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# Performance Investigation of Solar Water Heating System with V-Shaped Absorber Plate Integrated PCM Storage

Jalaluddin[1], Rustan Tarakka[1], Muhammad Rusman[2], Andi A. Mochtar[1]

**Abstract** – *The use of solar energy source using Solar Water Heating (SWH) system for hot water supply is increasing due to environmentally friendly technology. The increase of the application of solar energy equipment is beneficial for technology development related to the issue of sustainable energy and green energy buildings. This study develops a SWH system for hot water supply with modification of absorber plate. An integrated V-shaped absorber plate with phase change material (PCM) energy storage in the SWH system has been installed and its performance has been investigated experimentally. Two SWH systems consisting of V-shape absorber plate with and without PCM storage are built. The V-shape absorber plate is constructed and integrated with PCM storage in the system. The experimental tests of the two SWH systems using V-shaped absorber plate with and without PCM storage have been carried-out in the same operation time with various flowrates. The temperature of the paraffin has increased until the melting temperature and has decreased with the decrease of solar radiation in the afternoon. Paraffin as PCM storage contributes to increase the outlet water temperature. The results show that the average efficiency of the SWH system with PCM storage using paraffin is higher than the one of the SWH system without PCM storage. It has increased significantly of 20%, 14% and 13% with flowrates of 0.5; 1 and 1.5 L/min respectively. In addition, the characteristics of the PCM storage are shown clearly from 16:00 to 20:00 local time. After 16:00 local time, the storage energy can be a source of heat energy to heat the water up to the end of the day.* 

***Keywords**: Solar Water Heater System, V-Shaped Absorber Plate, Phase Change Material (PCM), Efficiency*

## Nomenclature

| | |
|---|---|
| $Q_u$ | Useful energy |
| $\dot{m}$ | Mass flow rate |
| $c_p$ | Specific heat |
| $\Delta T$ | Temperature difference |
| $I_T$ | Solar radiation |
| $A_c$ | Surface area |
| $\eta$ | Collector efficiency |
| $Q_{u,s}$ | Storage energy |
| $\beta$ | Slope angle of plate |
| $t,l$ | V-shaped dimension |

## I. Introduction

The focus on equipment that utilizes solar energy is increasing because this energy source is environmentally friendly with zero pollution and it is renewable [1]. Solar Water Heating (SWH) system as one of solar energy equipment is potentially developing in Indonesia for energy saving purpose especially for application in residential, commercial, and industrial buildings.

Researches on SWH system with flat-plate collector have been done to analyze its performance. Ayompe and Duffy [2] have investigated the thermal performance of SWH system in temperate climate over a year. Jafarkazemi and Ahmadifard [3] have conducted an analysis of energy and exergy of flat-plate collector. In addition, Subiantoro and Tiow [4] have investigated the performances of flat-plate collector with 1 and 2 glass covers and Deng et al. [5] have applied a micro-channel heat pipe in the solar collector. Using material such as Copper and Aluminum provides a good performance of collector but they are expensive. The thermal performance of a parabolic trough concentrator (CCP) by using mathematical modelling and their respective simulations on ray optics and heat transfer have been investigated by Palacios et al. [6]. Solar water collector using Polymer has been studied by Mintsa Do Ango et al. [7] by numerical simulation in order to optimize the design of Polymer solar water heater. Yang et al. [8] have utilized ceramics from ordinary ceramic and V–Ti black ceramic for flat-plate solar collector integrated with building. The use of V-shape absorber plate on solar water heater collector has been tested experimentally and compared with the one of conventional flat-plate absorber. The absorptivity of the V-shaped plate absorber has been better than the flat-plate absorber but top energy losses also have increased. The performance of the collector with the V-shape absorber plate compared with the one of flat-plate absorber has increased by 2.36% in the low flowrate of 0.5 L/min and 4.23% in the high flowrate of 2 L/min [9]. In order to enhance the thermal performance, solar water heating system is integrated with phase change material (PCM) thermal storage. Bouadila et al. [10] have conducted an experimental study of PCM storage using paraffin integrated on flat-plate collectors. The effects of PCM as storage medium in a SWH system have been experimentally investigated by Fazilati & Alemrajabi [11].

In this study, paraffin is used as PCM in spherical capsules as a storage material in the water heater tank. Using PCM in the tank increased the energy storage density up to 39% and the exergy efficiency up to 16%. Kayiem & Lin [12] have conducted an investigation on a flat plate solar collector integrated with Thermal Energy Storage (TES). The TES system consists of paraffin wax PCM and nanocomposite of paraffin wax. In addition, shell and tube TES using paraffin wax in a SWH system [13], domestic type of chromium flat plate solar water collector with PCM [14] and a V-corrugated absorber integrated with PCM storage in a solar distillation system [15] have been investigated. A review of the application of solar water heating systems with phase change material has been conducted comprehensively by Wang et al. [16].

Recently, Integrated Collector Storage Solar Water Heater (ICSSWH) [17] and energy storage solar collector with inserted oscillating heat pipe [18] have been studied to analyse the performance of SWH system. Wu et al. [19] have studied that solar water heating system with PCM can overcome the effect of the fluctuation of solar radiation. The collecting efficiency fluctuation with PCM is over 30% less than the one without PCM. Alwan et al. [20] have studied experimentally the effect of PCM energy storage in a basin solar still and have showed that the ratio of water productivity has increased 32% by the PCM energy storage. A flat-plate collector system using the PCM to store up a thermal energy during the daytime and release the energy during the night to prevent the FPSCs from freezing damage has been studied by Zhou et al. [21]. In addition, Palacio et al. [22] have conducted a comparative experimental analysis of a conventional flat-plate solar collector and an identical prototype with PCM thermal storage. The improvement performance of SWH by using PCM storage has been showed. Using PCM storage integrated to the absorber plate can improve the performance of SWH system as discussed previously.

This research presents a development of SWH system with using V-shaped absorber plate by modification of V-shaped absorber plate integrated with PCM storage using paraffin wax. Previous research related to this research is covered in introduction section. The next sections discuss the SWH system integrated with PCM storage, the experimental method, and collector efficiency. Experimental tests of two SWH systems with and without PCM storage have been carried out by operating both the SWH simultaneously. In the section result and discussion, effect of using PCM storage to the performance of SWH system with V-shaped absorber plate in the daytime and energy storage is discussed. The amount of heat stored in the PCM storage will reduce the top collector's energy loss. In this view, the SWH system using V-shaped absorber plate integrated with PCM storage is developed to enhance the thermal performance of the SWH system.

The modification of the absorber plate integrated with PCM storage is constructed to maximize energy absorbed by the absorber plate and heat transferred to the fluid. The collector efficiency, the characteristics of the PCM storage and further improvements for future development are presented in the conclusion section.

## II. SWH System with PCM Storage

SWH system is a heat exchanger that converts solar energy into thermal energy through water circulation.

Solar energy radiation is absorbed by the absorber plate and it is transferred to water. Furthermore, hot water produced by the SWH system is used for the needs of hot water supply in residential, commercial, and industrial buildings. The modification of the V-shaped absorber plate integrated with PCM storage as shown in Figure 1 has been performed in this study. This type of plate absorber has been used in the SWH system for experimental test.

## III. Experimental Set-Up

The experimental tests of two SWH systems have been carried out in the same operation time. The two SWH systems consist of V-shaped absorber plate: with PCM storage and without PCM storage as shown in Figure 2.

V-shaped absorber plate with PCM storage can be seen in Figure 3.

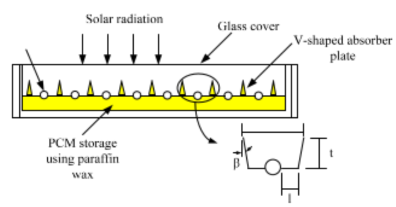



Fig. 1. V-shaped absorber plate integrated with PCM storage

Fig. 2. SWH system using V-shaped absorber plate: on the left, with PCM storage and on the right, without PCM storage

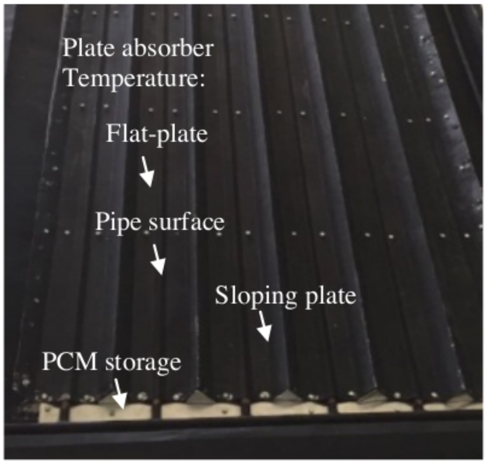



Fig. 3. V-shaped absorber plate with PCM storage

## IV. Collector Efficiency

The collector performance is determined by the collector efficiency obtained from the comparison of the useful energy through the hot water and available solar energy radiation. The useful energy, $Q_u$, is calculated based on the measurement data of inlet and outlet water temperature as follows:

$$Q_u = \dot{m} c_p \Delta T \quad (1)$$

where $\dot{m}$ is the mass flow rate (kg/s), $c_p$ is the specific heat (J/kg K) and $\Delta T$ is the temperature difference of inlet and outlet (°C).

Collector efficiency, η:

$$\eta = \frac{Q_u}{I_T A_c} \quad (2)$$

where $I_T$ is solar radiation (W/m$^2$) and $A_c$ is surface area of the collector (m$^2$). In the case of the SWH using V-shaped absorber plate integrated with PCM storage, hot water could be still produced after solar radiation is zero due to the available storage energy. The storage energy, $Q_{u,s}$, is calculated by using Eq. (1).

## V. Results and Discussion

This research has been conducted at the Renewable Energy Laboratory of Mechanical Engineering Department of Hasanuddin University, Gowa (119° 30' 06.1" E and 05° 13' 52.4" S). Experimental tests of two SWH systems with and without PCM storage have been carried out by operating both the SWH simultaneously.

The dimension of the collector is 163 cm length and 100 cm width. Water flows in copper tube with 0.017 m diameter and flowrates have been set to 0.5 L/min, 1 L/min and 1.5 L/min. Data has been recorded every 5 minutes from 09.00 to 20.00 local time.

### V.1. Solar Radiation

The intensity of the solar radiation during the experimental test had a minimum value in the morning and afternoon as well as a maximum value in the daytime as shown in Figure 4. The maximum solar radiation is 922 W/m$^2$ at 11:45 local time (6 Sept 2017), 856 W/m$^2$ at 11:35 local time (9 Sept 2017) and 942 W/m$^2$ at 11:55 local time (10 Sept 2017).

### V.2. Water, Ambient and Paraffin Temperatures

Figs. 5 show the temperatures of inlet and outlet water, ambient and Paraffin. The water inlet in both the SWH is circulated from the same reservoir and it had the same temperature. The outlet water temperature in the SWH using V-absorber plate with paraffin is higher than that of without Paraffin. Paraffin as PCM storage contributes to increase the outlet water temperature. The temperature of the paraffin has increased until the melting temperature and has decreased with the decrease of the solar radiation in the afternoon.

### V.3. Surface Temperatures of Absorber Plate

Surface temperatures of the absorber plate have been measured at flat-plate, pipe surface, and sloping plate as shown in Figure 3. The surface temperatures of the absorber plate are shown in Figs. 6. The temperature of the absorber plate with paraffin is higher than the one without paraffin. This shows the effect of the paraffin temperature on the absorber plate.

### V.4. Collector Efficiency

The efficiencies of the SWH with the V-shaped absorber plate with and without Paraffin are shown in Figs. 7. The collector efficiency of the SWH with paraffin is higher than the one without paraffin. The efficiency of SWH with paraffin tends to increase in operation time.

The storage energy in the paraffin helps to increase the transferred energy to the water.

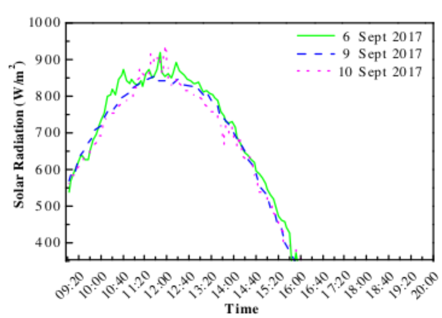
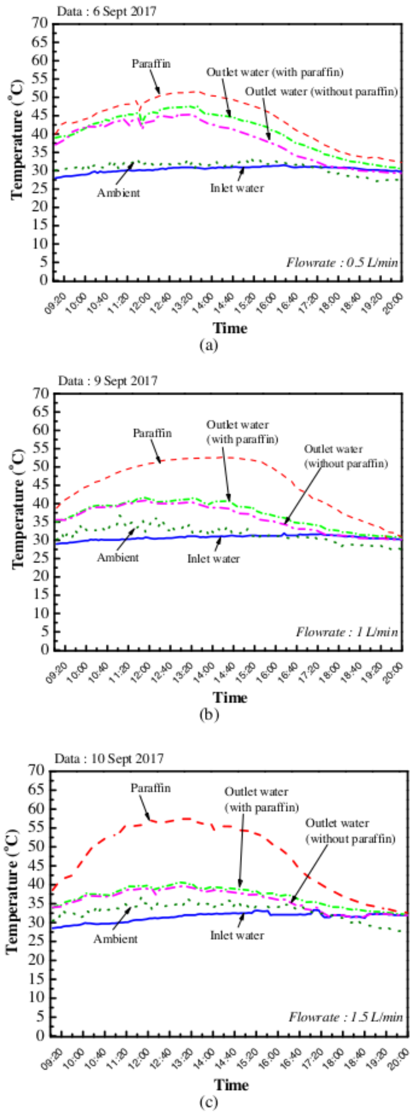


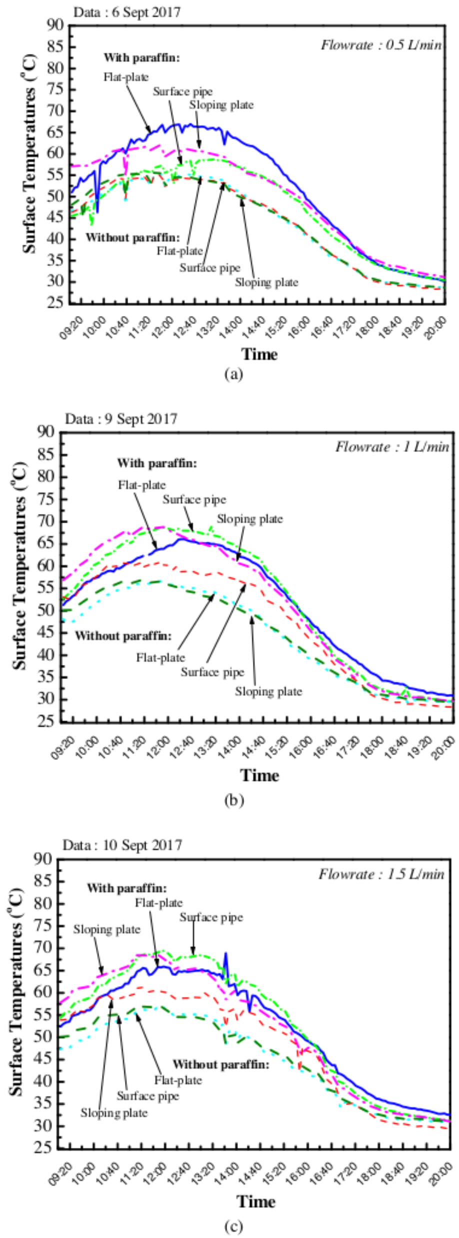

Fig. 4. Solar Radiation




Figs. 5. Water, ambient and paraffin temperatures

Table I shows the average efficiency of the collectors from 09:00 to 16:00 local time with flowrates of 0.5; 1 and 1.5 L/min.

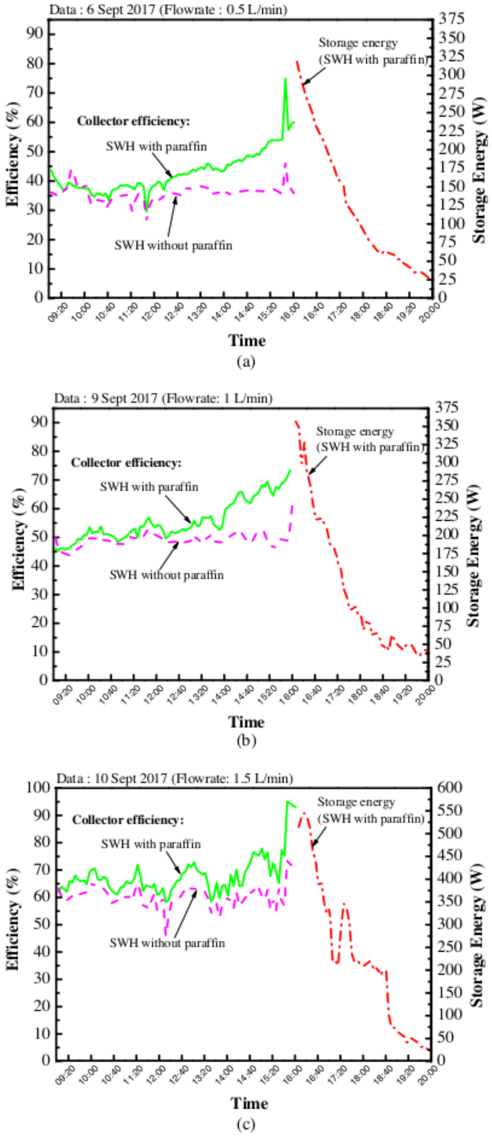
The average collector efficiencies of SWH with paraffin are 43, 56 and 68% respectively. For SWH without Paraffin, the average efficiencies are 36, 49 and 60% respectively. It shows an increase in collector efficiency due to the PCM storage of 20% (0.5 L/ min), 14% (1 L/min) and 13% (1.5 L/min). In addition, the storage energy by PCM storage is still available from 16:00 to 20:00 local time as shown in Figs. 7. The average storage energies from the collector with paraffin are 121 W (0.5 L/min), 127 W (1 L/min) and 225 W (1.5 L/min).




Figs. 6. Surface temperature of absorber plate on collector with paraffin and without paraffin

TABLE I
COLLECTOR EFFICIENCY AND STORAGE ENERGY

| Flowrate (L/min) | Average collector efficiency (%) (09.00-16.00 local time) | | Average storage energy (W) (16.00-20.00 local time) |
|---|---|---|---|
| | With paraffin | Without paraffin | |
| 0.5 | 43 | 36 | 121 |
| 1 | 56 | 49 | 127 |
| 1.5 | 68 | 60 | 225 |




(a)

(b)

(c)

Figs. 7. Collector efficiency of SWH with V-shaped absorber plate with and without paraffin

## VI. Conclusion

The development of SWH system using V-shaped absorber plate by modification of V-shaped absorber plate integrated with PCM storage using paraffin wax has been conducted. In order to analyze its performance, experimental tests of two SWH systems using V-shaped absorber plate with and without PCM storage have been carried out by operating both the SWH simultaneously in the same operation time with various flowrates.

The average collector efficiencies of SWH system with and without PCM storage from 09:00 to 16:00 local time with flowrates of 0.5; 1 and 1.5 L/min have been presented.

The efficiencies of SWH with PCM storage are 43, 56 and 68% respectively. For SWH without Paraffin, the average efficiencies are 36, 49 and 60% respectively.

These results show an increase of collector efficiency due to the PCM storage of 20% (0.5 L/ min), 14% (1 L/min) and 13% (1.5 L/min). The characteristics of the PCM storage are shown clearly from 16:00 to 20:00 local time. The average storage energies for the SWH system with PCM storage are 121, 127 and 225 W with flowrates of 0.5; 1 and 1.5 L/min respectively. The effect of PCM storage volume should be considered and it may become an interesting topic for further study.

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