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An experimental investigation of sea water distillation using flat absorber plate and fin absorber plate with PCM storage

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Abstract. The presented study investigates the experiment of the thermal performance of sea water solar distillation system using flat absorber plate and fin absorber plate with phase change material (PCM) storage. The two distillation systems operated simultaneously under the same conditions to study its thermal performances. The experimental investigation shows that the distillation using fin absorber plate with PCM storage achieves better thermal performance than that of using flat absorber plate. The daily water productivity of the distillation using fin absorber plate with PCM is 262.75 mL m^{-2} in average and the other one is 142.85 mL m^{-2} in average. The average daily efficiency increases of 48.5 % of the distillation using fin absorber plate with PCM storage compared with the distillation using flat absorber plate. Using absorber plate with fin and PCM storage in the distillation system contributes to increase the thermal performance of the system.

Keywords: solar distillation, PCM storage, water productivity, efficiency

1. Introduction

Solar distillation is a process of evaporation of sea water by using direct solar radiation energy to produce fresh air. It generally uses an absorber in the form of flat plate painted in black as an absorbent of the sun. A solar distillation system is an affordable device utilizing the energy from the sun to yield drinkable and potable water from salty water. A number of research have been studied to improve the performance of the solar distillation systems such as the productivity and efficiency. Using various phase change material (PCM) such as Potasium Dichromate, Sodium Acetate and Sodium Sulphate on the solar water distillation have been studied by Gugulothu *et al.* [1]. The sodium sulphate provides a better yield compared with others. The absorption of solar using v-corrugated integrated with phase-changing material (PCM) have been studied by Shalaby *et al.* [2]. The results showed that the best thermal performance was achieved for solar still using PCM compare with other configurations. The performance of single finned solar basins still manufactured from various materials such as iron, aluminum, copper, stainless steel, glass, mica and brass has been investigated [3]. Compared to the conventional pyramid still, the use of a v-corrugated absorber plate integrated with PCM under the pyramid still basin increased the accumulation yield by 87.4% [4]. In order to study the heat transfer characteristics of solar still, Yousef *et al.* [5] studied experimentally three solar cases of solar still including conventional type, solar still integrated with PCM and solar still using fin heat sink embedded in PCM. The result

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shows that the best thermal performance was achieved in the solar still with fins heat sink embedded in the PCM. Also, the energetic and exergetic of the four cases of the solar stills including conventional type, still integrated with PCM, still integrated with PCM and pin fins heat sink embedded in the PCM and still integrated with PCM and SWF in the basin are studied [6]. The result inform that the performance of still integrated with PCM, still integrated with PCM and pin fins heat sink embedded in the PCM and still integrated with PCM and SWF are better than the conventional still. *Sonker et al.* [7] studied the effects of basin water depth on total distillate water in a copper cylinder for different PCMs such as paraffin wax, stearic acid, and lauric acid. Xu *et al.* [8] investigated the melting performance of triplex-layer PCMs using paraffin wax with various melting temperature in the unit of a horizontal shell and tube latent thermal energy storage (LTES). The comprehensive storage density evaluation (CSDE) can be used as criterion to optimize the design of the horizontal shell and tube latent thermal energy storage (LTES) unit.

The use of V-shape absorber plate have been investigated to increase the absorptivity of absorber plate [9] and integrated with various PCM materials such as Stearid acid [10] and paraffin wax [11]. The results of these studies show that using V-shape absorber plate and PCM storage provided a better performance. A comparative experimental analysis of solar collector including a conventional type and an identical prototype using PCM thermal storage have studied by Palacio *et al.* [12]. It is also proved that using PCM storage can improve the performance.

This study presents an experimental investigation of solar distillation using flat absorber plate and fin absorber plate with PCM storage. The experimental tests of the both solar distillation systems were conducted simultaneously under the same conditions. Water productivity and efficiency were calculated based on recorded data to investigate the performance of the solar distillation systems.

2. Methodology

2.1 Experimental test

The two solar distillation systems consisted of a) the distillation system using flat absorber plate and the distillation system using fin absorber plate with PCM storage as shown in **Figure 1**. The experimental tests of the two systems were carried-out in the same operation time. **Figure 2** shows the experimental set up.

Figure 1. Solar distillation systems consisted of: a) Using flat absorber plate
b) Using fin absorber plate with PCM storage

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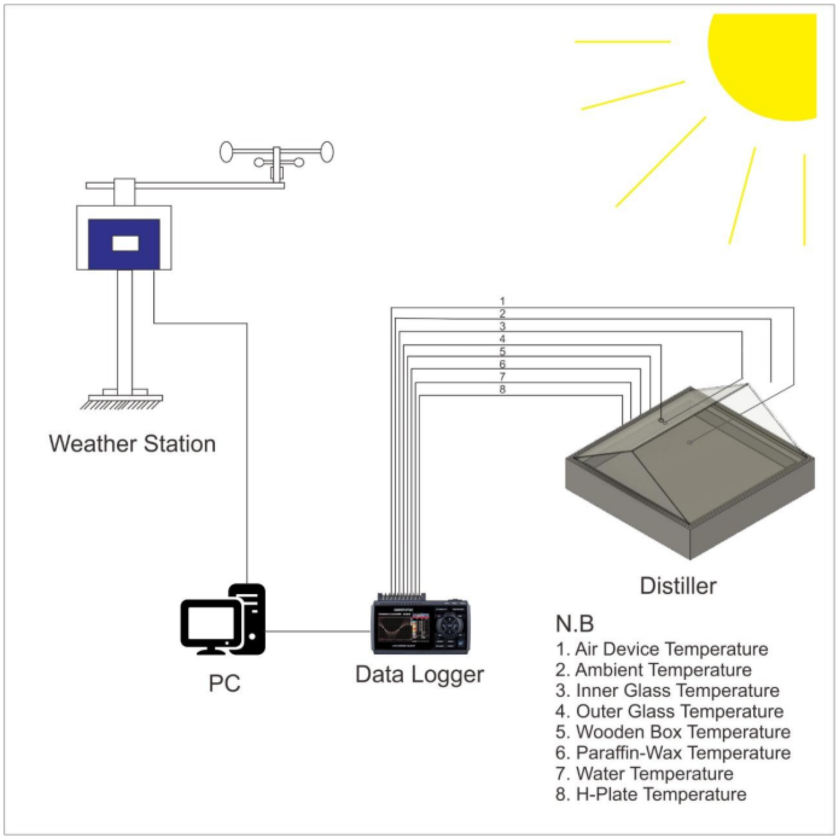

Figure 2. The experimental set-up

2.2 Performance of solar distillation

The energy balance for solar distillation follows equation 1 to 3. The hourly productivity is defined as:

$$P_{h,f} = h_{ewgi}(T_{w,f} - T_{gi.f}) \times \frac{3600}{L_w} \tag{1}$$

The daily productivity and efficiency can be expressed as:

$$P_{d,f} = \sum\nolimits_{24h} P_{h,f} \tag{2}$$

And

$$\eta_{d,f} = \left[\frac{(P_{d,f} L_{av})}{(A_p \sum I_t)\Delta t}\right] \times 100\% \tag{3}$$

Where Lav is the daily average of the latent heat of water vaporization and t is the time interval during which the solar radiation is measured.

2.3 PCM characteristics

Paraffin waxes are relatively obtained in a wide range of temperatures. It is also affordable, reliable, safe, and non-irritating substances. In heat storage systems, most technical grade waxes can be used as PCMs. Paraffin waxes are in active and stable from the chemical point of view. Also, paraffin wax is selected as a PCM because of its melting temperature range lies within the temperature range of solar distillation and its relatively high latent heat of fusion. The thermophysic of PCM materials is presented in **Table 1**.

Table 1. Thermophysic properties of PCM materials

Material	Melting temp.	Latent Heat of Fusion	C_p solid	C_p liquid	k solid	k liquid	ρ
	(°C)	(kJ kg^{-1})	(kJ kg^{-1} K^{-1})		(W m^{-1} K^{-1})		(kg m^{-3})
Paraffin Wax	40 - 53	251	1,92	3,26	0,514	0,224	830

3. Result and discussion

Experimental test of two solar distillation systems using flat absorber plate and fin absorber plate with PCM storage were carried-out by operating simultaneously under the same conditions to study its thermal performances. These tests were implemented in the Renewable Energy Laboratory of Mechanical Engineering Department, *Universitas Hasanuddin*, Gowa (1190 30' 06.1" BT and 050 13' 52.4" LS). The dimensions of the both solar distillation systems are 70 cm length, 70 cm wide and 15 cm high respectively. Data was recorded in every 5 minutes from 09.00 to 18.00 PM (local time). An example data recorded on August 13, 2020 is investigated to study the thermal performance.

3.1 Solar radiation intensity

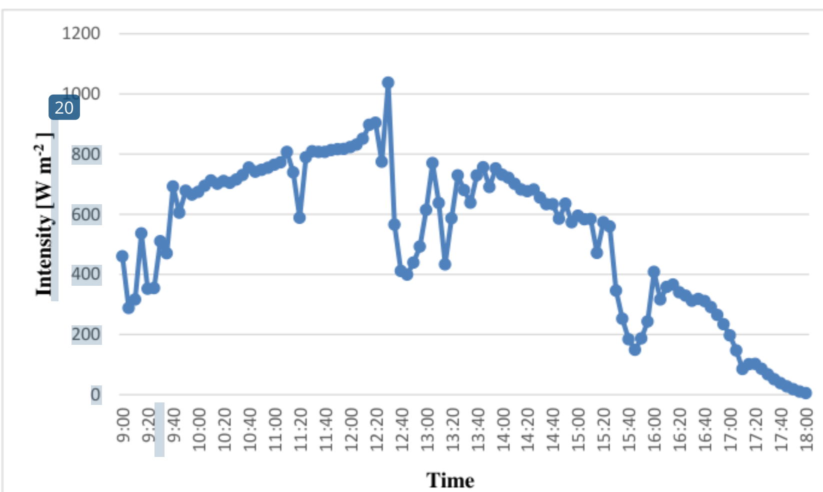

Figure 3. Solar radiation intensity

The intensity of solar radiation during testing has a minimum value in the morning and afternoon. The maximum value of the solar intensity occurs during the daytime as shown in **Figure 3**. The maximum solar radiation intensity is 1037 W m^{-2} at 12:30 PM 904 W m^{-2} at 12:20 PM and 897 W m^{-2} at 12:15 PM.

3.2 Water, inner cover and PCM temperatures

The maximum temperature of water, inner cover and PCM temperature as shown in **Figure 4**. The maximum temperature of sea water distillation using flat absorber plate is 57.9 ^{o}C at 15:00 PM, temperature of sea water distillation using fin absorber plate with PCM is 61.5 ^{o}C at 15:00 PM, temperature of inner glass cover sea water distillation using flat absorber plate is 61.7 ^{o}C at 14:00 PM, and temperature of inner glass cover sea water distillation using fin absorber plate with PCM is 63.2 ^{o}C at 14:00 PM. The maximum temperature of PCM is 55.5 ^{o}C at 16:00 PM.

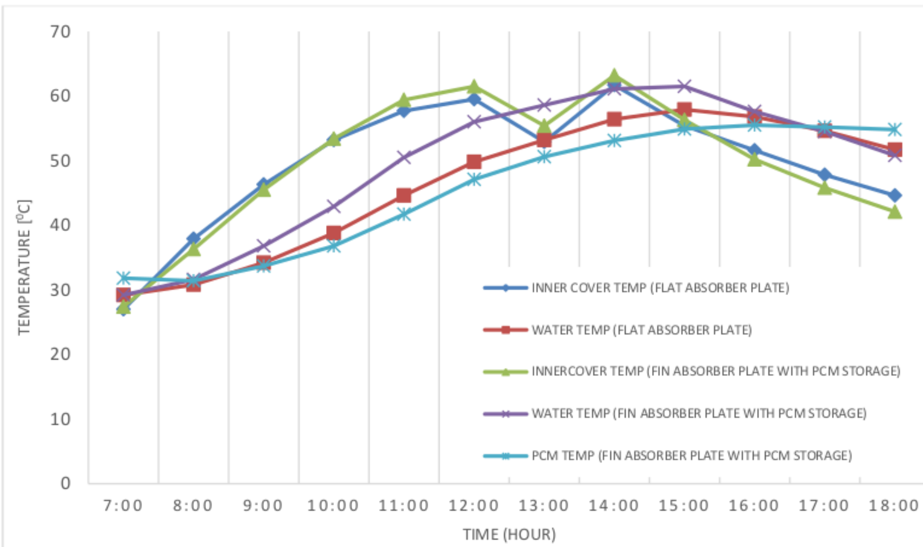

Figure 4. Water, inner cover and PCM temperature

3.3 Water productivity of solar distillation systems

The maximum productivity of sea water as shown in **Figure 5**. The maximum productivity of sea water distillation using flat absorber plate is 120 mL at 15:00 PM, productivity of sea water distillation using fin absorber plate with PCM is 190 mL at 15:00 PM.

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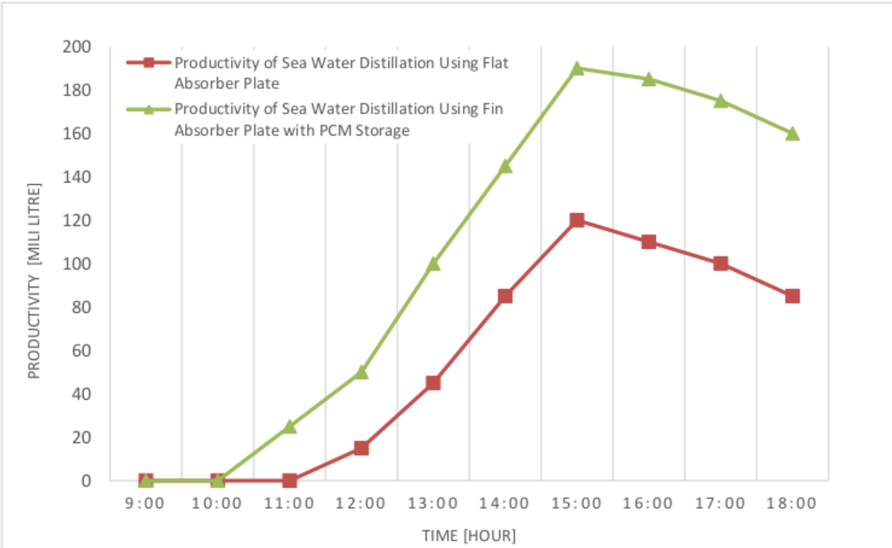

Figure 5. Water productivity of solar distillation systems

3.4 Solar distillation efficiency

The maximum efficiency of solar distillation as shown in **Figure 6**. The maximum efficiency of solar distillation using flat absorber plate is 25.62 % at 15:00 PM, efficiency of solar distillation using fin absorber plate with PCM is 35.04 at 15:00 PM.

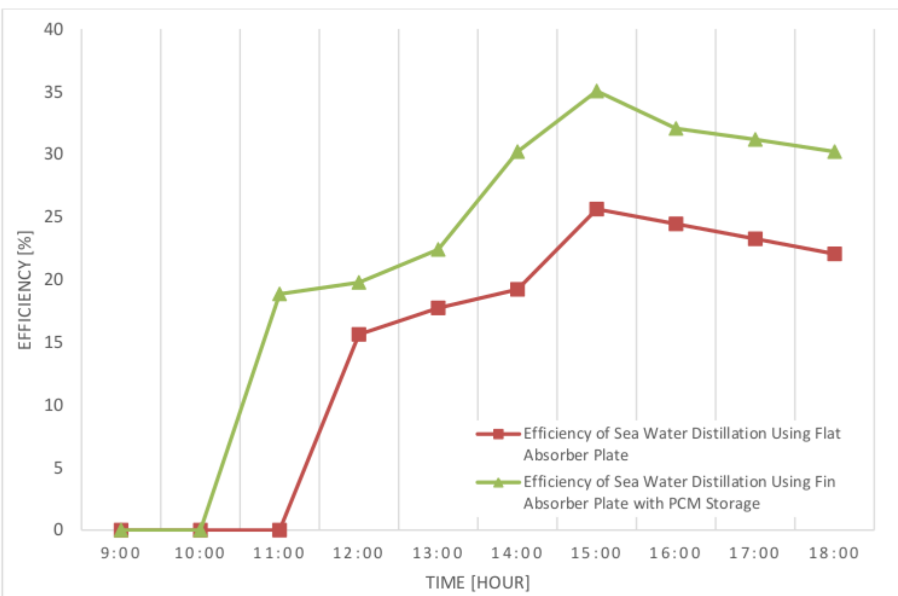

Figure 6. Solar distillation efficiency

4. Conclusion

Two solar distillation systems using flat absorber plate and fin absorber plate with phase change material (PCM) storage have been investigated experimentally. Following conclusions could be drawn from this study as following:

- The results show that the distillation using fin absorber plate with PCM storage achieves better thermal performance than that of using flat absorber plate.
- The daily water productivity of the distillation using fin absorber plate with PCM is 262.75 mL m^{-2} in average and the other one is 142.85 mL $m-^{2}$ in average. The average daily efficiency increase of 48.5 % of the distillation using fin absorber plate with PCM storage compared with the distillation using flat absorber plate.
- Absorber plate with fin and integrated with PCM storage in the distillation system contributes to increase the thermal performance of the system.

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