Preliminary Test of Double Slope Solar Still Integrating with Oil Palm Shells

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Abstract. The scarcity of freshwater is a problem almost all over the world. Sources of freshwater are decreasing along with industrial development, increasing human population, and this is exacerbated by environmental pollution. To overcome this, solar stills can be used to convert seawater into freshwater using solar energy. Solar still is very useful for use in remote areas to meet the needs of freshwater. Solar still has a simple construction and is easy to manufacture but has low productivity of freshwater. The productivity of freshwater in the solar still can be increased by increasing the absorption of heat energy in the solar still. In this study, oil palm shells were used to increase the absorption of heat energy in solar still. From the results of the study, it was found that the use of oil palm shells can increase the heat transfer in solar still up to 12.3%.

Keywords: *solar still; double slope; oil palm shells.*

1 Introduction

Scarcity of freshwater is a problem almost all over the world, sources of freshwater are decreasing along with industrial development, increasing human population, and this is exacerbated by environmental pollution [1]. The availability of freshwater is around 3% and the other 97% is sea water [2]. To overcome this, solar still can use to turn seawater into freshwater. Solar still is environmentally friendly because it uses renewable energy in the process, namely solar radiation [3]. Solar still is very useful for use in remote areas to meet the needs of freshwater. Solar still has a simple construction and is easy to manufacture, but has a low productivity of freshwater [4]. This low productivity of freshwater is strongly influenced by two factors, namely the process of evaporation and condensation in the solar still. The evaporation process can be increased by increasing the absorption of heat energy entering the solar still.

Various studies have been carried out to increase the absorption of heat energy entering the solar still by using heat storage materials, Nair et al. [5] evaluates the use of conch shells as a heat storage material on the productivity of freshwater solar still, their research results show that the use of conch shells can increase freshwater productivity by 25%. Vembu et al. [6] analyzed the use of coal cylinder in solar still. From their research it was obtained energy efficiency using a coal cylinder of 32.46% while conventional solar still is 22.04%. Perumal [7] increased the productivity of freshwater using natural materials, namely pebbles with different diameters. From the results of his research, it was found that the use of pebbles can increase the productivity of freshwater by up to 27.27% by using pebbles with a diameter of 2 mm. Agrawal et al [8] evaluated the use of pebbles as heat storage material in solar still. It was found that the productivity of freshwater and average energy efficiency using pebbles was higher, namely 1.78 kg/m2 and 20.8%, while conventional solar still was 1.325 kg/m2 and 16.6%. Balachandran et al. [9] increase the productivity of freshwater using eggshells. The use of egg shells increased productivity of freshwater by 18% from 2.07 L/m2 to 2.46 L/m2.

From previous research it was found that the use of heat storage materials from nature can increase the absorption of radiant energy in solar stills. In this study, oil palm shells were used to increase the absorption of heat energy in solar still. In this study, two solar stills were built, namely a conventional solar still (SSC) and a solar still using oil palm shells that get from waste (SSM). Both solar stills were tested under the same environmental conditions. The purpose of this research is to calculate the evaporation and convection heat transfer in SSC and compare it with SSM. Evaporation and convection heat transfer are things that greatly affect the productivity of freshwater in solar stills.

2 Thermal Model

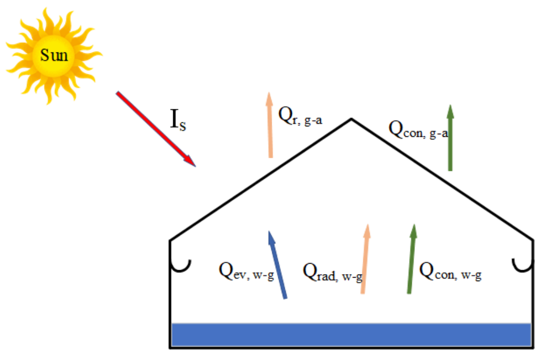

Figure 1 Energy balance on a solar still

Figure 1 shows the energy balance of the solar still. In this study, the heat transfer of evaporation and convection was calculated because these two heat transfers are the largest heat transfers that occur in solar stills. Convection heat transfer $(\dot{q}_{cw})$ from water to cover glass in solar still can be calculated using the following equation [10]–[12]:

$$\dot{q}_{cw} = h_{cwg} \ x \ A_b \ x \ \left(T_w - T_g\right) \tag{1}$$

Where h_{cwg}, the convection heat transfer coefficient from the water to the glass cover, A_b the surface area of the basin, T_g the glass cover temperature, and T_w the water temperature. h_{cwg} can be found by the following equation:

$$h_{cwg} = 0.884\left[T_w - T_g + \frac{\left(P_w - P_g\right)}{268.9x10^3 - P_w}\right]^{1/3} \tag{2}$$

Where P_w is the partial pressure of water vapor, P_g is the partial pressure of water vapor at the glass temperature. To find P_w and P_g use the following equation:

$$P_w = \exp\left(25.317 - \frac{5144}{T_w + 273}\right) \tag{3}$$

$$P_g = \exp\left(25.317 - \frac{5144}{T_g + 273}\right) \tag{4}$$

The heat transfer of evaporation $\dot{q}_{ewg}$ from the water to the cover glass in the solar still is calculated using the following equation:

$$\dot{q}_{ewg} = h_{ewg} \ x \ A_b \ x \ \left(T_w - T_g\right) \tag{5}$$

Where h_{ewg} is the heat transfer coefficient of evaporation. h_{ewg} can be found using the following equation:

$$h_{ewg} = 16.273\text{x}10^{-3} h_{cw} \frac{P_w - P_g}{T_w - T_g} \quad (6)$$

3 Set-Up Experimental

In this research, 2 solar stills were built. The first solar still is a conventional solar still with dimensions of 1 m x 1 m, the basin is made of iron plate with a thickness of 2 mm. The basin is painted with a matte black colour to increase the absorption of energy entering the solar still. To minimize heat dissipation, glasswool with a thickness of 50 mm is used on all sides of the solar still except the top side, then it is covered with plywood with a thickness of 5 mm. The solar still is closed using 5 mm thick transparent glass with a slope of 30° [13]. The sides of the glass and basin are sealed using a seal to prevent heat loss from the basin to the environment. In the two lowest side of solar stills, a half pipe is installed to collect the freshwater and drain it into the freshwater reservoir. This conventional solar still is called SSC. The second solar still is a conventional solar still added with palm shells inside the solar still or called SSM. All solar stills are equipped with thermocouples to measure the temperature of the solar still as shown in Figure 2. Solar radiation is measured using a pyranometer. All temperatures were measured every 5 minutes and solar radiation was measured every 1 minute during the test time.

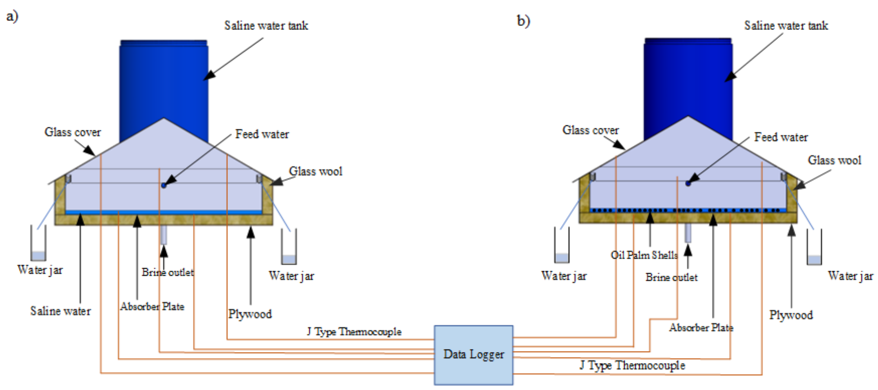

Figure 2 The position of the thermocouple for the two solar stills, a) SSC, b) SSM

Solar still was tested under the same environment simultaneously in August 2022 starting at 8:00 am – 6:00 pm at the Mechanical Engineering Postgraduate Building, Universitas Sumatera Utara, Medan City, Indonesia as shown in Figure 3.

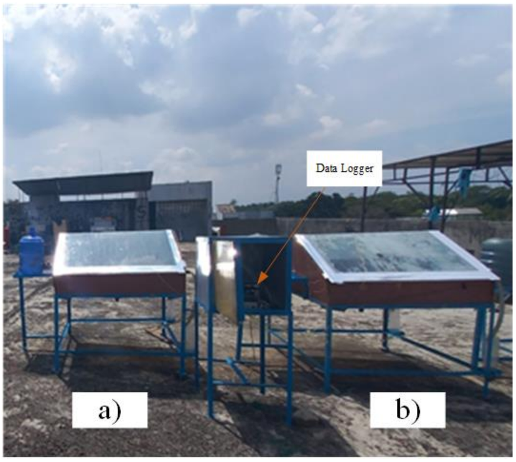

Figure 3 Experimental Setup, a) SSC, b) SSM

4 Result and Discussion

4.1 Solar Radiation

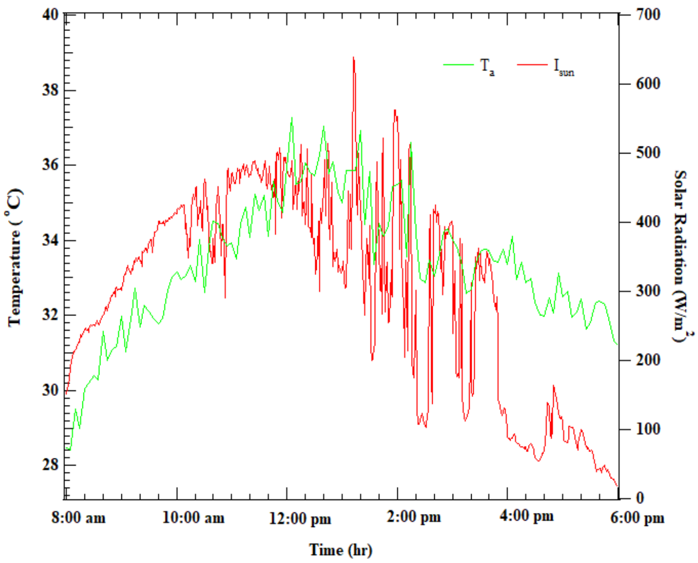

Figure 4 Graph of solar radiation

Figure 4 shows solar radiation and ambient temperature during the test day from 8.00 am – 6.00 pm. Solar radiation from 8:00 am slowly rises until 10:00 am, then fluctuates until 11:00 am, then rises until 11:30 am. Solar radiation then fluctuates until the end of the day. The highest solar radiation is 639.4 W/m2 at 1:12 pm. Trends in ambient temperature fluctuate following trends in solar radiation. The ambient temperature slowly fluctuates from 8:00 am – 12:05 pm and then fluctuates until the end of the day. The highest ambient temperature was 37.281°C at 12.05 pm. The highest values of solar radiation and ambient temperature occur at different times.

4.2 Convection Heat Transfer

Convection heat transfer in SSC and SSM from 8.00 am – 6.00 pm is shown in Figure 5. Convection heat transfer affects the evaporation heat transfer an also affect productivity of the freshwater produced. The trend of convection heat transfer in SSC is the same as the trend of convection heat transfer in SSM. Convection heat transfer on SSC starts to increase from 10:15 am at 1.19 Watt to peak at 2:35 pm at 17.71 Watt. Convection heat transfer at SSM began to increase from 10:05 am at 1.02 watts to a peak at 2:35 pm at 19.23 watts. The average heat transfer for SSC is 5.59 Watt and for SSM is 8.65 Watt. Heat transfer in SSM is higher because the use of palm shells causes an increase in the absorption of solar energy that enters the solar still. The use of oil palm shells increases convection heat transfer by 8.57%.

4.3 Evaporation Heat Transfer

The heat transfer of evaporation in the solar still is influenced by the heat transfer of convection in the solar still and greatly determines the amount of freshwater produced. Figure 6 shows the heat transfer of evaporation in the SSC and SSM from 8.00 am – 6.00 pm. The evaporation heat transfer trend corresponds to the convection heat transfer trend in Figure 5. The evaporation heat transfer trend of SSC and SSM has the same trend. The evaporation heat transfer of SSC slowly increased from 1.25 Watt at 10:05 am to the highest value of 245,736 Watt at 2:35 pm and the heat transfer of evaporation at SSM slowly increased from 1.3 Watt at 9:50 am to the highest value of 276.19 Watts at 2:35 pm. The average evaporation heat transfer at SSC is 79.7 Watt and the average evaporation heat transfer at SSM is 118.84 Watt. SSM has a higher evaporation heat transfer value than SSC because the use of oil palm shells increases the absorption of solar energy entering the solar still. The use of oil palm shells causes an increase in evaporation heat transfer of 12.39%.

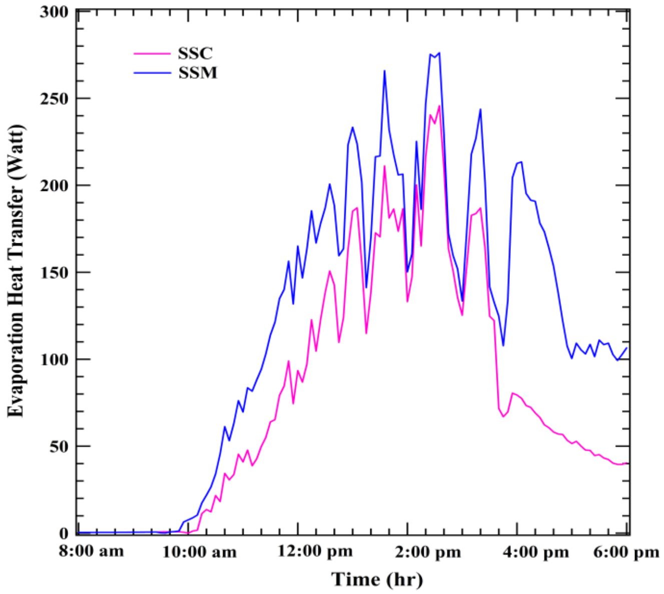

Figure 5 Evaporation heat transfer

5 Conclusion

It has been built and tested in conventional solar still and solar still with the use of oil palm shells, the research results show that the trend of heat transfer follows the trend of solar radiation. The use of oil palm shells in solar stills results in increased heat transfer in solar stills. The increase in convection heat transfer using oil palm shells was 8.57% and the increase in evaporation heat transfer using oil palm shells was 12.3% compared to conventional solar still. From the results of the study, it was also found that evaporation heat transfer is strongly influenced by convection heat transfer. The higher the convection heat transfer, the evaporation heat transfer will increase.

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Nomenclatures

A_b The surface area of the basin (m^2)

h_{cwg} Convection heat transfer from water to glass (W/m^2 K)

h_{ewg} Evaporation heat transfer from water to glass (W/m^2 K)

I_s The intensity of solar radiation (W/m^2)

T_g Glass temperature (°C)

T_w Water temperature (°C)

References

[1] S.A. Mohiuddin, A.K. Kaviti, T.S. Rao, and S.R. Atchuta, J Clean Prod 135100 (2022).

[2] Z.Y. Ho, R. Bahar, and C.H. Koo, J Clean Prod 334, (2022).

[3] Y.P. Sibagariang, H. v. Sihombing, E.Y. Setyawan, K. Kishinami, and H. Ambarita, in AIP Conf Proc (American Institute of Physics Inc., 2020).

[4] M.H. Esfe, S. Esfandeh, D. Toghraie, and V. Veisi, J Clean Prod 135020 (2022).

[5] R. Nair, S. Nambiar, K. Sai Taraka Praneeth, B. Sai Bala Abhinav, S. Menon, D. Sharma, M. Vijayaragavan, and B. Subramanian, Solar Energy 246, 181 (2022).

[6] S. Vembu, M.E.H. Attia, M. Thangamuthu, and G. Thangamuthu, Environmental Science and Pollution Research (2022).

[7] P. Perumal, Desalination Water Treat 253, 48 (2022).

[8] R. Agrawal, T. Sharma, M. Gupta, A. Singh, H. Upadhyay, and A. Shrivastava, International Journal of Ambient Energy 1 (2022).

[9] G.B. Balachandran, P.W. David, G. Rajendran, M.N.A. Ali, V. Radhakrishnan, R. Balamurugan, M.M. Athikesavan, and R. Sathyamurthy, Environmental Science and Pollution Research 28, 611 (2021).

[10] Y.P. Sibagariang, F.H. Napitupulu, H. Kawai, and H. Ambarita, Case Studies in Thermal Engineering 40, 102489 (2022).

[11] S. Kumar and G.N. Tiwari, International Journal of Thermal Sciences 50, 2543 (2011).

[12] N. Setoodeh, R. Rahimi, and A. Ameri, Desalination 268, 103 (2011).

[13] R. Samuel Hansen and K. Kalidasa Murugavel, Desalination 422, 59 (2017).