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Productivity of Solar Distillation in Indonesia using Sodium Thiosulfate Penta-hydrate as Thermal Energy Storage

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Abstract. The maximum temperature of water in solar distillate system determines the effectiveness of applying a Phase Change Materials (PCMs) as Thermal Energy Storage (TES). This paper evaluates the effectiveness of using Sodium Thiosulfate Penta-Hydrate as PCMs for double slope solar distillation systems operating in the Cilegon-Indonesia. The results of 5 tests during the day showed the average water temperature value in the basin with PCMs reaching 42.4 ˚C and without PCMs reaching 42.6 ˚C. While the maximum average temperature of water in the basin reaches 49.56 C for systems without PCMs and 49.2 C for systems with PCMs. Addition of PCMs in water increases distillate production at night if the maximum temperature of the water exceeds the melting point of the PCMs material (48 C). This is occurs when the maximum water temperature in the basin reaches 51 C, distillate production in systems with PCMs is 38% more than systems without PCMs.

Keywords. *Solar distillation, Sodium Thiosulfate, thermal energy storage, PCMs, melting point.*

1. Introduction.

Indonesia is an archipelago located around the equator : 6° N -11 ° S; 95 ° E-141 ° E, with a density of the fourth most populous in the world, reaching 250 million people who occupy an area of 1,922,570 square kilometers [1]. With such a large population, the fulfillment of clean water is a major problem that must be addressed immediately. Some areas in Indonesia, especially the eastern part of Indonesia, are arid regions with very little rainfall so that the source of clean water is very limited.

While other areas are swampy areas surrounded by abundant water but not suitable for consumption and even difficult to obtain clean water. For this reason, efforts should be made to develop appropriate water treatment technology by following available natural resources.

A large area of water area accompanied by high intensity of solar radiation throughout the year is very possible to apply distillation technology with solar energy as the main system in the supply of clean water. A simple solar distillation system is very appropriate to use in remote areas without clean water sources such as coastal areas, swamp areas or dry areas that rely on rainfall.

Solar distillation systems can be classified as direct and indirect systems. The direct system is to utilize direct solar energy to produce distillates in the solar collector, while for the indirect system the solar collector system is separate from the distillate production system. The direct collection system is appropriately utilized for a simple distillation system with low distillate water production [2].

For increasing the efficiency of this technology needs to be developed to make this system feasible to implement. One of the efforts to increase the effectiveness of distillation systems with solar energy is

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to use PCM technology as an energy storage material. Some things that become the main foundation for the use of PCM material in solar distillation systems are:

1. The intensity of fluctuating solar radiation requires thermal energy storage for the process to take place continuously.
2. The phase change process of material is carried out by absorbing and releasing considerable thermal energy at a constant temperature.
3. The temperature change phase of the material used must be below the maximum temperature of raw water during the process of absorption of solar radiation energy.

PCM as Thermal Energy Storage

When thermal energy supply and thermal energy demand do not coincide then a technique is needed to store thermal energy when there is excess energy supply and release it when there is energy demand. The phase change material (PCM) has high energy density with small storage volume as heat thermal energy storage [3]. The thermal energy storage process has three stages: charging, storing and discharging which the stages may occur simultaneously. Table 1. Show the relationship between phase changes material and the thermal energy storage stage.

The main types of thermal energy storage are sensible and latent. Sensible thermal energy storage type stores thermal energy by the increased temperature of the storage material. Latent thermal energy storage stores thermal energy by changes the phase of the material, in general, the process of phase change occurs at a constant temperature (e.g. melting, evaporation, and sublimation).

Table 1. The relationship between thermal energy storage stages and phase-change materials.

	To		
From	Solid	Liquid	Gas
Solid	Charging/ discharging by sensible heat	Charging by melting	Charging by sublimation
Liquid	Discharging by solidification	Charging/ discharging by sensible heat	Charging by evaporation
Gas	Discharging by desublimation	Discharging by condensation	Charging/ discharging by sensible heat

Otherwise, the discharge of latent thermal energy occurs through a decrease in temperature or phase change of material (e.g. solidification, condensation or de-sublimation). Figure 1. Shows the charging/discharging process for thermal energy storage, which the upward direction shows the process of storing thermal energy, while the reverse direction is the process of releasing thermal energy from the storage media.

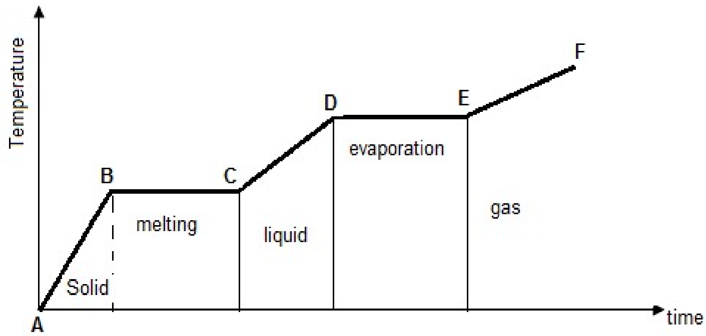


Figure 1. Temperature – time energy storage process

The heat energy is stored during the process of heating the solid material A-B is determined based on equation (1):

$$Q_{A-B} = m.\int_{A}^{B} C_{p,s}(T).dT \qquad (1)$$

Where:
Q_{A-B} : Sensible heat A to B (kJ),
m : The mass of PCM (kg),
$C_{p,s}(T)$: Specific heat capacity of solid. (kJ/kg.K),
T : Temperature (K).

The heat energy is stored during the process of melting (Phase change of solid to liquid), B-C is determined based on equation (2):

$$Q_{B-C} = m.\Delta h_{s-l} \qquad (2)$$

Where :
Q_{B-C} : Latent heat of melted B to C (kJ),
M : The amount of solid that is melted (kg),
Δh_{s-l} : Specific enthalpy for melt (kJ/kg).

The heat energy is stored during the process of heating the liquid material (C-D) is determined based on equation (3):

$$Q_{C-D} = m\int_{C}^{D} C_{p,l}(T).dT \qquad (3)$$

Where :
Q_{C-D} : Sensible heat of liquid C to D (kJ),
m : mass of PCM (kg),
$C_{p,l}(T)$: Specific heat capacity of liquid (kJ/kg.K).

The heat energy is stored during the process of evaporation (Phase change of liquid to gas), D-E is determined based on equation (4):

$$Q_{D-E} = m.\Delta h_{l-g} \qquad (4)$$

Where :

Q_{D-E} : Latent heat of evaporated B to C (kJ),
m : The amount of liquid that is evaporated (kg),
Δh_{l-g} :Specific enthalpy for evaporated (kJ/kg).

The heat energy is stored during the process of heating the gas material (E-F) is determined based on equation (5):

$$Q_{E-F} = m \int_E^F C_{p,g}(T).dT \quad (5)$$

Where :
Q_{E-F} : Sensible heat of gas E to F (kJ),
m : a mass of PCM (kg),
$C_{p,g}(T)$: Specific heat capacity of gas (kJ/kg.K).

Therefore, if the material as an energy store through a phase change from solid to gas, Equation (6) shows the total amount of energy that can be stored in a material when absorbing energy:

$$Q_{A-F} = m.\left[\int_A^B C_{P,s}(T).dT + \Delta h_{s-l} + \int_C^D C_{p,l}(T).dT + \Delta h_{l-g} + \int_E^F C_{p,g}(T).dT\right] \quad (6)$$

Energy storage capacity is very dependent on the working temperature through which the PCM material passes. If the working temperature is below its melting temperature, the stored energy is only determined as in equation (1), whereas if the working temperature is between the melting temperature and the boiling temperature, the amount of energy stored is the sum of equations (1), (2) and (3).

Table 2. Phase change temperature of several PCMs

No	Name	Phase -change temp. (°C)	Process	Description
1	Potassium fluoride Tetrahydrate ($KF.4H_2O$)	18.5	melting	inorganic[3]
2	Manganese nitrate hexahydrate	25.8	melting	inorganic[3]
3	Calcium Chloride hexahydrate ($CaCl_2.6H_2O$)	34	melting	inorganic[3]
4	Sodium Thiosulfate Penta Hydrate	48 - 49	melting	organic [7]
5	Myristic acid,palmitic acid, and stearic acid	50 – 70	melting	organic [7]

Thermal energy storage systems store energy in Phase Change Materials usually from solid to liquid or from liquid to gas. The Material of PCM can be classified into two types: Organic PCMs (examples: Paraffin wax) and inorganic PCMs (examples: Salt Hydrates) [4-7]. Table 2. Shows the temperature of phase change from some of the material.

The use of PCM for a solar water heater shows that efficiency of the system increases with the increase in the release of thermal energy due to phase change of material from liquid to solid in the evening hours [9]

Used of bitumen as thermal energy storage in solar still in the day and release the energy for the desalination process in the night, the experiment shows the presence of bitumen as PCMs increase the efficiency of the system [10]. Two different PCMs in solar water distillation is conducted in February in Hyderabad, India conclude that the presence of Sodium Sulfate as PCMs in water could better be compared Sodium Acetate [11]

Solar Distillation Systems

A solar distillation system consists of a shallow basin, a sloping transparent glass cover and a channel for collecting the distillate water from a solar still. Solar radiation passes the transparent glass cover heat the water in the basin until some of the water evaporated. The air in the systems becomes moist, furthermore the moist flow upward from the hot water to the glass cover and condensed at the underside of the glass cover. Still, water collected through the channel to the collector.

The addition of PCMs as energy storage by placing the PCMs at the bottom of the basin in which is in contact with the water. The PCMs will store the thermal energy when solar radiation has a high intensity in the day and will release the thermal energy in the evening to help the process of evaporation of water in the basin.

2. EXPERIMENTAL SETUP

The experiment used two similar solar distillation systems to test simultaneously as shown in Figure 2. One system for the distillation of water without PCM and the other distillation water with Sodium Thiosulfate Penta-Hydrate as PCM in the basin. The type of solar distillation is a single basin with double slope type, this type is suitable for use in the Indonesian region because Indonesia has a climate like a summer climatic conditions. For summer climatic conditions, system double slope basin stills provide better performance than single basin type. Vice versa, the system single slope is better for cold climatic conditions [12].

Figure 2. Two similar of solar distillation systems without PCMs and with PCMs

The basin has 108 cm x 60 cm and 30 cm of the depth size, insulated with glass wool as coated on the outer side for preventing heat loss. Two transparent glasses with a 3 mm thickness cover on the top of the basin install with a 45-degree inclination. Water in the basin has 10 cm depth without PCMs and the other one adds 7 kg of Sodium Thiosulfate Penta-Hydrate as PCMs.

Several type k-thermocouples (with measurement range: –270 to 1260 ˚C and $\pm$ 0.1 ˚C) installed on the system include:

T_w: Water temperature in the basin

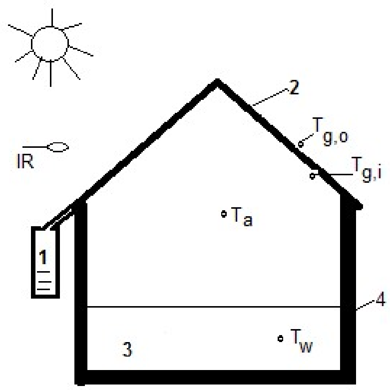
T_a: Air temperature under the glass cover.

T_{gi}: Temperature underside of the glass cover.

T_{go}: Temperature upper side of the glass cover.
Lux meter measured the solar radiation intensity every hour from 08.00 until 17.00

3. METHODOLOGY

The experiment conducted concurrently with data retrieval pauses conducted every hour from 08.00 to 17.00. Held in May 2019 in Cilegon-Indonesia. The location has $6°03'55"S$ and $106°03'48"E$ the climate in summer and rarely rain. Still, water collects and records every day from 08.00 until 08.00 the next day. The experiment was repeated 5 times (respectively on May 20, May 21, May 22, May 23 and 25 May in 2019). Figure 3 shows the sketch of measurement.



1. Measurement glass
2. Cover glass
3. Water with or without PCMs
4. Insulation wall

Figure 3. Measurement sketch of the experimental setup.

4. RESULTS AND DISCUSSION

4.1 Solar Radiation Intensity

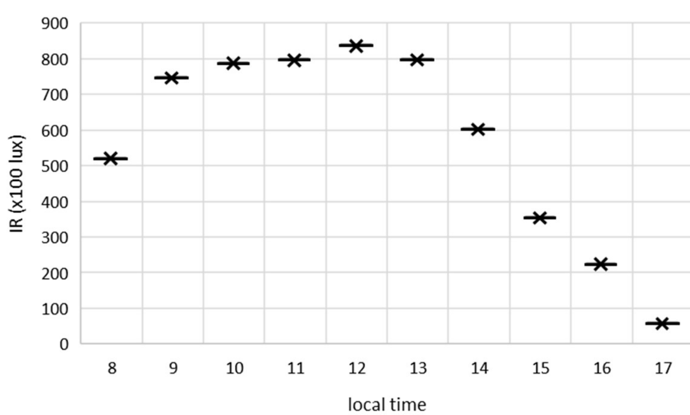


Figure 4. The average solar radiation intensity

Figure 4 presents the average solar radiation intensity for every hour for 5 days of observation. At 12.00 obtained the highest solar radiation intensity with a value of 83.560 klux. The unit conversion of lux to W/m^2 is $1\ lx = 0.0079\ W/m^2$, so the maximum solar radiation intensity reaches $660.124\ W/m^2$.

4.2 Total Condensate Production

Figure 5 shows the amount of distillate water produced in a day and the maximum temperature of the water in the basin for a system with PCMs and without PCMs.

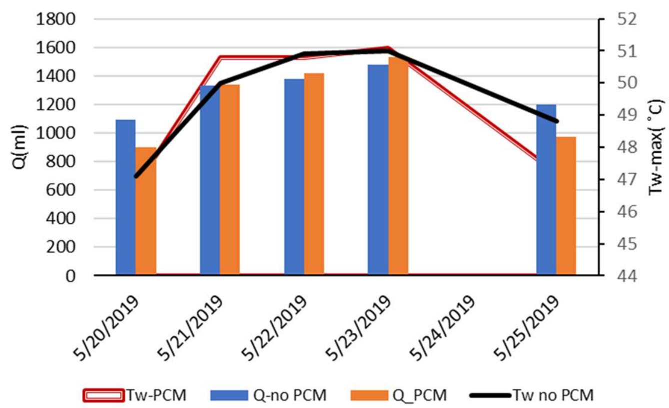


Figure 5. Still water product in a day and maximum temperature of water in the basin.

In general the higher the maximum temperature of water in the basin, the more distillate water production. If the temperature of the water in the basin exceeds the melting point of Sodium Thiosulfate, like PCM, then the production of distillate water in a day for systems with PCM is more than that of systems without PCM. Then the condition of the results of observations per day be described

On May 20, 2019
The maximum temperature of pure water in the basin reached 47.1 ℃ and 46.8 ℃ for water with Sodium Thiosulfate in the basin. The addition of Sodium Thiosulfate into the water also absorbs heat entering the basin so that the water temperature with Sodium Thiosulfate is lower than pure water.

Distillate water produces in pure water systems reaches 1090 ml greater than using Sodium Thiosulfate that only reaches 900 ml. This is due to the temperature of the water in the basin lower than the melting point of Sodium Thiosulfate Penta-Hydrate (48-49 ˚C as shown in Table 1). Thus, the use of Sodium Thiosulfate Penta-Hydrate as an energy storage material (PCM) is unsuccessful because it does not undergo a phase change process.

On May 21, 2019
The maximum temperature of the water with Sodium Thiosulfate Penta-Hydrate, like PCM, in the basin, reached 50.8 ˚C. While the maximum temperature of pure water in a basin reaches 50 ˚C. Condensate water produced in a system with PCM is 1340 ml, this value is slightly higher than a system without PCM that produces 1330 ml. This shows that the PCM material used has undergone a phase change process due to its melting point exceed (above 48℃). Thus, the thermal energy storage process has occurred through the absorption and release of latent heat of Sodium Thiosulfate Penta-Hydrate occurred when the intensity of sunlight decreases.

On May 22, 2019, and May 23, 2019
The maximum temperatures of water in the basin with PCM and without PCM are almost the same and the value is greater than the melting point of the Sodium Thiosulfate Penta-Hydrate so that the PCM material undergoes a phase change and occur a heat energy storage. The condensate produced in the system with PCM is higher than the system without PCM.

On May 25th, 2019
The maximum temperature of water without PCM in the basin is 48.8 ℃. This value is slightly higher than the maximum temperature of the water with a PCM of 47.2 ℃. Because the water temperature in

the basin does not reach the melting temperature of the PCM material used, there is no storage of heat energy in the form of latent heat. Condensate water produced in systems without PCM reaches 1200 ml greater than using PCM which only reaches 970 ml.

4.3 Daytime Condensate Production

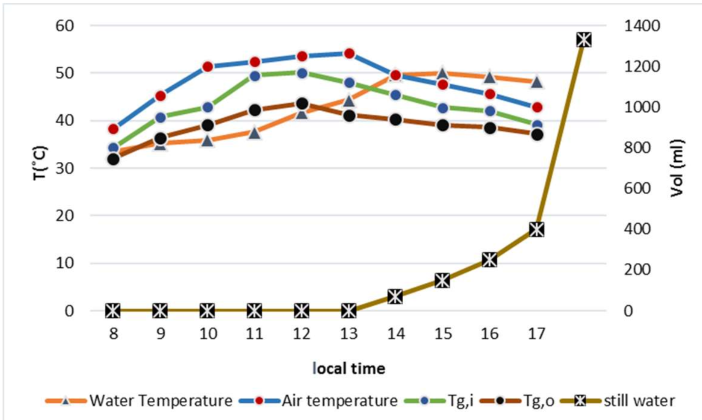


Figure 6. Temperature and still water production without PCM.

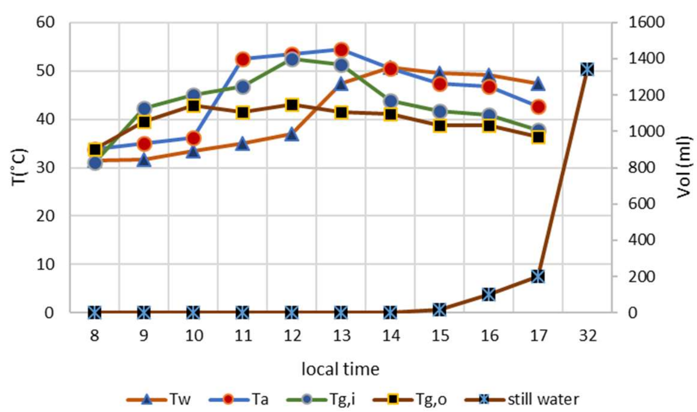


Fig.7 Temperature and still water production with Sodium Thiosulfate Penta-Hydrate as PCM

The condensate produced in a system without PCM starts to appear at 14:00, when the temperature of the water in the basin (T_w) starts to be higher than the temperature of the inner glass cover ($T_{g,i}$). The distribution of temperature and the amount of distillate produced is shown in Figure 6. The inner surface of glass cover ($T_{g,i}$) has highest temperature, and water in the basin (T_w) has lowest temperature. Distillation systems without PCM produce a 400 ml condensate amount during the observation from 08.00 to 17.00, with water in the basin reaches a maximum temperature of 50 ˚C.

Distillation system with the addition of sodium as PCM produces a total of 200 ml condensate for observation from 08.00 to 17.00. This amount is small compared to a distillation system without PCM. In addition, condensate production in a system with PCM can observed at 15.00, one hour after the system without PCM produces condensate. This is due to heat entering the system heats water and PCM material. So that the water temperature in the system with PCM is slightly lower than the water temperature without PCM.

4.4 Condensate Production at Night.

During the day, the solar distillation system without PCM produces higher distillates than the system with Sodium Thiosulfate Penta-Hydrate, as PCM. A comparison of distillate production at night for systems without PCM and with PCM shows in Figure 8. On May 20 and May 25, 2019, the maximum temperature of water in the basin is lower than the melting temperature of the Sodium Thiosulfate Penta-Hydrate, energy storage through phase change does not occur, so that no heat released from PCM to help distillate water production at night. Conversely, the maximum temperature of the water that exceeds the melting temperature of PCM can release its thermal energy at night to help produce distillate water.

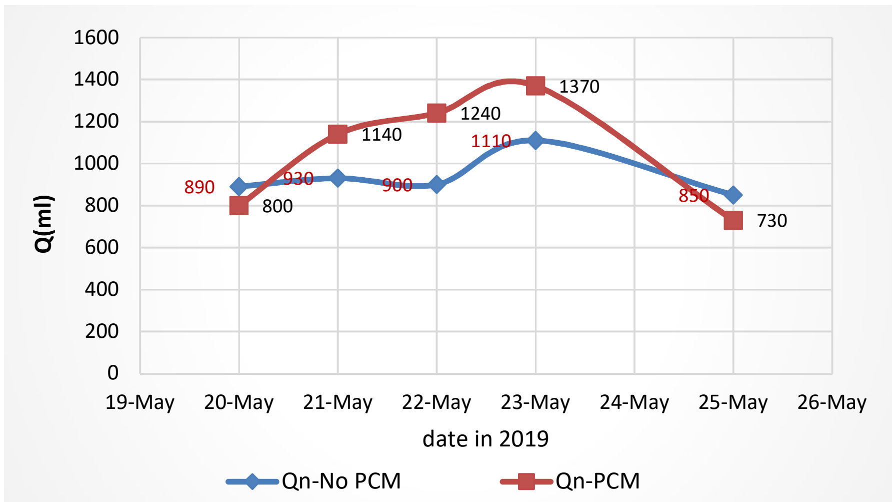


Fig. 8 Production of distillates per day for night-time.

5. CONCLUSIONS

Utilization of solar energy in the water distillation system in Cilegon -Indonesia observed with a double slope solar distillate system. With 10 cm depth of water in the basin. Measurement of average raw-water temperatures in the basin during the day shows $\bar{T} = 42.622$ ˚C; $\sigma^2 = 0.7385$ ˚C. The maximum temperature of water in the basin for 5 times measure repetition has range: 46.8 - 51.5°C. The addition of Sodium Thiosulfate Penta-Hydrate as thermal energy storage effectively works when the maximum temperature of water in the basin exceeds the melting point of Sodium Thiosulfate Penta-Hydrate (48-49 ˚C). Generally, at night, condensate production in systems with PCMs is higher than without PCMs, due to the release of energy from energy stored during the day. The use of Sodium Thiosulfate Penta-Hydrate as PCMs increases condensate production at night 38% higher than systems without PCMs, this occurs when the maximum temperature of the water in the basin reaches 51 ˚C.

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