Enhanced the productivity of Fresh Water Using double slope solar still with the addition of triangular waveform absorber plate

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Abstract- Solar still type double slope was fabricated with 0.01 m thick wooden frame and covered by 2 mm thick transparent glass. The glass cover was inclined at 35°. The triangular waveform absorber plate and basin solar still was made of aluminium plates with size 0.63 × 0.39 × 0.17 m^3 and sawdust is used as an insulator. The effect of adding triangular waveform absorber plate on the productivity of solar still was studied. It was found that the productivity of freshwater is about 20 % higher than the conventional solar still in the same conditions. Based on the test results, it concluded that the adding of triangular waveform absorber plate can improve the productivity of the solar still.

Keywords: Absorber, Distillation, Productivity

1. INTRODUCTION

Water is one of the most important sources of life where there is only 1% of potable water, 97% sea water and 2% in the form of ice on the overall water contained in the earth [1]. Availability of fresh water per capita in Indonesia continues to shrink caused by increased population growth. On the one hand, some areas have a source of water, which salt content is high enough so it cannot be used as drinking water.

Solar distillation is one method for getting fresh water from sea water or brackish water that can be applied in Indonesia considering the geographic potential location of Indonesia allows received solar radiation in a large quantity and the installation cost of solar distillation is relatively cheap.

The general principle of solar distillation is the utilization of solar radiation for heating the water in the solar still until evaporated and when it touches the surface of the glass cover, the water vapor will condense as a result of solar distillation.

Many investigations have been conducted over the years towards improving the daily distillate output of solar stills. Research conducted by Rada Z. Asadi [2] in 2013 to treat the waste water using solar distillation showed that distilled produced was free from solids, 93.8 ± 1.4% lower in terms of COD (Chemical Oxygen Demand), 99.3 ± 0.5% in the case of TDS (Total Dissolved Solid), 85.7 ± 12.7% in the case of TSS (Total Suspended Solid) and 94.8 ± 2.2% in terms of turbidity.

Kabeel in 2010 [3] analyzed the cost of 17 solar distillation designs and found that the design of the roof type solar distillation (double slope) has the highest water productivity about 1533 and 1511 L / m2 year with lower costs i.e. 0.0135 and $ 0.031 / L.

Kalidasa [4] found that the productivity of a solar still can be maximized by increasing the surface area of the basin with adding the rectangular fins in a basin of solar still. Gawande and Bhuyar [5] in 2012 has been tested solar still with variations in glass cover thickness and found that the distillate yield of solar still with the cover glass thickness of 3.5 mm is 31.13% higher than the solar still with the cover glass thickness of 4 mm.

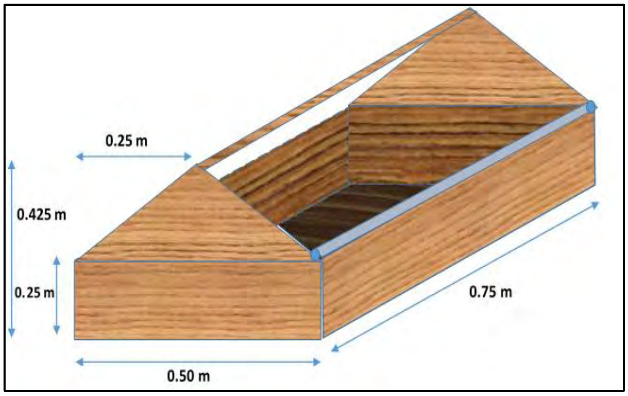

Figure 1. Design of double slope single basin solar still

Burbano [1] in 2014 has been testing an aluminium basin solar still with variations in insulating materials and found that the distillate yield of solar still with sawdust as insulating material was

410 ml and the solar still with Styrofoam as insulating material was 310 ml.

The objective of this studi is to increase the productivity of solar still with the addition of triangular waveform absorber plate.

2. EXPERIMENTAL DETAILS

A double slope, single basin solar still has been fabricated with a size of 0.75 × 0.50 m^2 of wooden frame with a thickness of 0.01 m. The height of the front and back side of 0.25 m. Both sides of the glass cover have the same inclination angle of 35° so the path of side has height 0.42 m. The transparent glass cover has a size of 0.67 × 0.24 m^2 with a thickness of 2×10^{-3} m.

The basin of solar still made of aluminium plate with size of 0.63 × 0.39 × 0.17 m^3 and painted black to improve the absorption of solar radiation intensity. Sawdust as insulating material was installed on the bottom and the four sides of basin solar still with a thickness of 0.05 m.

PVC pipe with a diameter of ¾ inches was fixed on the front and back side (glass tilt point) to collect the water condensate from inner surface glass cover. A valve was fixed at the end of pipe to simplify the measure of water condensate. The design of double slope, single basin solar still can be seen in Figure 1.

The triangular waveform absorber plate with an overall size of 0.63 × 0.39 m^2 has been made using an aluminium plate with 6 triangular waveform and each of it has base and height of 0.06 and 0.02 m, respectively. The triangular waveform absorber plate was painted black to increase the absorption of solar radiation intensity. The installation of a triangular waveform absorber plate on a solar still can be seen in Figure 2.

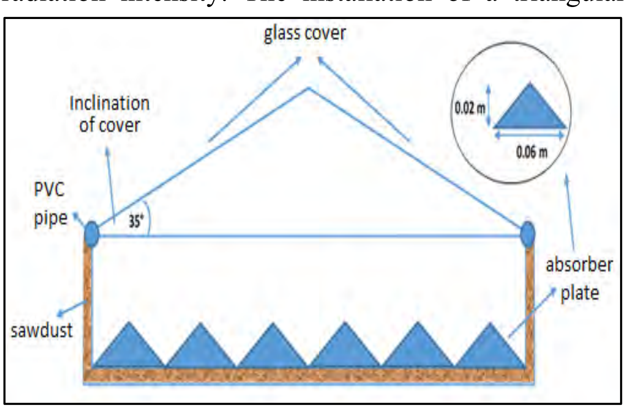

Figure 2. Instalation of triangular waveform absorber plate on solar still

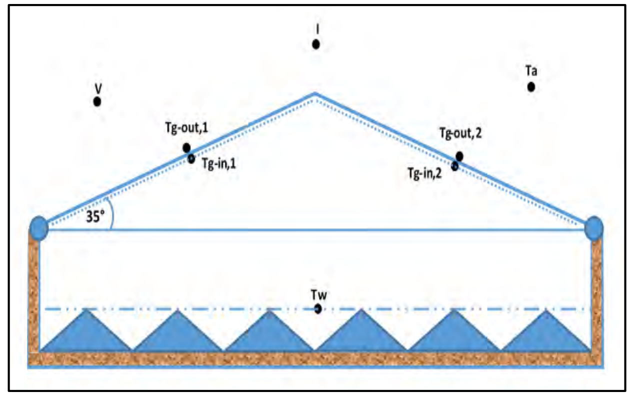

Figure 3. The Measurement Point on Experimental of Solar Still

The testing of solar still without triangular waveform absorber plate and solar still with triangular waveform absorber plate has conducted with water surface in the basin has a depth of 0.02 m. The measurement points of experimental of solar still can be seen in Figure 3. The testing has conducted at Institute Technology of Sepuluh Nopember (7.2817° S, 112.7947° E). The experiments were conducted from 8 a.m. to 4 p.m. the total radiation, the wind velocity, the temperature of water, inner surface glass cover, ambient and the condensate collected were recorded for every 30 mins.

Heat Transfer

The total input energy for double slope solar still is the sum of total radiation energy falling on both side of glass cover and is given by [4], [6],

$$\begin{aligned} Q_i &= Q_{iN} + Q_{iS} \\ &= A_{gN} I_N + A_{gS} I_S \end{aligned} \tag{1}$$

where $A_{gN,gS}$ are the surface areas of north and south side glass cover (m^2), $I_{N,S}$ is solar radiation intensity measured on north and south side of solar still (W/m^2).

The energy available for utilization by solar still is the total solar radiation transmitted through the both side of glass covers for given time and it is given by [4], [6]:

$$\begin{aligned} Q_\tau &= Q_{\tau N} + Q_{\tau S} \\ &= \tau_N A_{gN} I_N + \tau_S A_{gS} I_S \end{aligned} \tag{2}$$

where $\tau_{N,S}$ is transmittance of north and south side of glas cover.

The convection heat transfer from the water to the glass cover surface is given by [4], [6]:

$$Q_{c,wg} = h_{c,wg} A_b (T_w - T_g) \quad (3)$$

where A_b is the basin area (m^2) and $T_{w,g}$ are water and inner glass cover surface temperature (^{0}C). The convective coefficient "$h_{c,wg}$" (W/m^{2}K) from the water to glass cover is calculated using [4], [6]:

$$h_{c,wg} = 0.884\left[(T_w - T_g) + \frac{(p_w - p_g)(T_w + 273.15)}{268900 - p_w}\right]^{1/3} \quad (4)$$

where p is the partial pressure of water vapour in the air (N/m^2) and can calculated for given temperature (^{0}C) using the following correlation [4], [6]:

$$p = 7235 - 431.43T + 10.76T^2 \quad (5)$$

For the evaporative heat transfer from the water to the glass cover surface is given by[4], [5]:

$$Q_{e,wg} = h_{e,wg} A_b (p_w - p_g) \quad (6)$$

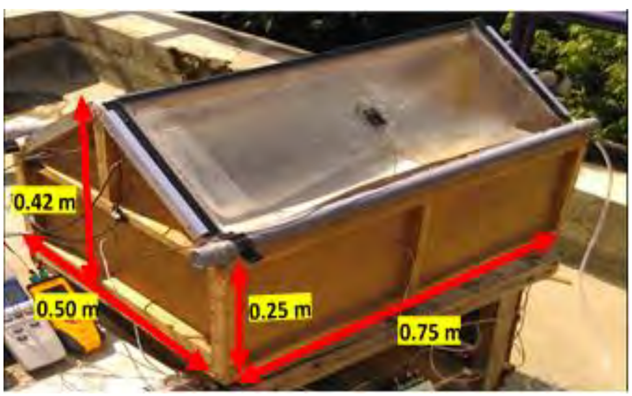

Figure. 4. Photograph of on Experimental set up of Solar Still

Dunkle [7] assumed that the p_w and p_g are considerably smaller than the total pressure p, and the mean operating temperature is 50 ^{0}C, the evaporative heat transfer coefficient "$h_{e,wg}$"(W/m^{2}K) can calculated using :

$$h_{e,wg} = 0.016273\, h_{c,wg} \quad (7)$$

The latent heat of evaporation of water h_{fg} (J/kg) at a given water temperature (^{0}C) is given by the following correlation [4], [6]:

$$h_{fg} = (2503.3 - 2.398T) \times 1000 \quad (8)$$

Figure. 5. Photograph of the triangular waveform absorber plate

The Radiation heat transfer from the water to the glass cover surface is given by [4], [6]:

$$Q_{r,wg} = \sigma \times \varepsilon_{wg} \times A_b \times [(T_w + 273.15)^4 - (T_g + 273.15)^4] \quad (9)$$

where σ is Stefen-Boltzman constants (5.67x10^{-8} W/m^{2}K^4) and ε_{wg} is emissivity of water surface.

The convection heat transfer from the glass cover surface to the atsmosphere including the radiation effect is calculated using [4], [6]:

$$Q_{c,ga} = h_{c,ga} A_g (T_g - T_a) \quad (10)$$

The convective heat transfer coefficient from glass cover surface to atmosphere "$h_{c,ga}$" (W/m^{2}K) can calculated by [4], [5]:

$$h_{c,ga} = 5.7 + 3.8V \quad (11)$$

where V is wind velocity (m/s^2).

The radiation heat transfer from glass cover surface to ambient can calculated using [4], [6]:

$$Q_{r,ga} = \sigma \times \varepsilon_g \times A_g \times [(T_g + 273.15)^4 - (T_{sky} + 273.15)^4] \quad (12)$$

where T_{sky} is sky temperature, T_{sky}=T_a -6

The instantaneous water production of the solar still is given by[4], [6]:

$$m_e = \frac{Q_{e,wg}}{h_{fg}} \quad (13)$$

The overall production of solar still can be predicted using [4], [6]:

$$m_{total} = \sum m_e(t)\Delta t = \sum Q_{e,wg}(t)\Delta t / h_{fg} \quad (14)$$

Efisiensi Sistem Distilasi

Basically, all of the research aim to improve the efficiency of solar distillation. The efficiency of solar still can be calculated by [8]:

$$\eta = \frac{M \times h_{fg}}{A_b \times I(t) \times \Delta t} \times 100\% \quad (15)$$

where M is the mass of distillate output during the time interval Δt, and $I(t)$ is solar radiation intencity over the time interval Δt

3. RESULT AND DISCUSSION

Figure 6. shows the quantity of solar radiation received during the testing of solar distillation system. Overall, the solar radiation received by both of the solar distillation systems is nearly equal, only on some measurement points has significant difference. This happens due to environmental factors such as dense clouds that block the solar radiation. From the measurement results, the highest solar radiation is 880 Watt/m^2 obtained at 13:30 for solar still without triangular waveform absorber plate and for solar still with the triangular waveform absorber plate is 887 Watt / m^2.

Solar radiation received will be used to heat the water in the basin of solar still. Figure 7. shows the difference of water temperature between the solar still without the triangular waveform absorber plate and the solar still with the triangular waveform absorber plate. Although solar radiation received on the morning is lower, the water temperature of the solar still with the triangular waveform absorber plate had increased faster than the water temperature of solar still without the triangular waveform absorber plate. This shows that the use of the triangular waveform absorber plate can improve the solar radiation absorption of solar still and it also can reduce the preheating time of water. It is also reported by V. Velmurugan [9] that the addition of the rectangular fins on conventional solar still can reduce the preheating time required for evaporation of water in the basin of solar still.

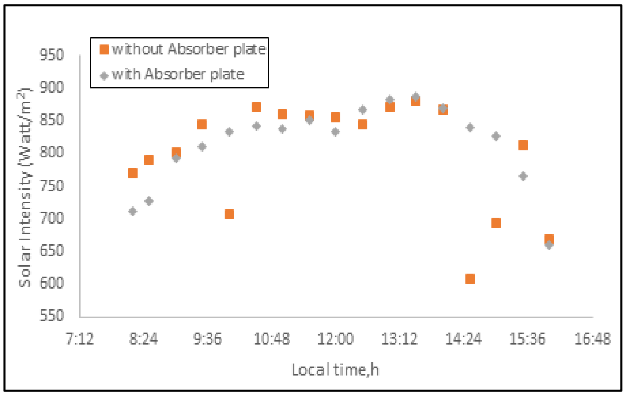

Figure 6. Variation in direct solar intensity on testing of solar still

On the testing of distillation system, solar radiation received is also absorbed by the glass cover that causing its temperatures increased. Figure 8. shows the temperature variation of the inner surface of glass cover caused by the solar radiation absorbed and also due to the heat transfer from the water surface.

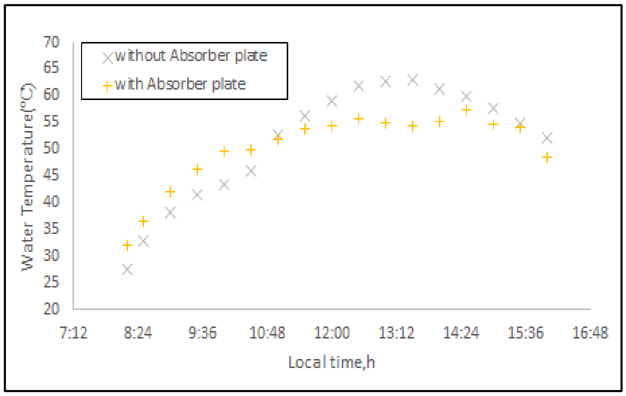

Figure. 7. Variation in water temperature on testing of solar still

As seen in Figure 8. the initial temperature of the inner surface of glass cover for both of the solar still is higher than the initial temperature of water. For the solar still without the triangular waveform absorber plate, the initial temperature of the inner surface of glass cover is 35.9 °C and the initial temperature of water is 27.5 °C while the initial temperature of the inner surface of glass cover and the initial temperature of water for solar still with the triangular waveform absorber plate are 37.4 °C and 32.2°C, respectively. Increasing of surface temperature of glass cover for both of solar still did not differ significantly because of glass cover used has the same thickness and material so that the heat absorptivity is no different.

The evaporation occurred in the solar distillation system when the surface temperature of water is higher than the temperature of the inner surface of glass cover. Figure 9. shows the variation of the temperature difference between the water surface and the inner surface of glass cover on the testing of the distillation system. Based on the graph, it appears that

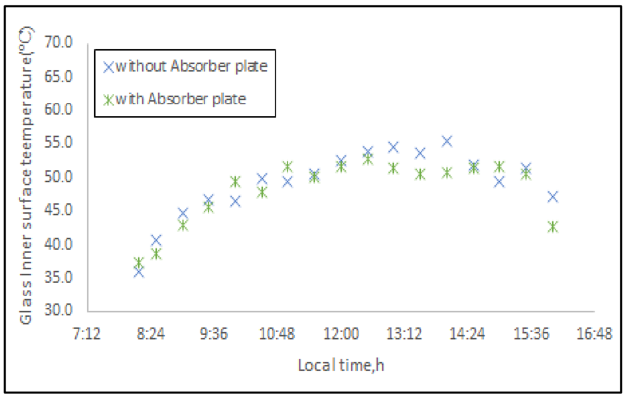

Figure. 8. Variation in glass inner surface temperature on testing of solar still

the temperature difference between water and glass is negative at initial time of testing for both of solar still. This caused by the water temperature is lower than the temperature of glass. In the testing of solar still using the triangular waveform absorber plates, the temperature difference is positive at 9:30 while the solar still without triangular waveform absorber plate occurred at 11:00.

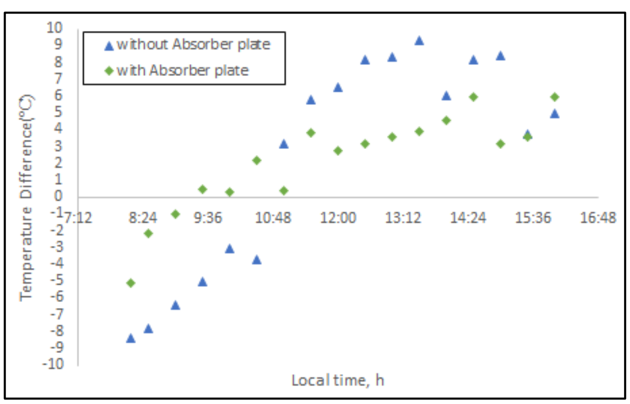

Figure. 9. Variation in temperature difference of water-glass cover on testing of solar still

It has been described in Figure 7. that the use of a triangular waveform absorber plate on solar still causing water temperatures rise more rapidly than the water temperature of the solar still without triangular waveform absorber plate.

The mass of water produced in the solar distillation can be predicted using equation (16) which depended on the temperature difference between the water surface and the inner surface of the glass cover. Although the temperature difference is positive, the condensation of water vapor on the glass cover surface also affected by heat transfer from the glass to the ambient which can be calculated using equation (12) and (14) [10].

Solar distillation testing was conducted to see the effect of the use of triangular waveform absorber plate on the productivity of water can be observed in Figure 10. It is shown in the graph that the water production was not occured at the testing initial time for both of solar distillation. This happens because the surface temperature of water is lower than the surface temperature of glass cover so that the evaporation of water has not occurred.

The water productivity of solar still increased from the morning until the noon. By late afternoon, the water productivity of solar still decreased. The highest productivity of water for the both of solar still occurred at 13:30 due to the highest solar radiation also occured at that time. The highest productivity of solar still by using triangular waveform absorber plates is 56 ml and without triangular waveform absober plate is 59 ml. Overall, it can be seen that the water production of solar still by using triangular waveform absorber plate is higher than the solar still without triangular waveform absorber plates.

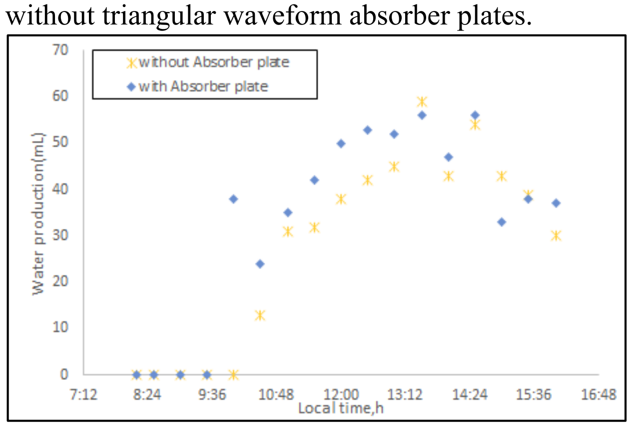

Figure. 10. The variation in water production on testing of solar still

Total water produced during the 8 hours for solar still without triangular waveform absorber plate is 469 mL and 561 mL for solar still by using a triangular waveform absorber plate. In other words, the use of the absorber plate in the solar still can improve the water productivity by 20 % compared to the solar still without a triangular waveform absorber plate. The same thing was reported by Velmurugan [11] that the use of rectangular fins on single slope, single basin solar still can improve the water productivity by 30% compared to conventional solar still. Total water produced is shown in Figure 11.

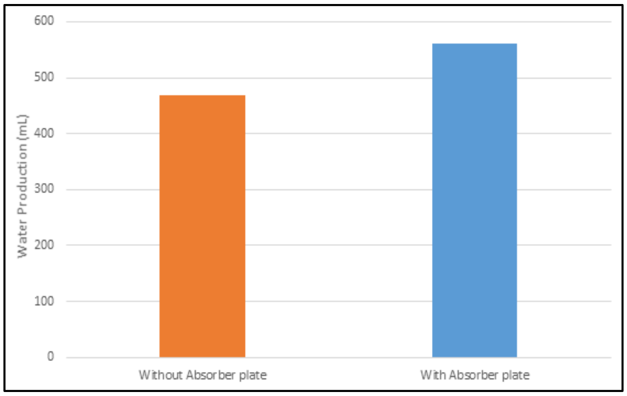

Figure. 11. Total water production of solar

4. CONCLUSION

This study has been designed and fabricated the solar distillation of sea water type double slope, single basin with the addition of triangular waveform absorber plate.

Based on the test result of a solar still with the addition of triangular waveform absorber plate for 8 hours, the total water produced by 561 ml and 469 ml for solar still without using the triangular waveform absorber plate. It can be concluded that the use of triangular waveform absorber plate can improve water productivity by 20 % compared to sea water solar still conventional.

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