar water heater runs at a constant flow rate, excess energy can be stored in the PCM and this excess energy reheats the water of the system as time precedes and solar radiation attenuates. Accordingly, the solar water heater with PCM performs better than the traditional one.

Solar irradiance lessens with time after noon. However, the water temperature in the storage tank keeps rising constantly till about 1 h before the end of the constant flow rate test. Then the temperature reaches a climax and stabilizes afterwards (Fig. 7). The constant fusion temperature, which characterizes a phase change material, is not shown itself in the temperature profile because the presence of barium carbonate does not effectively boost the growth