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Study of Solar Water Heater Using Absorber Plate Integrated with Composite Thermal Storage

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Abstract. An absorber plate from Solar Water Heating System (SWHS) is the primary tool to absorb solar energy. Thermal energy storage receives special attention in solar energy applications, including high energy storage performance and energy conversion efficiency. A combination of absorber plate of the SWHS with thermal energy storage (TES) material aims to evaluate its performance. TES composite (TESC) is a Metal Matrix Composite (MMC) made of alumina (Al_2O_3) and pure aluminium (Al) composite material with a thickness of 15 mm. It is placed under the absorber plate to store heat energy before being transferred to the water and reduce top heat losses. Experimental tests were carried out by testing two models of absorber plates on a solar thermal energy unit with similar conditions. The first model is a standard flat-plate (SFP) absorber without TES composite. The second model combines standard flat-plate absorber and TES composite (SFP-TESC) placed under the SFP absorber. Each model was tested in the solar thermal energy unit for 2 (two) hours with the first 1 hour, the heat source is ON, and the next 1 hour is OFF. The results show that the average efficiency of the SFP model with various flow rates is 74.90% (8 L/h), 73.02% (10 L/h) and 69.23% (12 L/h). Meanwhile, the average efficiency of the SFP-TESC model with various flow rates is 67.10% (8 L/h), 68.43% (10 L/h), and 67.60% (12 L/h). Increasing the energy stored transferred to the circulating water can help to improve the efficiency of the SFP-TESC model.

INTRODUCTION

Energy policy supports renewable energy sources such as wind, hydro and solar energy. The solar energy field receives special attention in thermal applications due to its high energy storage performance and energy conversion efficiency [1]. The design of a Thermal Energy Storage (TES) system must meet the requirements of high energy density in the storage material (storage capacity), good heat transfer between the fluid and storage material, mechanical and chemical stability of the storage material, low heat loss during storage time, and easy control [2]. Thermal energy is stored in solids as sensible heat. This type of storage allows higher storage temperatures and can solve the problem of high-pressure liquid media [3]. Sensible heat storage materials are a group of materials that do not experience a temperature phase change during the storage process. The ability of a material is very dependent on the value of energy density or heat capacity per unit volume.

A TES material is essential if it is inexpensive and has good thermal conductivity [4]. The most commonly used is solid-state thermal storage materials include sand-rock minerals, concrete, fire bricks, and ferroalloy materials [5]. In addition, TES material is also made of metal matrix composite (MMC) or Ceramic matrix composite (CMC).

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Composite materials are essential and effective in many industrial engineering applications due to their physical and thermal properties. The thermal properties of materials are related to heat energy and its response—thermal properties such as heat capacity, thermal expansion, and thermal conductivity [6].

One type of MMC is Aluminium (Al)-Alumina (Al_2O_3) composite. Aluminium is a matrix material widely used in composites because of its lightweight, low cost, and easy fabrication. The preferred reinforcement in the MMC should have a high modulus, low density, good wettability, proper shape with a specific aspect ratio to minimize stress concentration, and a coefficient of thermal expansion comparable to that of the metal matrix to reduce the development of internal stresses due to temperature changes. The reinforcements of the MMC are oxides or carbides, and the most widely used are alumina (Al_2O_3) or silicon carbide (SiC) and graphite [7]. Composite materials, especially solar water heaters, are still being developed as a storage medium in solar thermal energy applications. Several studies for absorber and storage materials, including metal foam [8], ceramic [9], and ceramic foam [10], have been investigated. As a heat-enhancing material, metal foam can generally improve the heat transfer process and collector efficiency [11, 12]. Combining metal foam with phase change material (PCM) will further enhance collector performance [13, 14]. Another collector material being developed is an absorber coated in black V-Ti ceramic. The thermal efficiency of the solar ceramic collector is relatively above 50% [15]. This collector has advantages such as low cost, long lifetime, no attenuation of absorptivity, and building integration [9]. However, the collector's characteristic indicates high heat losses [16].

The development of solar water heaters has been carried out at the Renewable Energy Laboratory of Hasanuddin University. Investigating the possibility of producing hot water using a hybrid system with a ground source cooling system has been carried out [17–19]. The use of a V-shaped absorber plate indicates an increase in the absorptivity of the absorber plate [20]. It can be integrated with various PCM materials such as paraffin wax [21]. The study showed that using V-shaped absorber plates and PCM storage improved collector performance. However, the difficulties encountered in the construction of PCM storage problems due to fluid leakage reduce the simplicity of the design. To improve construction simplicity, using solid Thermal Energy Stored Composite material as storage energy should be considered.

The combination of absorber plates with solid TES composite (TESC) can be applied in the application of solar water heaters. The TESC can store excess heat from the absorber plate before being transferred to circulating water. The heat stored in the TESC is expected to be transferred to the circulating water when the heat source is slowly reduced. This research studies absorber plates integrated with TESC in the solar water heating system (SWHS). Experimental tests were conducted by testing two models of absorber plates with and without TESC on a solar thermal energy unit with similar conditions.

EXPERIMENTAL SETUP

This research was conducted at the Renewable Energy Laboratory of Hasanuddin University, Indonesia (119 30' 6.1" BT and 5 13' 52.4" LS). Testing equipment using a solar thermal energy unit is shown in figure 1. The experimental setup can be seen in Figure 2. The test section is a rectangular box filled with absorber plates and storage materials. There are two (2) absorber modification models tested, namely 1) Standard flat-plate (SFP) model 2) SFP model with Aluminium-Alumina Composite (SFP-TESC). Testing was conducted by running the solar energy unit for 2 hours for each model. Recorded data were collected during testing with an interval of 1 minute automatically. The recorded data include artificial solar intensity, inlet and outlet fluid temperatures, and flow rate.

FIGURE 1. Solar thermal energy unit

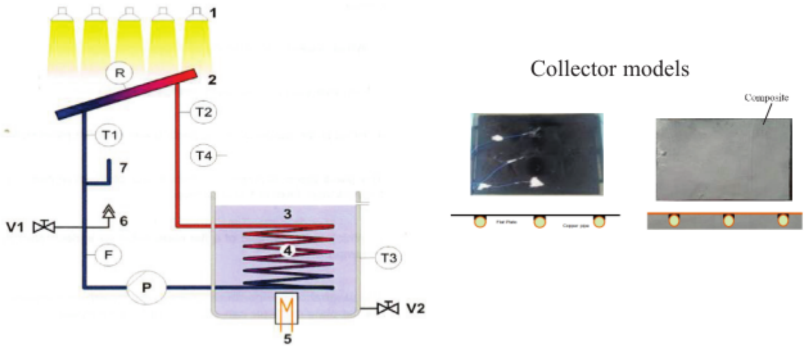


FIGURE 2. Experimental setup

THERMAL PERFORMANCE

The collector's performance is determined by the collector's efficiency, which is obtained from comparing the useful energy of the collector through heating water and available solar energy. The useful energy, Q_u is calculated based on the temperature measurement data of the inlet and outlet water of the collector specified as following

$$Q_u = \dot{m}\, C_p\, (T_{f,o} - T_{f,i}) \quad (1)$$

$\dot{m}$ is the mass flow rate (kg/s), C_p is the specific heat (kJ/kg.K) and $T_{f,o}$ is the temperature of the fluid leaving the collector (°C), and $T_{f,i}$ is the temperature of the fluid entering the collector (°C).
The collector efficiency is as follows

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

I_T is the solar intensity (W/m^2), and A_C is the collector surface area (m^2).

RESULTS AND DISCUSSION

Experimental tests were carried out by testing for each model of absorber plate on the solar thermal energy unit with similar conditions. Recorded data were collected automatically. Figure 3 shows the radiation intensity in the testing for each model at various fluid flow rates of 8 L/h, 10 L/h, and 12 L/h. The radiation intensity given by the heat source and received by the absorber plate tends to be constant over time when the heat source is set ON. After the heat source is set OFF, the radiation intensity becomes zero. The radiation intensity of the SFP and TESC models tend to be similar, approximately 1.3 -1.4 kW/m^2.

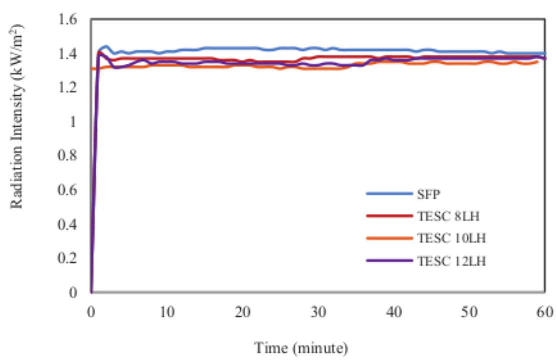


FIGURE 3. Radiation intensity

Inlet and outlet water temperatures from the collector model are shown in figure 4. Water was circulated from the storage tanks in a closed system. The inlet water temperature tends to increase as the water temperature in the storage tank increases. Heat transfer from the absorber plate and storage material to the fluid will continue to grow as long as the heat source is working. After the heat source is stopped, the heat stored in the plate and storage material will slowly decrease until the inlet, and outlet water temperatures are identical. The SFP model tends to have a higher outlet temperature than the TESC models. The addition of composite material at the bottom as a storage material significantly increases the heat absorption process from the absorber plate. In addition, the heat storage time is longer than the SFP model, even though the output temperature is lower. The maximum exit water temperature in the TESC model is around 44.2 ºC at a flow rate of 8L/h. This result is higher than paraffin at approximately 35-40 ºC [26]. A higher outlet temperature is obtained by using asphalt on the absorber with a value of 52ºC with an inlet water temperature of 36ºC [27]. However, in the TESC model, the stored heat is not entirely transferred to the circulating water. The thickness factor of the composite material also reduces the heat transfer to the circulating water. However, the stored heat is not entirely transferred to the circulating water. The thickness factor of the composite material also reduces the heat transfer to the circulating water.

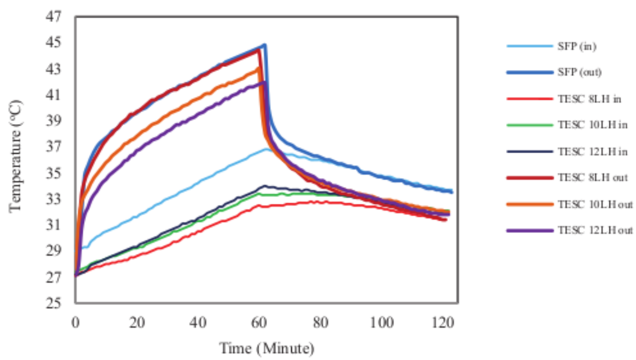
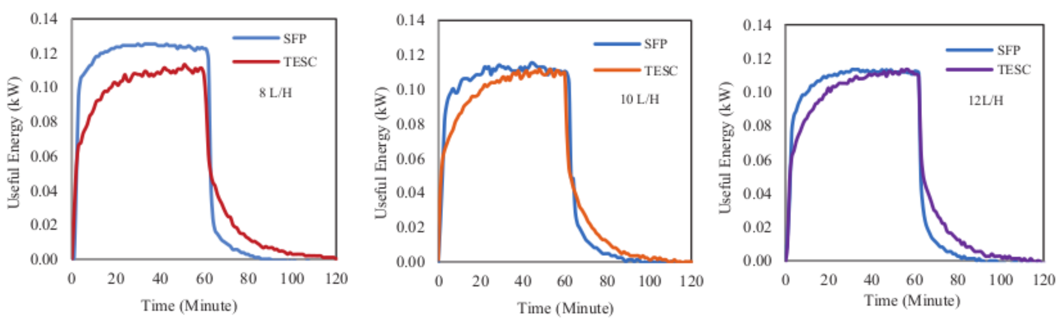


FIGURE 4. Inlet and outlet water temperature of the collector models

The useful energy by transferring heat to circulating water is shown in figure 5. When the heat source is set ON, the useful energy transferred to circulating water in the SFP model is about 0.11-0.12 kW at all water flow rates. The valuable power of the SFP model is 0.1253 kW (maximum) when its flow rate is 8 L/h and 0.1134 kW (minimum) when its flow rate is 12 L/h. In addition, the useful energy transferred to circulating water of the TESC model is approximately 0.11 kW at all flow rates. After the heat source is set OFF, the valuable energy stored in the absorber plate of the SFP model decreases highly. As a comparison, the useful energy in the TESC model has a significant difference using a combination of asphalt with an average value of 100-380 kW [27]. However, the useful energy of the circulated water of the TESC model is still available when the heat source is set OFF. It is shown that TESC materials are effective enough in storing heat energy for a longer time. However, the heat transfer from storage material to circulating water is not large enough.



(a) (b) (C)

FIGURE 5. Useful energy

The thermal efficiency of the collector models is shown in figure 6. The thermal efficiency of the SFP model is higher than that of the TESC model at flow rates of 8 L/h and 10 L/h. However, the thermal efficiency of the TESC model shows an increase and is higher than that of the SFP model. The average thermal efficiency of the TESC model at 8 L/h, 10 L/h and 12 L/h are 67.14; 68.43 and 67.60 %, respectively. The collector efficiency increases and is more stable after 20 minutes when the heat source is ON. The efficiency obtained in the TESC model research is similar to the paraffin combination model with an average of 68% [26], model A dual-function solar heating system (DFSHS) around 60-75% [25]. At the same time, the combination model with asphalt material efficiency is in the range of 70-79% [27]. However, The addition of TESC material at the bottom of the absorber plate increases the amount of heat stored in the TESC for a long time. A large amount of heat stored in the TESC material becomes ineffective in transferring heat to the circulating water because the heat is only transmitted to a large area of the TESC material. The thickness of the material, which is two times the diameter of the water pipe, causes heat energy to be lost to the environment through the surface area of the material so that the useful energy is not too large.

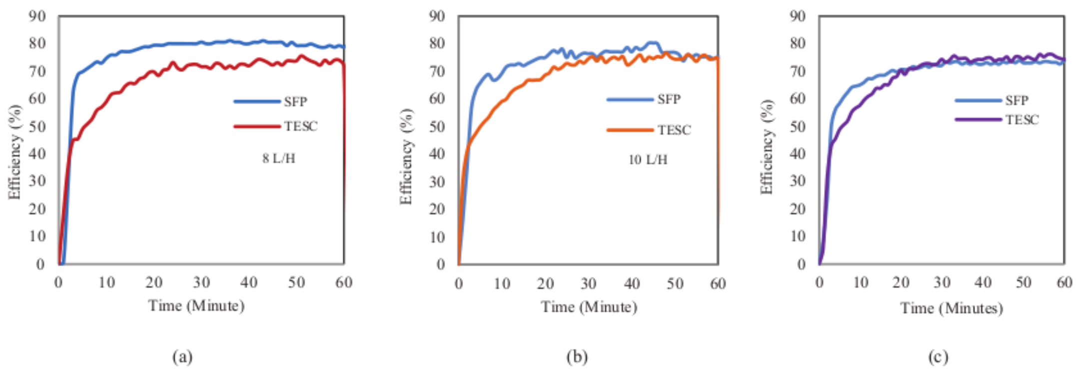


FIGURE 6. Thermal efficiency

CONCLUSION

The addition of TESC material on the bottom surface of the absorber plate on the performance of SWHS has been studied experimentally. The results show that the average thermal efficiency of the SFP model with various flow rates is 74.90% (8 L/h), 73.02% (10 L/h) and 69.23% (12 L/h). Meanwhile, the average thermal efficiency of the SFP-TESC model with various flow rates is 67.10% (8 L/h), 68.43% (10 L/h) and 67.60% (12 L/h). Increasing the energy stored transferred to the circulating water can help to improve the efficiency of the SFP-TESC model.

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