*Applied Mechanics and Materials*
*ISSN: 1662-7482, Vol. 913, pp 45-51*
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*Submitted: 2021-12-21*
*Accepted: 2022-08-11*
*Online: 2023-03-03*

# Study of Modified Absorber Plate with Aluminium Foam of Solar Water Heating System

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**Keywords:** Solar Water Heater System, Aluminium Foam, Absorber Plate.

**Abstract.** Solar water heating system (SWHS) is water heating equipment that utilizes solar energy for domestic and industrial needs. An absorber plate is the main part of the SWHS that functions to absorb solar energy. Porous materials are efficient in increasing heat transfer, energy efficiency, energy storage, and reducing reflectance losses. Efforts have been made to add aluminium foam as a porous material on the lower and upper surfaces of the absorber plate. Porous materials function absorbs heat and store radiant heat energy before being transferred to the fluid. Experimental tests were carried out by testing three models of absorber plates on a solar thermal energy unit with similar conditions. The first model is a standard flat plate (SFP) without aluminium foam. The second model combines standard flat plate and aluminium foam (SFP-TAF), placed on top of the SFP. The third model combines standard flat plate and aluminium foam (SFP-BAF), placed under the SFP. The results showed that the SFP-BAF model has a higher thermal efficiency than the other models. The SFP-BAF model has an efficiency increase of 2.71 % at a flow rate of 10 L/h and 5.39 % flow rate of 12 L/h compared with the standard model (SFP). The position of the aluminium foam at the bottom surface is substantial enough to help absorb and store radiant heat for transfer to circulating water.

## Introduction

The priority of energy policy is the utilization of renewable energy sources such as solar energy. Solar energy is used in industrial and domestic applications for water heating, water distillation, space heating, etc. The solar water heating system (SWHS) design is built-in lower operating temperatures, fewer mechanical components, and is easy to fabricate. However, the performance of the SWHS is still inadequate compared to conventional devices due to the working fluid's low operational heat transfer characteristics [1]. Recent developments in the thermo-economic performance of the SWHS include collector design, modification of the thermo-physical properties of heat transfer fluids, integrated thermal energy storage, and flat plate solar collector (FPSC) hybrid systems.

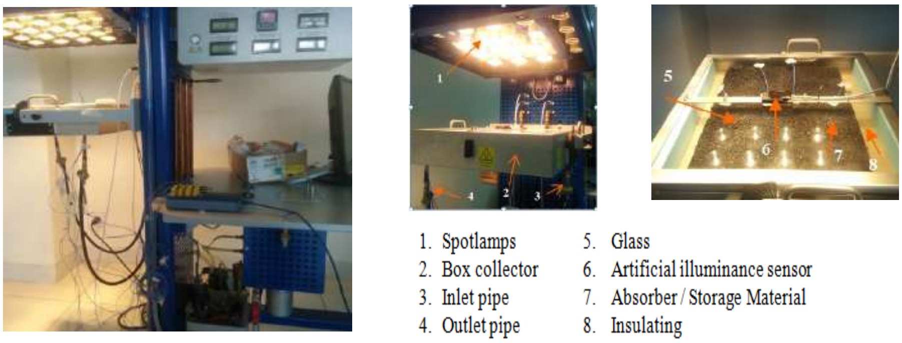
The increase in the design factor and the convective heat transfer coefficient between the fluid and the absorber material is the most desirable factor to improve the overall performance of the solar collector. Porous materials are efficient in increasing heat transfer, energy efficiency, energy storage [2], and reflectance losses [3]. The use of porous materials affects the thermal efficiency of the system, such as black steel wool fibres porous in solar still [4], aluminium foam in solar air heater [5], and copper foam in volumetric solar absorption [6].

Several researchers have studied the advantages of adding porous materials to engineering applications. The addition of absorbent material with a low volume capacity can increase higher temperatures which have a direct effect on increasing energy storage in the solar pond [7], an increase in temperature of 2-2.5 times from the initial temperature after passing through a thermal energy storage system designed from the structure metal foam and PCM [8]. In addition, the use of porous materials with agitators in solar water heaters can increase convective heat transfer, reduce thermal losses, and increase efficiency gradually [9]. The development of porous material (metal foam) in the SFP collector, especially the placement of metal foam at the bottom of the absorber plate, began to be developed. The insertion of metal foam between the absorber plate and the insulator indicates an increase in heat transfer to the collector and the thermal efficiency of the collector [10]. Combining metal foam block and PCM on the collector increases the heat transfer coefficient [11].

The development of water heating technology to produce hot water has been studied in the Renewable Energy Laboratory of Hasanuddin University. The possibility of producing hot water using a hybrid system with a ground source cooling system has been investigated [12–14]. The use of a V-shape absorber plate shown an increase in the absorptivity of the absorber plate [15] and integrated with various PCM materials such as paraffin wax [16]. These studies show that using a V-shape absorber plate and PCM storage provided better performance. However, difficulty in construction for PCM storage due to fluid leakage reduces design simplicity. To improve construction simplicity, using porous material as storage energy should be considered. This research focuses on the study of modified absorber plates with aluminium foam for energy storage. Experimental tests were carried out by testing three models of absorber plates on a solar thermal energy unit with similar conditions.

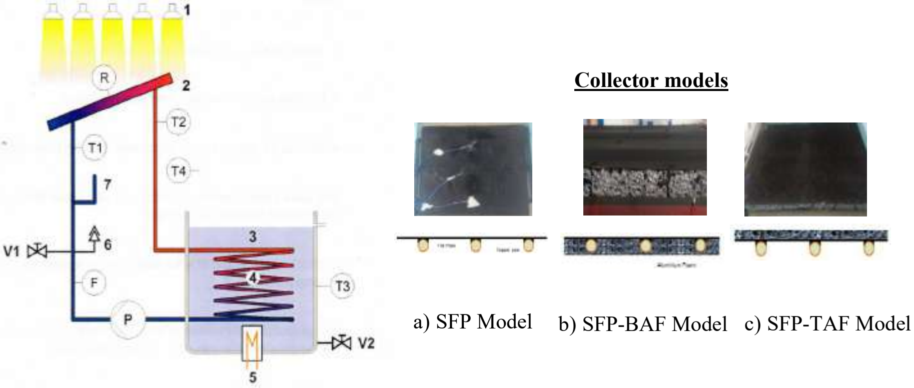
## Experimental Set-Up

This research was conducted at the Renewable Energy Laboratory of Hasanuddin University, Indonesia (1190 30' 06.1" BT and 050 13' 52.4" LS). Testing equipment using a solar thermal energy unit as shown in Fig. 1. The experimental set-up can be seen in Fig. 2. The test section is a rectangular box filled with absorber plates and storage materials. There are three (3) absorber modification models tested, namely 1) Standard Flat Plate (SFP) model, 2) SFP model with Bottom Aluminium Foam (SFP-BAF), and 3) SFP model with Top Aluminium Foam (SFP-TAF). 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.



1. Spotlamps
2. Box collector
3. Inlet pipe
4. Outlet pipe
5. Glass
6. Artificial illuminance sensor
7. Absorber / Storage Material
8. Insulating

**Fig. 1.** Solar thermal energy unit



a) SFP Model b) SFP-BAF Model c) SFP-TAF Model

**Fig. 2.** Experimental set-up

## Thermal Performance

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

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

$\dot{m}$ 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 following

$$\eta = \frac{Q_u}{I_T\, A_C} \tag{2}$$

$I_T$ 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. The testing was operated with heat source ON in 1 hour and OFF in 1 hour. Recorded data were collected automatically within 2 hours. Fig. 3 shows the radiation intensity in the testing for each model at various fluid flow rates of 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 become zero. The radiation intensity of the models tends to be similar approximately 1.3-1.4 kW/m$^2$ in the flow rate of 10 L/h. In the flow rate of 12 L/h, the radiation intensity of the SFP and SFP-TAF models is approximately 1.4 kW/m$^2$. The radiation intensity of the SFP-BAF model is approximately 1.3 kW/m$^2$.

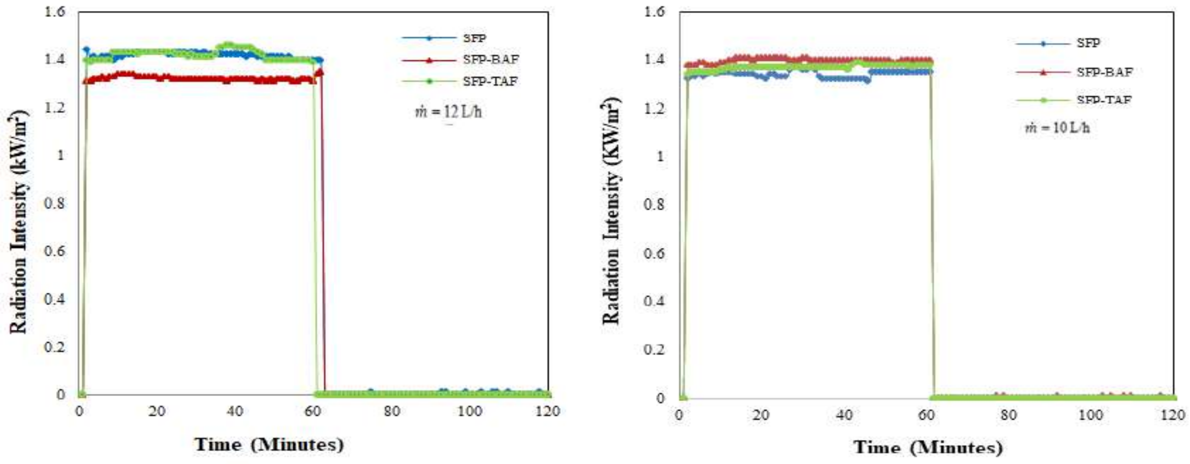


**Fig. 3.** Radiation intensity

Fig. 4 shows the relationship between the water inlet and outlet temperatures of each testing model. Circulated water flows through the storage tank with closed system. The water inlet temperature has an increasing trend as the water temperature in the storage tank increases. Radiation heat transfer from the absorber plate and storage material to the fluid will continue to increase 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 the same. The SFP-BAF model tends to have a higher outlet temperature than the other models. The addition of aluminium foam at the bottom as a storage material significantly increases the heat absorption process from the absorber plate and the heat storage time. However, the influence of fluid flow velocity also affects the increase of the outlet water temperature. If the fluid velocity increases, the outlet temperature will continue to decrease.

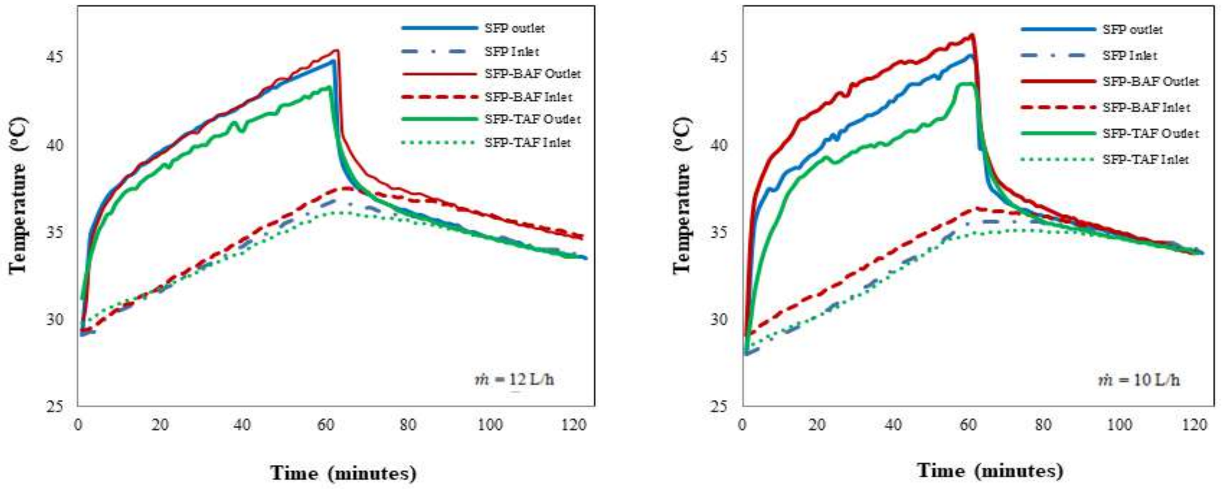


**Fig. 4.** Water temperature inlet and an outlet collector

Fig. 5. shows the surface temperature of the absorber plate and aluminium foam. The surface temperature of absorber plate and aluminium foam are measured from the amount of radiation absorbed by the upper surface and transmitted to the lower material. The SFP-TAF model has a higher temperature trend than the other models. The average surface temperature is above 90 °C, both at the flow rate of 10 L/h and 12 L/h.

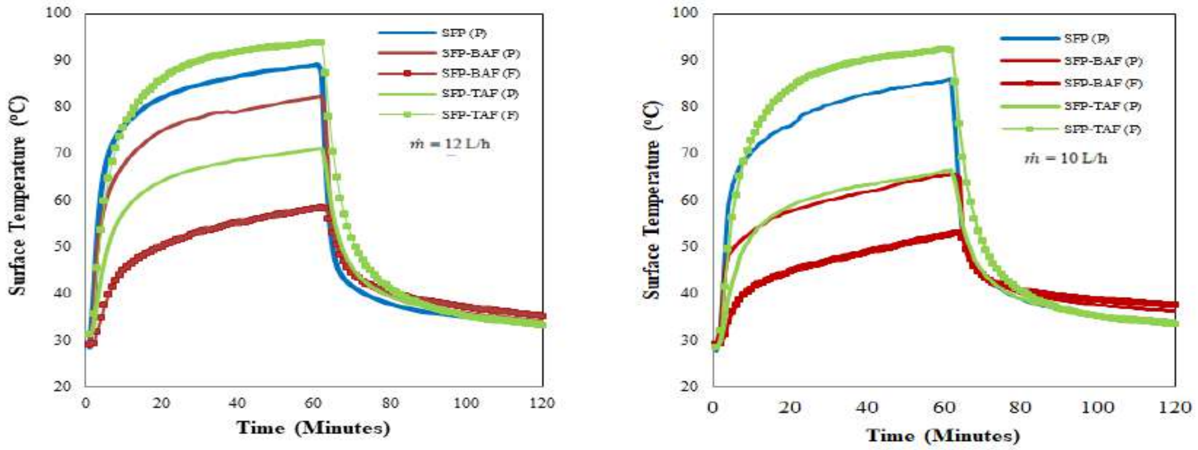


**Fig. 5**. The surface temperature of the absorber plate and aluminium foam

The placement of aluminium foam at the top in this model indicates a higher heat absorption than the flat plate. The presence of pores in the aluminium foam reduces reflected radiation, thereby increasing the absorption of radiant heat. Thus, the surface temperature of the aluminium foam increases. In the SFB-BAF model, the surface temperature of absorber plate indicates a lower temperature than other models. Its because of transferring energy to the aluminium Foam as an energy storage flaced under the absorber plate.

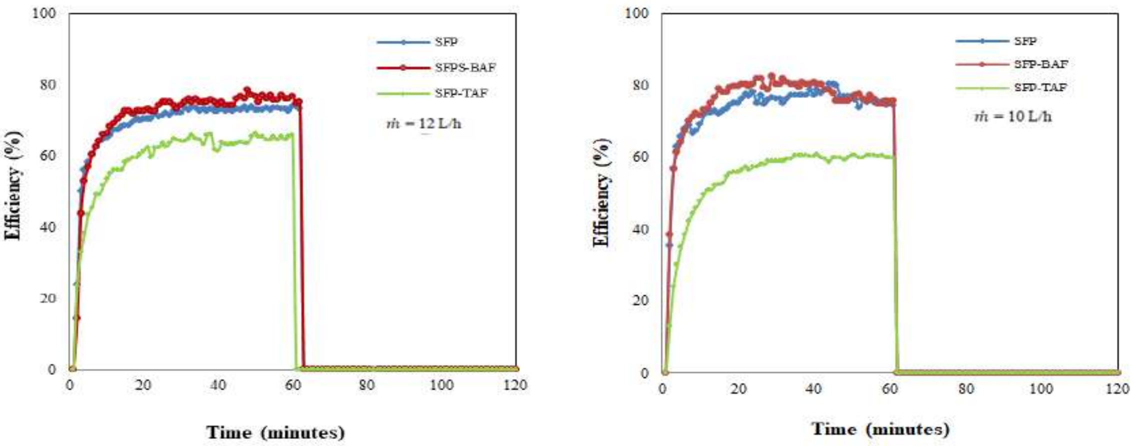


**Fig. 6**. Thermal efficiency of the collector

Fig. 6. shows the thermal efficiency of the three models of absorber plates. The higher thermal efficiency was obtained in the SFP-BAF model at a flow rate of 10 L/h of 82.5 % as shown in Table 1. The SFP-BAF model has higher thermal efficiency than the SFP and SFP-TAF models in various flow rates. The SFP-BAF model where aluminium foam placed under the absorber plate increased thermal efficiency compared to the standard model (SFP) at the flow rate of 10 L/h and 12 L/h of 2.71% and 5.93 % respectively. The increase of its efficiency is because the aluminium foam acts as a heat-absorbing material and increases heat transfer. The surface temperature of the aluminium foam and the difference of the inlet and outlet temperatures of the circulating water is relatively high. In addition, aluminium foam also acts as a material for storing heat energy and retaining heat for a long time.

On the other hand, the placement of aluminium foam on the top of the absorber plate can reduce the thermal efficiency of the collector. The amount of heat absorbed by aluminium foam will be transferred into absorber plate and circulating water. This transferring heat is not optimal due to storage energy in the aluminium foam. The temperature difference between the inlet and outlet of circulating water seems low. However, the position of the aluminium foam can assist to reduce the reflectance of radiation to maximize energy absorption.

Changes in the circulating water flow rate from 10 L/h to 12 L/h causes decreased thermal efficiency. Increasing the fluid velocity can reduce the conduction time to transfer thermal heat to the circulating fluid [10]. In addition, the thickness of aluminium foam material as a heat storage material needs to be considered because it dramatically affects heat loss to the surroundings and the pressure drop [17].

**Table 1**. Percentage increase in efficiency

| Model | Flow rate [L/h] | Maximum efficiency [%] |
|---|---|---|
| SPF | 10 | 80.26 |
| | 12 | 73.92 |
| SFP-BAF | 10 | 82.50 |
| | 12 | 78.58 |
| SFP-TAF | 10 | 60.63 |
| | 12 | 65.79 |

## Conclusions

The performance of the SWHS with the addition of aluminium foam on the top and bottom surfaces of the absorber plate have been investigated experimentally. The SFP-BAF model has a higher thermal efficiency than other models. The SFP-BAF model has an efficiency increase of 2.71 % at a flow rate of 10 L/h and 5.39 % flow rate of 12 L/h compared with the standard model (SFP).

The position of the aluminium foam at the bottom surface is substantial enough to assist absorb and store radiant heat for transfer to circulating water. The effectiveness of the SFP-BAF model needs to be considered in the future related to the thickness of the aluminium foam to increase the heat transfer rate to the fluid and to reduce heat loss to the surroundings.

## Acknowledgement

This study was supported by the Laboratory-Based Education (LBE) Research Fund 2021, Engineering Faculty of Hasanuddin University.

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