Single Slope Modification Design for Experimental Study of Solar Desalination System Performance

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Munawar Alfansury Siregar*, Sudirman Lubis*, Himsar Ambarita**, Ashok Kumar Singh***, Wawan Septiawan Damanik*

*Mechanical Engineering, Universitas Muhammadiyah Sumatera Utara, Jl.Mukhtar Basri No.3 Medan-North Sumatera, Indonesia.

**Mechanical Engineering, Universitas Sumatera Utara, Jl. Almamater, Medan 20155, Indonesia.

***Mechanical Engineering Department, Galgotias College of Engineering and Technology, Greater Noida, 201306, UP, India.

*Email: wawanseptiawan@umsu.ac.id; Corresponding Author

ABSTRACT

Fresh water from the desalination process is expected to be commercially produced in large quantities for world consumption needs. In this paper, experimental testing is carried out to obtain the overall characteristics of the desalination device to suit the placement of the test area. The single slope passive desalination tool model with a slope of 35° is still used as the object being tested because of its low cost and environmentally friendly use of solar energy. It is hoped that the performance improvement can be made after obtaining the characteristics of the desalination tool as a whole. It is obtained that the heat energy absorbed reaches 0.31 kWh with a solar intensity of 534.40 W/m^2 at the same time. The production of fresh water during the test always follows the brightness and solar intensity. Experimentally obtained the allergy from the desalination device of 0.53 kW/m^2 with an energy efficiency of 58.4% with the highest amount of hourly fresh water production of 2.6 kg.

Keywords: Desalination, Passive, Single slope, Solar still.

INTRODUCTION

Several desalination methods have been developed by world researchers as reviewed by many researchers (Sahota et al., 2016; Rasul et al., 2021). Desalination of seawater can be utilized and is able to meet the needs of the current difficulty of getting fresh water sources (Ambarita et al., 2016). For solar desalination, there are many models that have been researched and developed by several people, namely the single tilt and double tilt models, which have also been classified into two passive and active work systems (Singh et al., 2020;Subramaniyan et al. 2021). Of the several desalination methods that have been developed, desalination is the oldest water distillation method in the world and has undergone many combinations (Sampathkumar et al., 2010). Therefore, the use of solar energy as the main energy to increase the temperature of water into steam is one of the solutions in utilizing renewable energy (Sahota et al., 2017; Kılıç et al 2021). In recent years the use of electrical energy is still used to obtain large amounts of energy and also produce a lot of fresh water, but to use large amounts of electrical energy, it also costs a lot to buy fuel. About 10 tons of fuel are consumed to spin the tubing and generate electricity (Kalogirou et al., 2005). Dwivedi & Tiwari (2010) conducted a test on water purification using an active system dual slope model desalination process using a naturally circulating copper collector. The result is that the amount of energy absorbed by water reaches 4.7 kW/day. Still (Dwivedi & Tiwari, 2009) previously developed a desalination tool for passive and active models focusing on the large heat transfer coefficient of the two models. Meanwhile, the amount of clean water produced annually on the single slope model is more, namely 499.41 L/m^2, and the double slope model is 463.41 L/m^2. Modi & Modi (2020) conducted a test on a desalination device and show that the use of gunny piles is 23.71% better than those without axle piles. Murugavel et al. (2010)

tested the passive desalination process with a dual slope model. The amount of water produced is 0.1 L/m^2. Joshi & Tiwari (2018) conducted an active system single slope model desalination tool with a three-stage copper collector. The report from the research results shows that the lowest drinking water production cost is found in the first model. (Singh 2017) reported different still designs and related performances and based on the observations, it was concluded that the proficient combination of components help in the improvement of results. Several studies have shown that studies on single slope desalination models have been carried out. But basic testing must be carried out in Indonesia as the impact of climate change remains a key element of success. Data analysis will be carried out experimentally, and the results obtained from the research are expected to provide the necessary information in the development of a single slope solar desalination system.

METHODS AND PROBLEM FORMULATION

The desalination system is designed with a single slope model with a slope of 35^o from the bottom of the evaporator with an area of 1 m^2 as shown in Fig. 1. Sunlight will enter and propagate through the evaporator glass to the surface of the water. Solar thermal energy, there will be at least three possibilities for the process of dissipating heat energy, namely, the sun's heat will bounce off the glass surface into the surrounding air when it is about to enter the evaporator, the second the sunlight will bounce after touching the surface of the water inside the evaporator, and the third light the sun will bounce off the bottom surface of the evaporator to the outside environment.

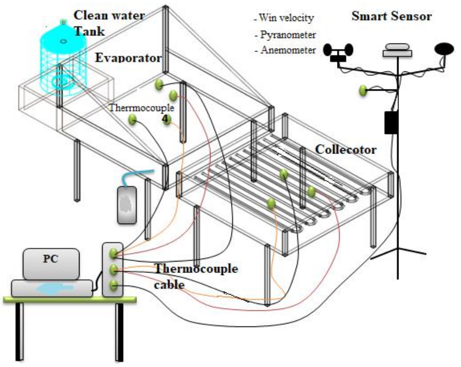

Figure 1 Schematic of single slope desalination

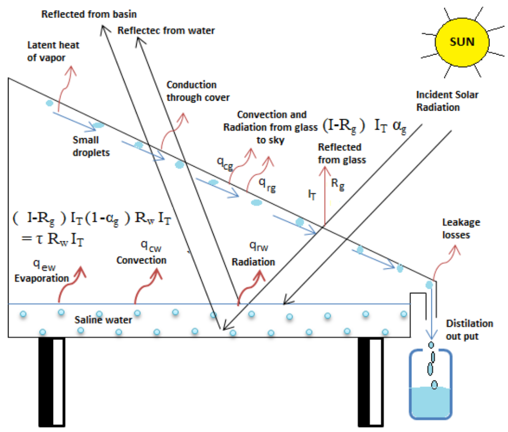

Figure 2 Heat transfer scheme of single slope desalination

Table 1 Desalination device schematic description.

No	Information	Dimensions Specification	No	Information	Specification
1	Sea water tank	19 liters	8	Cooper pipe	3/4 in
2	Evaporator wall	ACP 4 mm	9	Collector glass	Glass / 4 mm
3	Evaporator glass	Clear glass 4 mm	10	Thermocouple	Type K TP3
4	Thermocouple	Type K Dekko TP3	11	Anemometer	Benetech GM8902
5	Fresh water tank	5 liters	12	Pyranometer	Lutron SPM-1116SD
6	Computer	Asus A442U i7	13	R H smart sensor	Lutron COH-9902SD
7	Collector wall	ACP 4 mm	14	Ambient thermocouple	Lutron COH-9902SD

From Fig. 2, there are two possible heat losses from the base walls and the surrounding walls. This is estimated to be very small, considering that the entire insulation process uses good heat insulation, so the process can be considered adiabatic. However, the observation of the heat energy that comes out through the base wall and the circumference of the evaporator is always observed to ensure that the insulation continues to work properly. Apart from those mentioned, heat loss is also necessary when releasing heat from the water vapor attached to the inner glass surface so that water vapor falls more quickly into the clean water storage tank. This assumption makes the writer more enthusiastic in looking for the characteristics and performance of the desalination tool to carry out development in further research.

MATHEMATICAL FORMULATION

This research was conducted as a comparison and development of the tests that had been done previously in the literature study. Therefore, the equations used will be adopted from previous researchers with the same model. The importance of mapping the process of heat transfer rate in desalination helps in observing the possibility of heat energy loss during testing.

HEAT TRANSFER COEFFICIENT IN AND OUTSIDE THE EVAPORATOR

The amount of heat energy absorbed by water during the test will be calculated to determine the effectiveness of the desalination device. Before getting the amount of energy absorbed by water, first calculate the evaporative heat transfer coefficient that is absorbed by water using the following equation (Singh et al., 2016).

$$h_{e,wg} = 16.273 \times 10^{-3} h_{c,wg} \left[\frac{P_w - P_{gi}}{T_w - T_{gi}} \right] \quad (1)$$

Where the Stefan Boltz constant value is used and $h_{e,wg}$ [W/m^{2}C], the temperature used to find the internal coefficient is the data obtained during the test, which is stored in the data logger. Where the convection heat transfer coefficient $h_{c,wg}$ [W/m^{2}C] can be found with the following equation (Singh et al., 2016).

$$h_{c,wg} = 0.884 \left[(T_w - T_{gi}) + \frac{(P_w - P_{gi}) T_W}{268.9 \times 10^3 - P_W} \right]^{\frac{1}{3}} \quad (2)$$

High water temperature results in an irradiative heat transfer process from the water to the inner surface of the glass. This greatly affects the condensation rate of water vapor on the glass surface. The value of the radiative and convection heat transfer coefficient that is absorbed by the outer glass [W/m^{2}C] can be calculated by the following equation (Boubekri & Chaker, 2011).

$$h_{rga} = \frac{\in_g \times \sigma \times \left(T_g^4 - T_{sky}^4\right)}{\left(T_g - T_a\right)} \tag{3}$$

Where convection heat transfer coefficient outside the evaporator can use the following equation.

$$h_{cg} = \begin{bmatrix} [5.7 + 3.8 \times V] \colon \leq 5m/s \\ [6.15 \times V^{0.8}] > 5\,\mathrm{m/s} \end{bmatrix} \tag{4}$$

Where h_{cg} [W/m^{2}C] and the total heat transfer coefficient outside the evaporator are as follows.

$$h_{goTot} = h_{cg} + h_{rg} \tag{5}$$

ENERGY, EFFICIENCY, AND EXERGY EVAPORATOR

The heat energy absorbed by the tool is not only received by the glass, but almost all surfaces in contact with free air get heat propagation from sunlight either by convection, conduction, or radiation.

$$T_{go} = \left[\frac{\frac{k_g}{L_g} + T_{gi} + h_{gotTot} T_a}{\frac{k_g}{L_g} + h_{goTot}} \right] \tag{6}$$

Where the thickness of the condensation cover L_g is 0.003, the thermal conductivity of the condensation k_g cover is 0.78 W/m^{2}C, and Ta is the ambient temperature. The value T_{W0} is taken from the water temperature when testing. After getting the water temperature in the basin or evaporator, then calculate the mass of water every hour during the test as follows

(Tiwari *et al*., 2018).

$$m_{eW} = \frac{h_{eW} A_b \left(T_W - T_{gi}\right)}{L} \times 3600 \qquad (7)$$

Following the equation (Tiwari, 2018), the energy and exergy equations absorbed by water during testing can follow the following equation (Tiwari *et al*., 2018).

$$En_{hourly} = h_{ewg} \left(T_w - T_{gi}\right) \qquad (8)$$

The final results of this study will be used as the basis for further research to determine the effectiveness of using the desalination tool in regions, especially Asia and Indonesia.

EXPERIMENTAL SETUP

To obtain clean water from the desalination process, planning for an efficient device in terms of material use and energy utilization will determine the success of the test. The solar desalination device is designed using a wall made of Aluminum Composite Panel (ACP) with a thickness of 0.004 m, which is expected to work according to the type of material. Furthermore, the thickness of the cover glass is 0.004 m for the steam condensation process as well as a place for sunlight to enter the planned evaporator. The inner surface of the evaporator is painted using a black dye which can absorb sunlight better. The outer side of the evaporator is isolated using Styrofoam material with a thickness of 0.020 m. Sea water is entered into the evaporator manually by opening the drain tap from the seawater storage tank until the water level in the evaporator reaches 0.003 m. The size of the evaporator is 1 m^2 with a 35^o glass slope towards the south from western Indonesia. The clean water obtained during the test will be accommodated in a container for a plastic bottle connected to the pipe into the evaporator as shown in Fig. 3. Clean water will be weighed and recorded how many hours and days as data and as comparison data with the amount of clean water calculated using the equation.

Figure 3 Experimental equipment and data acquisition systems

Data acquisition is used to record temperature changes during testing. On the inside of the evaporator are placed 4 type K thermocouples, namely on the bottom side, on the water, the middle chamber, and the inside of the condensing glass.

RESULTS AND DISCUSSIONS

By directly testing the desalination device for seven days and each experiment was carried out for 9 hours, hitting 08.00 a.m to 17.00 P.m local time. In the experiment, the heat energy used to raise the temperature of pure water expects heat from the sunlight without the addition of a heating collector as an additional electric heater.

OVERALL TEMPERATURE AGAINST SOLAR INTENSITY

The recorded history of temperature when testing the average solar intensity can be seen in Fig. 4. The temperature of the water, the outer and inner glass surfaces always follow the solar intensity. The water temperature and air temperature in the evaporator are always close together because the air in the evaporator is partly water vapor which evaporates from the water surface, which is at its temperature at the time of the test. The highest solar intensity on the fourth day reaches 689.1 W/m^2 by a significant temperature of the outer glass.

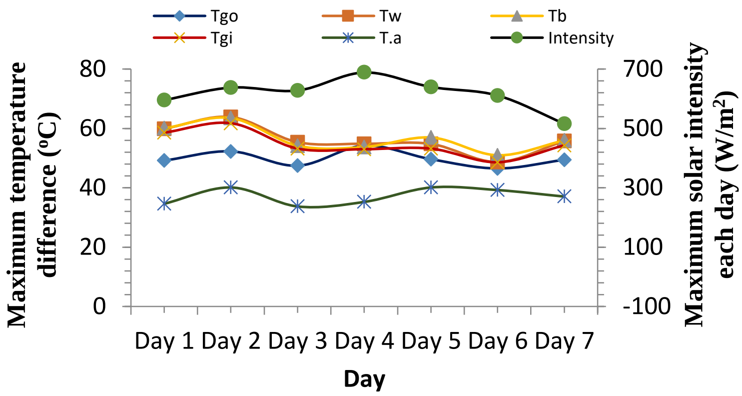

Figure 4 Day variation of maximum temperature difference, among the solar intensity and overall temperature

The picture shows the phenomenon that the temperature does not always follow the solar intensity. For example, at the end of the test time in the afternoon, the solar intensity drops because it starts in the afternoon, but the water temperature, the inner glass temperature, increases due to the accumulation of heat at the bottom of the evaporator in the water so that this will last long enough for the energy stored in the water to run out due to the heat transfer process to an environment where the temperature begins to decrease. The environmental temperature here also affects but not for tropics because environmental temperature always follows the high and low solar intensity and wind speed, in contrast to areas that have winter.

CHARACTERISTICS OF THE SYSTEM

In starting the exploitation of the solar desalination system single slope model, the main temperature that is expected to be high is the temperature of the water in the evaporator. The ambient temperature will help the condensation process from water vapor that will enter the clean water container. The highest water temperature in the test carried out was on the first day of testing, reaching 59.86 ^{o}C as shown in Fig. 5, and the faster it would produce water vapor if the water temperature in the evaporator could be increased. Therefore, the results of clean water obtained during testing are very significant for water temperature and will decrease when the heat energy absorbed by water from sunlight starts to run out.

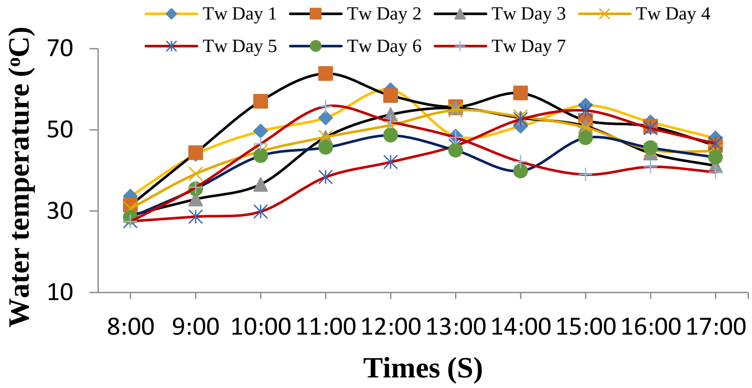

Figure 5 Hourly variation of water temperature (Tw)

The environmental temperature when testing will be the basis and reference for water temperature because, in a pure environment, there is no heat build-up which has the potential to increase the outside air temperature. The difference between the temperature of the water in the evaporator and the ambient temperature can be considered to represent the amount of energy absorbed by the water.

Table 1 Fresh water produced experimentally and numerically.

Experiment	Water Temperature during Experiments [ºC]			Fresh water produced [Kg]		Deviation %
	Max	Min	Averaged	Numerical	Experiment	
Day 1	59.86	33.67	46.77	1.76	1.52	15.48
Day 2	63.82	31.45	47.64	1.73	1.46	18.31
Day 3	55.34	28.91	42.13	1.19	0.96	24.07
Day 4	54.81	30.64	42.73	2.56	2.31	10.42
Day 5	54.75	27.51	41.13	0.83	0.73	13.74
Day 6	48.66	28.45	38.56	1.21	0.97	24.78
Day 7	55.75	27.45	41.60	1.59	1.35	17.81

Although in essence, the water vapor condensation process requires a lower temperature to become water, but the adherent water vapor will return to water by itself without any additional cooling on the evaporator glass, only expecting a cool air flow rate around the outer glass surface. Deviations on the third and sixth day is a phenomenon where the distance between the amount of water from the test results is far below the calculated amount of water, causing a very high range from other days. This fits perfectly with the recorded history of the highest solar intensity data in Fig. 6, namely on the fourth day of testing. Even though on the second day of testing, the maximum water temperature was higher when compared to the fourth day of testing, it happened for a short time so that the water temperature did not have time to absorb more energy and convert it into water vapor. The highest clean water production was found on the fourth day of testing, namely 2.5554 kg with a maximum water temperature of 54.81 ^{o}C in the evaporator.

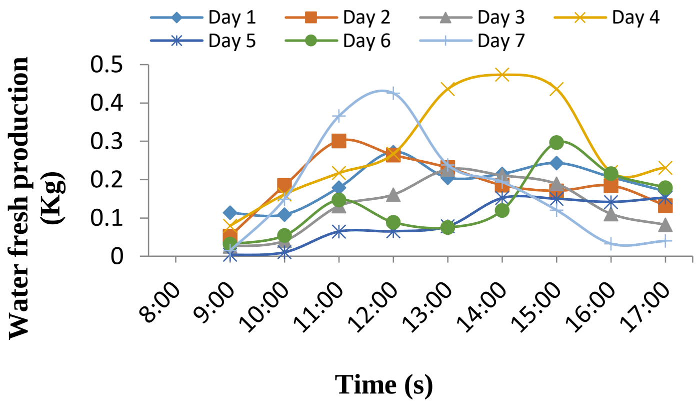

Figure 6 Hourly water fresh production

The rate of evaporation of water vapor in the evaporator is significantly derived from the heat of the sun. Even though the test starts at 08.00 a.m, the amount of clean water is taken from 09.00 a.m. The time span of one hour is the process of water evaporation. The amount of energy absorbed by water is observed during the test and is shown in Fig. 7 with a comparison by the heat energy source and the temperature of evaporation in the evaporator.

ENERGY AND ENERGY EFFICIENCY

Energy and energy exergy are needed in the process of finding and exploiting system performance, two parameters are used in this case. The first is the solar intensity that carries heat energy through the propagation of its rays into the evaporator glass and is absorbed by water so that the temperature increases and turns into water vapor that sticks to the inner surface of the glass. And the second is the amount of clean water produced during the testing process. The volume of clean water continues to be considered because the success of this tool lies in a large amount of clean water production. The energy efficiency of the desalination device shows the amount of energy used which is used to raise the temperature of the water so that the water evaporates and produces dew that sticks to the surface in the evaporator glass. Irregular energy absorption is shown in Figure 7 due to factors of erratic weather changes that prevent sunlight from entering the evaporator.

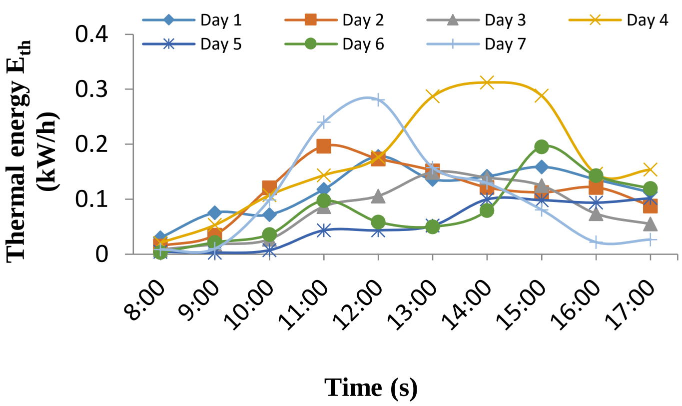

Figure 7 Hourly variation of absorbed thermal energy

The peak energy absorption, on average, starts from noon until late in the afternoon, even though when the test time is stopped, there is still residual heat energy absorbed in the water in the evaporator. This indicates that water production continues during the night, even with the remaining heat energy. The absorption of heat energy on the fourth day reached 0.312 kWh, and this lasted quite a long time for up to 3 consecutive hours the brightness on that day was very good shown Fig. 4 that solar intensity on that day was very high, reaching 689.1

W/m^2 higher than other days.

EXERGY AND ACHIEVEMENT

The effectiveness of the useful desalination tool is measured by calculating the value of exergy energy. The curve in Fig. 8 states the amount of energy that is useful for increasing the temperature of the water to form water vapor that flows into the clean water tube. The amount of exergy energy does not appear like the value of energy efficiency, and this is because the amount of energy used is not forced, which means that heat energy works naturally in heating water. There is no forced heating of the water. There has been an increase in water temperature due to the large heat energy during absorption, and the water heating process occurs naturally.

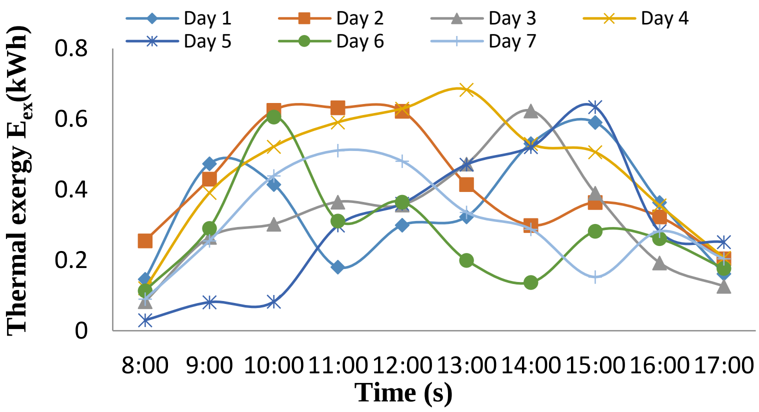

Figure 8 Hourly variation of thermal exergy

The achievement of using thermal exergy energy from the desalination device is shown in Fig. 9.

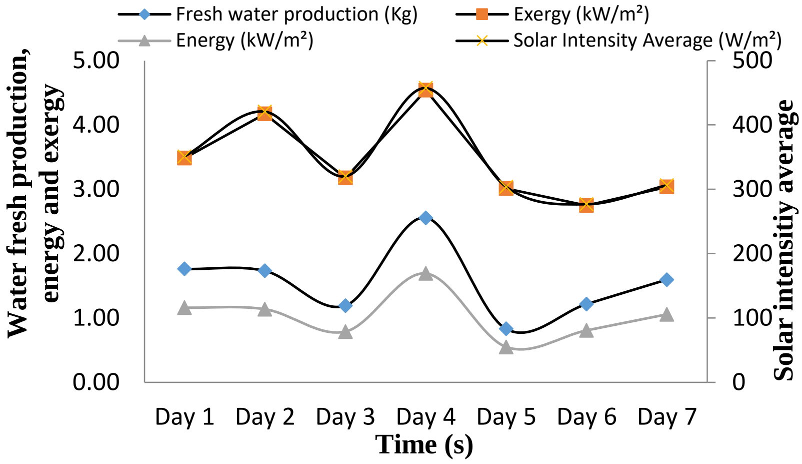

Figure 9 Shown on average the solar intensity against energy, exergy, and water production

The curve of Fig. 9 illustrates that the work of the solar desalination tool still depends on the solar intensity absorbed by water at the time of testing. The production of fresh water produced during testing always follows the rhythm of the energy absorbed by the water. This implies a high level of correlation between fresh water production, energy, exergy, and solar intensity. The observation from the test is that the water will increase if the water temperature is higher than the naturally accepted heat. However, it is feared that the wind speed outside the collector cover glass will not be able to reduce the temperature of the condensation vapor properly, so it is necessary to take into account the addition of heat energy to the condensation steam cooler. Suppose that the water temperature during the highest test on the second day reaches 63.54 ^{o}C with a water evaporation coefficient value of 24.62 W/m^2 at a wind speed of 3.35 m/s. The amount of water production obtained is 0.304 Kg this is a natural fit. If the water temperature is increased without cooling the condensing glass, this will be useless, remembering that the condensation process requires a low temperature to convert water vapor into water.

CONCLUSIONS

The water temperature will increase along with the brightness level of the day during the test (solar intensity). In the afternoon, the water temperature will last several hours higher than the environmental temperature due to the accumulation of heat in the evaporator so that the water production process will continue until evening even though there is no sunlight. With high solar intensity, the heat energy absorbed by water will last until the afternoon; this is in accordance with the conclusion of the previous statement that water production continues in the afternoon. Wind speed is needed in the desalination process to speed up the condensation process on the glass surface, so the evaporator needs a new function, namely as a cooler. Fresh water production is 2.31 kg/day. However, not all high temperatures provide large amounts of fresh water production. It is feared that water vapor is difficult to condense into the water because of the high temperature of the evaporator chamber, and a large amount of energy is useless. Water vapor adhering to the inner glass surface needs to be cooled so that it flows more easily into the fresh water tank and this is a subject of future research.

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