Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 43, No. 3, pp. 291-300
Published Year 2020

Performance Investigation Of Solar Water Heating System Integrated With PCM Storage

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ABSTRACT: The availability of hot water supply is an essential needs for households and industries. Use of solar water heater (SWH) to meet the hot water supply is solution with efficient and low cost technology. This research presents a development of SWH with modification of the absorber plate integrated with phase change material (PCM) storage. The V-shaped absorber plate integrated with PCM storage using stearid acid in the SWH was investigated experimentally. The performance of this SWH was compared with the conventional type using flat plate absorber. The experiment was performed for the two types of SWH by operating them simultaneously. It starts from 09:00 AM to 3:00 PM (local time) with flowrates of 0.5; 1.0 and 1.5 L/min respectively. The average performances of SWH with PCM storage are 34.6% (0.5 L/min), 43.7% (1.0 L/min) and 60.0% (1.5 L/min) respectively. For the SWH with flat plate absorber, the average performances are 30.9% (0.5 L/min), 33.8% (1.0 L/min) and 48.7% (1.5 L/min) respectively. The results show an increase of performance of SWH by using PCM storage (stearid acid) of 3.7% (0.5 L/min), 9.9% (1.0 L/min) and 11.3% (1.5 L/min) respectively.

KEYWORDS: V-shaped Absorber Plate, Flat Plate Absorber, Stearid Acid.

INTRODUCTION

The needs of energy are increasing along with the technological developments. Energy sources that are widely used today are non-renewable energy sources such as petroleum, coal and natural gas. However, renewable energy sources has a great potential to be developed such as solar energy. Approximately, a half of the sun's energy enters the earth's surface and total solar energy absorbed by the atmosphere, ocean, and soil is around 3,850,000 exa joules (EJ) per year [1].

Nowadays, solar energy technology has been widely used for hot water supply using solar water heating (SWH) system. In order to improve the performance of the SWH system, various studies have been conducted including modification of the absorber plate and its material. Performances of SWH system with flat plate collectors have been investigated [2,3]. Optimization of single and double glazing flat plate collectors [4] and investigation of the novel flat plate collectors with micro-channel heat pipe [5] have been studied. The design of polymer flat plate solar collectors was proposed [6]. Flat plate solar collector using ceramic (ordinary ceramics and V-Ti black ceramics) integrated with the building was conducted by Yang et al. [7]. The use of a V-shaped absorber plate in a SWH have been conducted and investigated [8]. Performance of the SWH with V-shaped absorber plate was compared with that of the conventional flat plate absorber. The performance of the SWH with V-shaped absorber plate enhanced of 2.36% with flowrate 0.5 L/min and 4.23% with flowrate 2.0 L/min. Using the V-shaped absorber plate increased the absorber plate temperature and also energy losses to the top.

A number of studies have been conducted in SWH system integrated with phase change material (PCM) storage in order to improve its performance. The effect of using PCM as a storage medium on the SWH has been studied experimentally by Fazilati & Alemrajabi [9]. In this research, paraffin was used as PCM in round capsules as storage material in a water heater tank. An experimental study of PCM storage using paraffin integrated with flat plate collector has been conducted by Bouadila et al. [10]. Al-Kayiem & Lin [11] conducted research on SWH which is integrated into the heat storage system. The heat storage system consists of paraffin as PCM and nanocomposite of paraffin. PCM floor including capillary plaits and macro-packaged PCM layer [12] and also shell and tube TES system using paraffin wax [13] was applied in SWH system. Recently, integrated collector storage solar water heater (ICSSWH) [14] and Energy storage solar collector with inserted oscillating heat pipe [15] have been studied to analyse the performance of SWH system. Furthermore, a review of the SWH system have been conducted comprehensively by Wang et al. [16].

This research presents a development of SWH system integrated with PCM storage on its absorber plate. Using V-shaped absorber plate in the SWH increased the plate temperature. However, energy losses to the top was also increase. In order to reduce the energy losses, the V-shaped absorber plate is integrated with PCM storage using stearid acid. The SWH using V-shaped absorber plate integrated with PCM storage was build. Its performance was investigated and compared with that of SWH using flat plate absorber plate.

MATERIAL AND METHODS

SWH system is a heat exchanger that converts solar radiation into thermal energy through the water flowing. Solar radiation is absorbed by the collector's plate and transferred to the water. Furthermore, hot water is used for hot water supply in residential, commercial and industrial buildings.

The modification of the absorber plate with the use of an integrated V-shaped absorber plate with PCM storage as shown in Figure 1 was carried out in this study.

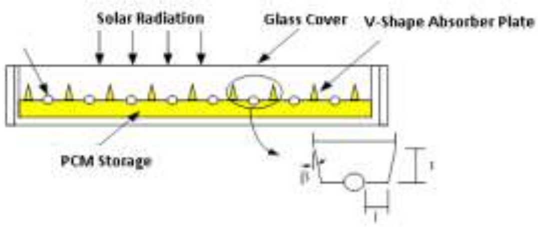


Figure 1. SWH collector using V-shaped absorber plate with PCM storage

The experimental test equipment consisted of two SWH collectors: a) using V-shaped absorber plate with PCM storage and b) flat plate absorber without using PCM storage as shown in Figure 2. V-shaped absorber plate with PCM storage can be seen in Figure 3.

Figure 2. Solar water heater test equipments:

(a) Using V-shaped absorber plate with PCM storage and (b) flat plate absorber without using PCM storage

PCM storage using stearid acid was integrated with V-shaped absorber plate in the SWH system. Stearic acid or Octadekanot acid is one type of PCM from 18 carbon saturated fatty acids. The charateristic of PCM thermophysic is shown on Table 1.

Figure 3. V-shaped absorber plate with PCM storage

Table 1. Thermophysic Properties of PCM Materials

Properties	Stearid Acid
Melting Temperature (°C)	55.1
Latent Heat (kJ/kg)	160
Density (kg/m$^{3)}$ when it is:	
Solid	965
Liquid	848
Specific Heat (kJ/kg °C) when it is:	
Solid	1.6
Liquid	2.2
Thermal Conductivity (W/m. K) when it is :	
Solid	0.36
Liquid	0.172

The performance of the SWH is determined by the efficiency of the collector with obtained from the comparison between useful energy of the collector through hot water and solar energy available. Actual useful energy, Q_u is calculated based on temperature measurements of inlet and outlet water as following

$$Q_u = \dot{m} c_p \Delta T \tag{1}$$

where $\dot{m}$ is the mass flowrate (kg/s), C_p is specific heat (kJ/kg °C) and ΔT is temperature difference between inlet and outlet water (□C).

While theoretical useful energy, Q_u is determined as following

$$Q_u = A_c . F_R [S - U_L (T_i - T_a)] \tag{2}$$

where F_r is heat release factor, S is solar radiation absorbed by the absorber plate (W/m²), U_L is total heat losses (W/m² K), T_i is water temperature (□C) and T_a is ambient temperature (□C).

Collector efficiency η is:

$$\eta = \frac{Q_u}{I_T A_c} \tag{3}$$

where I_T is the solar intensity (W/m^2) and A_c is surface area of the collector (m^2).

RESULTS

This research was conducted in the Renewable Energy Laboratory of Mechanical Engineering Department, Hasanuddin University, Gowa campus (119^0 30’ 06.1” BT and 05^0 13’ 52.4” LS). The experimental test equipments of two SWHs using V-shaped absorber plate with PCM storage and flat plate absorber without using PCM storage is conducted by operating the two SWHs simultaneously. The dimensions of the collector are 163 cm length and 100 cm wide. Water flowing through copper pipes with diameter 0.017 m was set with flowrates of 0.5; 1.0 and 1.5 L/min. Data was recorded from 09:00 AM to 3:00 PM (local time) with interval 5 minutes.

The intensity of solar radiation during the experiments has a minimum value in the morning and afternoon. The maximum value of the solar intensity occurs during the daytime as shown in Figure 4. The maximum solar radiation intensity is 887 W/m^2 at 12:05 PM (local time on September 30, 2017), 909 W/m^2 at 11:55 AM (local time on October 1, 2017), and 901 W/m^2 at 11:55 AM (local time on October 02, 2017).

Figure 5 shows the inlet and outlet water temperatures of the collectors. The inlet water of the two collectors comes from the same reservoir so that it has the same temperature. The outlet water temperature of the collector with V-shaped absorber plate integrated with PCM storage using stearic acid is higher than that of the collector with flat plate absorber. The average outlet water temperature of the collector using V-shaped absorber plate with PCM storage for each flowrate is 42.96 °C (0.5 L/min), 38.54 °C (1.0 L/min) and 37.68 °C (1.5 L/min). While, the average outlet water temperature of the collector using flat plate collector is 41.64 °C (0.5 L/min), 36.8 °C (1.0 L/min) and 36.4 °C (1.5 L/min).

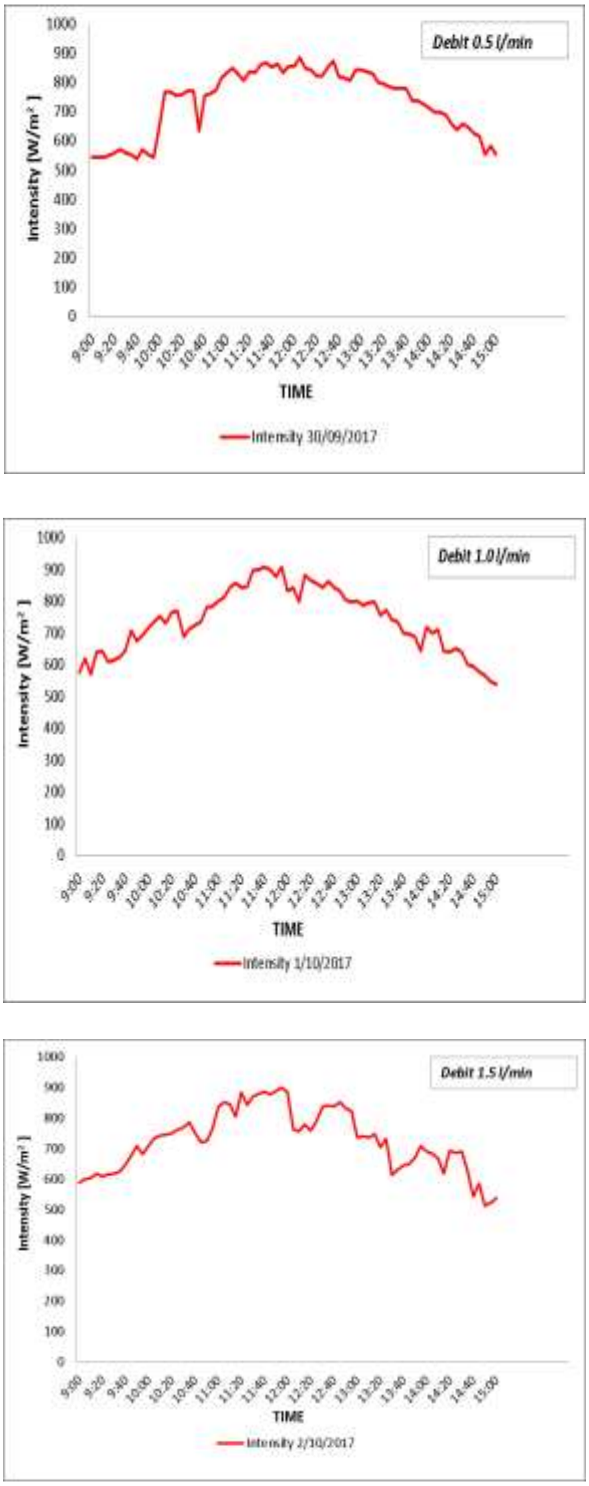
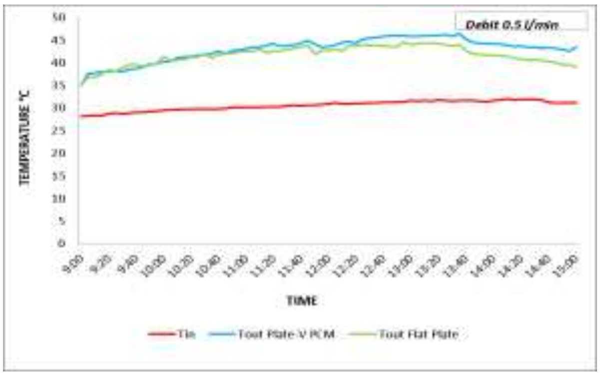
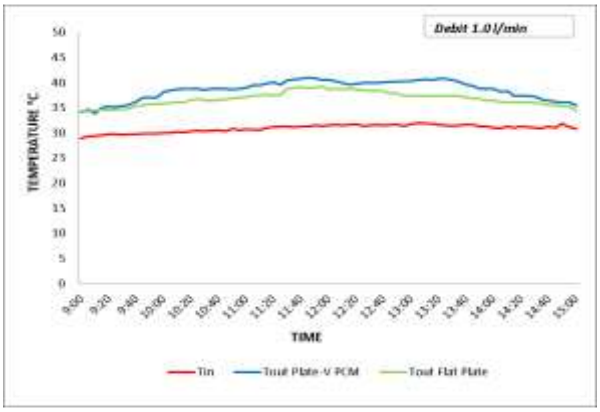


Figure 4. Intensity of solar radiation with flowrates of 0.5, 1.0 and 1.5 L/min

Data: September 30, 2017



Data: October 01, 2017



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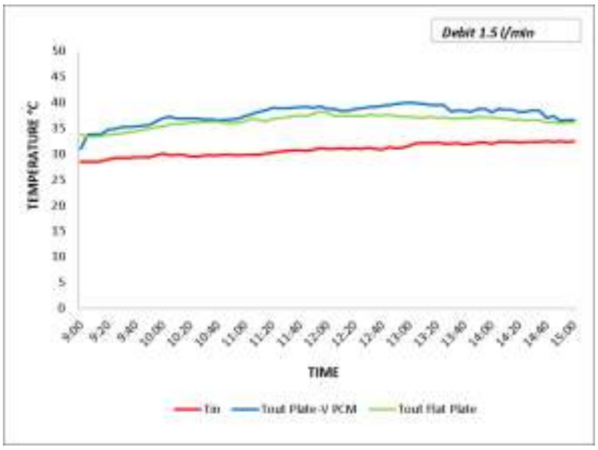
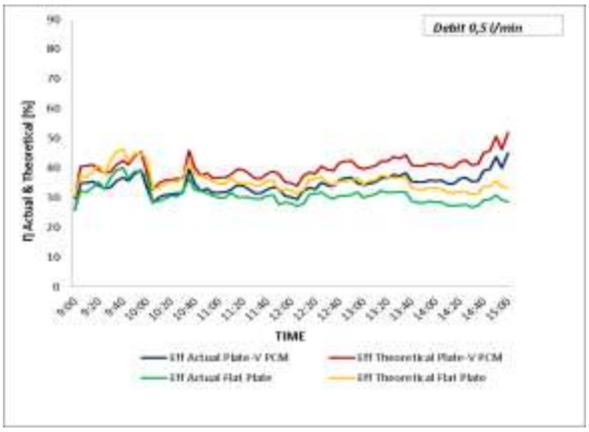


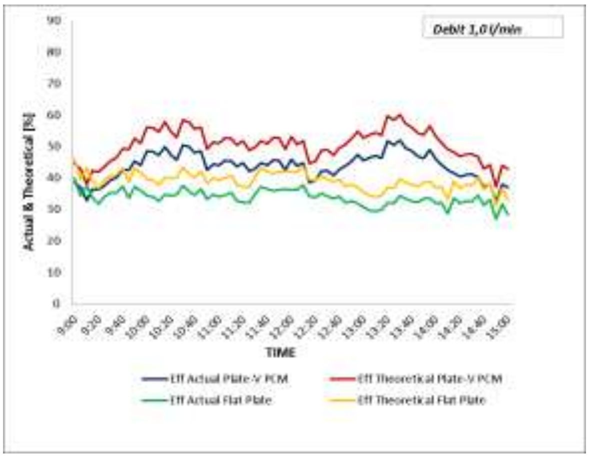
Figure 5. Inlet and outlet water temperatures of the collector with flowrates of 0.5, 1.0 and 1.5 L/min

The efficiencies of the collector with V-shaped absorber plate integrated with PCM storage using stearid acid and the collector with flat plate absorber are shown in Figure 6. Table 2 shows the average collector's efficiency from 09:00 AM to 3:00 PM (local time) with flowrates of 0.5, 1.0 and 1.5 L/min respectively. The actual efficiency of the collector with V-shaped absorber plate integrated with PCM storage for each flowrates is 34.6% (0.5 L/min), 43.7% (1.0 L/min) and 60.0% (1.5 L/min). The actual efficiency of the collector with flat plate absorber is 30.9% (0.5 L/min), 33.8% (L/min) and 48.7% (1.5 L/min). In addition, the theoretical efficiency of the collector with V-shaped absorber plate integrated with PCM storage for each flowrates is 40.1% (0.5 L/min), 50.6% (1.0 L/min) and 69.4% (1.5 L/min). The theoretical efficiency of the collector with flat plate absorber is 35.8% (0.5 L/min), 39.1% (L/min) and 56.3% (1.5 L/min).

Data : September 30, 2017 (flowrate of 0.5 L/min)



Data : October 01, 2017 (flowrate of 1.0 L/min)



Data : October 02, 2017 (flowrate of 1.5 L/min)

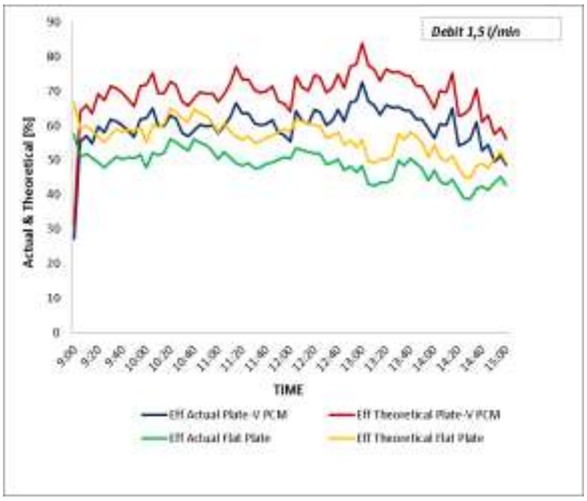


Figure 6. Efficiencies of collector with V-shaped absorber plate with PCM storage using stearid acid and flat plate absorber

Table 2. The average collector's efficiency actual and theoretical

Date	Flowrate (L/min)	Average actual efficiency (%)		Average theoritical efficiency (%)	
		Time: 09.00 AM – 03.00 PM (local time)			
		PCM storage	Flat-plate absorber	PCM storage	Flat-plate absorber
30-Sep-17	0.5	34.6	30.9	40.1	35.8
1-Oct-17	1.0	43.7	33.8	50.6	39.1
2-Oct-17	1.5	60.0	48.7	69.4	56.3

DISCUSSION & CONCLUSIONS

Based on the comparison of the thermal performance as mention in Figure 6, the performance of SWH increases with using V-shaped absorber plate with PCM storage compared with that of using flat plate absorber. The result shows an increase in actual performance of solar water heater with using PCM storage of 3.7% for flowrate 0.5 L/min, 9.9% for flowrate 1.0 L/min and 11.3% for flowrate 1.5 L/min.

Increasing the performance of the SWH is due to reducing the top energy losses and providing energy transfer to the water from PCM storage. Using the V-shaped absorber plate increasing the absorber plate temperature. PCM storage will absorb energy from the absorber plate and storage it. The energy transfer to the water in pipe not only from the absorber plate but also from the PCM storage. This fact proves that the performance of the solar water heater with PCM storage is higher than that of with flat plate absorber.

Finally, SWH with modification of the absorber plate integrated with PCM storage have been developed. In order to investigate its performance, experimental test of two SWHs using V-shaped absorber plate with PCM storage and flat plate absorber without using PCM storage was carried out simultaneously. Based on the performance investigation of the two SWHs, it is concluded that using V-shaped absorber plate integrated with PCM storage (stearid acid) enhances the performance of the solar water heater. The performance of solar water heater with PCM storage increases of 3.7 %

in the low flowrate (0.5 L/min) and of 9 to 11 % in the high flowrate (1.0 to 1.5 L/min). This result will be a valuable information for SWH application.

The amount of PCM based on mass needs to be detailed simulated in the future study to obtain the configuration between the amount of PCM and collector area that provide an optimal performance.

ACKNOWLEDGEMENT

This research is supported and financed by the Institute of Research and Community Services of Hasanuddin University.

REFERENCES

[1] ASHRAE. *ASHRAE Handbook: HVAC Applications, SI Edition.* "American Society of Heating, Refrigerating and Air-Conditioning Engineers", Inc. 1791 Tullie Circle, N.E., *Atlanta* GA 30329. 2011

[2] Ayompe, L.M., Duffy, A.. "Analysis of the thermal performance of a solar water heating system with flat plate collectors in a temperate climate". *Applied Thermal Engineering*, Vol. 58, no.1-2, pp. 447-454. 2013

[3] Jafarkazemi, F., Ahmadifard, E., "Energetic and exergetic evaluation of flat plate solar collectors". *Renewable Energy*, Vol. 56, pp. 55-63. 2013

[4] Subiantoro, A., Ooi, K.T. "Analytical models for the computation and optimization of single and double glazing flat plate solar collectors with normal and small air gap spacing". *Applied Energy*, Vol. 104, pp. 392-399. 2013

[5] Deng, Y., Zhao, Y., Wang, W., Quan, Z., Wang, L., Yu, D. "Experimental investigation of performance for the novel flat plate solar collector with micro-channel heat pipe array (MHPA-FPC) ". *Applied Thermal Engineering*, Vol. 54, no.2, pp. 440-449. 2013.

[6] Mintsa Do Ango, A.C., Medale, M., Abid, C. "Optimization of the design of a polymer flat plate solar collector". *Solar Energy*, Vol. 87, pp. 64-75. 2013.

[7] Yang, Y., Wang, Q., Xiu, D., Zhao, Z., Sun, Q., "A building integrated solar collector: All-ceramic solar collector". *Energy and Buildings*, Vol. 62, pp. 15-17. 2013.

[8] Jalaluddin, Arif, E., Tarakka, R. "Experimental Study of an SWH System with V-Shaped Plate". *Journal of Engineering and Technological Sciences*, Vol. 48, no.2, pp. 207-217. 2016.

[9] Fazilati, M.A., Alemrajabi, A.A. "Phase change material for enhancing solar water heater, an experimental approach". *Energy Conversion and Management*, Vol. 71, pp. 138-145. 2013.

[10] Bouadila, S., Fteïti, M., Oueslati, M.M., Guizani, A., Farhat, A. "Enhancement of latent heat storage in a rectangular cavity: Solar water heater case study". *Energy Conversion and Management*, Vol. 78, pp. 904-912. 2014.

[11] Al-Kayiem, H.H., Lin, S.C. "Performance evaluation of a solar water heater integrated with a PCM nanocomposite TES at various inclinations". *Solar Energy*, Vol. 109, pp. 82-92. 2014.

[12] Huang, K., Feng, G., Zhang, J. "Experimental and numerical study on phase change material floor in solar water heating system with a new design". *Solar Energy*, Vol. 105, pp. 126-138. 2014.

[13] Mahfuz, M.H., Anisur, M.R., Kibria, M.A., Saidur, R., Metselaar, I.H.S.C. "Performance investigation of thermal energy storage system with Phase Change Material (PCM) for solar water heating application". *International Communications in Heat and Mass Transfer*, Vol. 57, pp. 132–139. 2014.

[14] Allouhi, A., Msaad, A.A., Amine, M.B., Saidur, R., Mahdaoui, M., Kousksou, T., Pandey, A.K., Jamil, A., Moujibi, N., Benbassou, A. "Optimization of melting and solidification processes of PCM: Application to integrated collector storage solar water heaters (ICSSWH) ". *Solar Energy*, Vol. 171, pp. 562-570. 2018.

[15] Wu, W., Dai, S., Liu, Z., Dou, Y., Hua, J., Li, M., Wang, X., Wang, X. "Experimental study on the performance of a novel solar water heating system with and without PCM". *Solar Energy*, Vol. 171, pp. 604–612. 2018.

[16] Wang, Z., Qiu, F., Yang, W., Zhao, X. "Applications of solar water heating system with phase change material". *Renewable and Sustainable Energy Reviews*, Vol. 52, pp. 645-652. 2015.