Effect of cooling water on the glass cover of the double slope solar still

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Abstract. Water plays an essential part in human life. In our daily activities, water is something we must consume for our survival. As one of the largest seawater resources country in the world does not guarantee Indonesian citizens of having pure water to consume. Since, most of the water is already polluted by factories, industries and households. The needs of pure water are increasingly needed as the human population gradually increased. One of the technology to produce pure water is solar distillation. This research aims to find out the water productivity results and the efficiency of glass cover cooling by flowing water over the glass cover on passive double slope solar still. The results showed that the actual and theoretical water productivity calculation for this method are 4.36 liters and 7.57 liters. The efficiency for actual and theoretical of the system 52.32% and 90.88% respectively.

1. Introduction

Freshwater is increasingly needed by humans in daily activities, from the need of drinking to other needs such as cooking, washing, bathing, and so on and due to an increase in the standard of living, the productivity of freshwater must also be equalized so that water needs can be fulfilled. According to the United Stations Organization that in 2025, an estimated 1800 million people in the world will experience a scarcity of clean water [1].

Desalination is widely adopted in the Middle East, Arab States, North America, Asia, Europe, Africa, Central America, South America and Australia to meet the needs of clean water and water treatment needs. Nearly 10000 tons of oil are needed each year to produce 1000 m³ / day of clean water [2]. Conventional desalination systems operated by using fossil fuels also contribute to greenhouse emissions or GHG (Green House Gas) [3]. These has encouraged researchers to look for alternative ways to power systems with renewable energy.

Some of the renewable energy used by the desalination process is generally in the form of solar, wind, and geothermal energy. One of the three, 57% of desalination systems are supplied with solar energy as renewable energy [4]. Even countries which rich in fossil fuels such as the Middle East and the Arab Nations have also turned their attention to solar energy with the aim of providing clean water without polluting the environment. The utilization of solar energy in desalination system in order to produce pure water has so many variations. One of them is passive double slope solar still [5, 6]. The higher condensation rate the more productivity will be obtained. Kalidasamurugavel et al [7] defined that the temperature difference between the glass cover and the basin water temperature increases the condensation rate. The main objective of doing this paper is to study the effect of various parameters like temperature, cooling of condensing glass covers, solar radiations etc. on the productivity of DSSS.
2. Solution Method

2.1. Sample Preparation
Sea water obtained from The Coast of Bali Lestari, Serdang Regency, North Sumatera, Indonesia with a salt content of around 3%, is taken as the main ingredient in this experiment.

2.2. Experimental set-up
The DSSS with glass cover cooling technique is shown in fig. 1 with the area of basin 1.932 m² which is made of the Aluminium Composite Panel (ACP) with 3 mm thickness and painted black at inside surfaces to absorb the solar radiation. The heights of the solar still walls are 0.2 m at the east-west ends and 0.459 m at the center. Two window glasses of area 1 × 1 m² with 3 mm thickness have been placed over the walls of the solar still at inclination angle 15° and the height from ground to the basin area is 0.625 m.

The experimental process is by filling the evaporator with sea water at the depth of 2 cm and the outer glass temperature will be cooled by flowing pumped cold water over the glass cover. During the experimental process from 8 AM to 6 PM, the volume output of distillation was measured every 30 minutes by using measuring cylinder. There are 6 thermocouples used in this experiments which to measure the water temperature in basin, the inner and outer of west side glass, the inner and outer of east side glass, and the water temperature in cold water tank which is used to decrease the outer glass temperature. For solar radiation and wind speed measurement is by using HOBO Microstation Data Logger.

![Figure 1. Experimental Setup of DSSS](image)

2.3. Thermal Modelling
Natural convection occurs in moist air in the tub because of the temperature difference between the surface of the water and the inner surface of the glass cover. The convective heat transfer coefficient is given as follows:

\[
h_{\text{wge}} = 0.884 \left[ (T_w - T_{gE}) + \frac{(P_w - P_{gE})(T_w + 273)}{2.689 \times 10^5 - P_w} \right]^{1/3} \]

(1)
Where $h_{cwgE}$ [W/m²°C] is convection heat transfer coefficient of east side glass cover, $h_{cwgW}$ [W/m²°C] is convection heat transfer coefficient of west side glass cover, $T_w$ [°C], $T_{giE}$ [°C], $T_{giW}$ [°C] are water temperature in basin, east side inner glass temperature, west side inner glass temperature respectively. $P_w$ [N/m²], $P_{giE}$ [N/m²], $P_{giW}$ [N/m²] are water saturated partial pressure, east side glass saturated partial pressure, west side glass saturated partial pressure respectively which can be found by the equations below

$$P_w = \exp \left[ 25.317 - \frac{5144}{273 + T_w} \right]$$  \hspace{1cm} (3)

$$P_{giE} = \exp \left[ 25.317 - \frac{5144}{273 + T_{giE}} \right]$$  \hspace{1cm} (4)

$$P_{giW} = \exp \left[ 25.317 - \frac{5144}{273 + T_{giW}} \right]$$  \hspace{1cm} (5)

Double slope solar still performance depends on the evaporative and convective heat transfer coefficient. Evaporative heat transfer coefficient as follows

$$h_{ewgE} = 0.016273 \frac{P_w - P_{giE}}{T_w - T_{giE}}$$  \hspace{1cm} (6)

$$h_{ewgW} = 0.016273 \frac{P_w - P_{giW}}{T_w - T_{giW}}$$  \hspace{1cm} (7)

Where $h_{ewgE}$ [W/m² °C] is evaporation heat transfer coefficient of east side glass cover, $h_{ewgW}$ [W/m² °C] is evaporation heat transfer coefficient of west side glass cover.

Efficiency of DSSS is the ratio of the amount of heat energy used to get a certain amount of distilled water to solar energy that occurs within a certain time interval. The efficiency of the system can be found using the following equation.

$$\eta_{theoretical} = \frac{m_{dt} x hfg}{\Sigma I(t) A_b t} \times 100\%$$ \hspace{1cm} (8)

$$\eta_{actual} = \frac{m_{da} x hfg}{\Sigma I(t) A_b t} \times 100\%$$ \hspace{1cm} (9)

Where $m_{dt}$ [kg] and $m_{da}$ [kg] are theoretical distillation output mass and actual distillation output mass respectively. $\Sigma I$ [W/m²] is total solar radiation within a certain time interval. Where $hfg$ [J/kg] is latent heat of vaporization can be found with the following equation

$$h_{fg} = 3044205.5 -1679,1109 T_w - 1,14258 T_w^2$$ \hspace{1cm} (10)

The theoretical output of the double slope solar still per 30 minutes can be obtained as follows
Where \( m_{ewE} \) [kg] \( m_{ewW} \) [kg] are theoretical distillation output mass on east side and theoretical distillation output mass on west side respectively.

3. Result and Discussion

The results below were obtained in the experimental process on 29th of June 2019 from 8 AM to 6 PM at Medan City, North Sumatera, Indonesia with geographic coordinate 3°34’ North and 98°40’ East.

\[
m_{ewE} = \frac{h_{ewE} (T_w - T_{giE}) A_b \times 1.800}{h_{fg}}
\]

\[
m_{ewW} = \frac{h_{ewW} (T_w - T_{giW}) A_b \times 1.800}{h_{fg}}
\]

\[
m_{dt} = m_{ewE} + m_{ewW}
\]

From figure 2, the highest and lowest temperatures of the water in the basin are 56.47°C and 26.37°C respectively at 1.30 PM and 8 AM. The highest and lowest temperatures of the east side outer glass are 43.48°C and 26.95 °C at 2.30 PM and 8 AM. The highest and lowest temperatures of the east side inner glass are 46.71°C and 26.35°C at 2 PM and 8 AM. The highest and lowest temperatures of the west side outer glass are 45.85°C and 23.97°C respectively at 2 PM and 8 AM. The highest and lowest temperatures of the west side inner glass are 47.67°C and 24.30°C respectively at 2 PM and 8 AM. The highest and lowest temperatures of the cooling water are 38.53°C and 24.35°C. While the highest and lowest temperatures of the environment are 35.42°C and 28.35°C at 1.20 PM and 8 AM.
Figure 3. Solar radiation with time

From figure 3 showed that the solar radiation starts at 68.1 W/m² at 8 AM and ends at 16.9 W/m² at 6 PM. The maximum solar radiation measured is 639.4 W/m² at 13.17 PM and total solar radiation during this experimental is 212424.9 W/m².

Figure 4. Comparison of theoretical and experimental output

From figure 4, the highest and lowest theoretical distillation volume of double slope solar still are 884.130 ml and 8.77 ml at 1.30 PM and 6 PM. The theoretical distillation volume ends with 134 ml at 6 PM. While, the highest actual distillation volume are 540 ml at 1.30 PM. At 8 AM to 8.30 AM there are no actual distillation volume obtained. Meanwhile at 6 PM the actual distillation volume produced is 100 ml. The total theoretical distillation volume produced was 7.57 litres while the actual total distillation obtained was 4.36 litres.

4. Conclusion

With the amount of solar radiation which is 212424.9 W/m² absorbed by the system on 29th of June 2019, total theoretical distillation volume produced was 7.57 litres and the actual total distillation obtained was 4.36 litres. In which, the theoretical efficiency of the system obtained is 90.88% and the actual efficiency of the system is 52.32%.
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