Energy analysis desalination of single slope solar still

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Abstract. The surface of the evaporator glass in the seawater desalination process by utilizing solar energy as the main energy source is a phenomenon that has been widely studied and developed in order to get increased performance efficiency to produce fresh water. The heat energy from the sun will enter through the surface of the evaporator glass and absorbed by water inside the evaporator, while the evaporator wall is insulated using aluminium foil with a thickness of 20 mm in the hope that the heat energy received will not be wasted around the environment. The process of evaporation of seawater begins when the water has reached the point of evaporation without pressure and occurs naturally. When seawater starts to evaporate, it can be calculated the amount of heat energy absorbed by the water until it reaches the point of evaporation, in order to determine the increase in performance and efficiency of the desalination process. Efforts to improve continue to be done if it is still possible to increase the efficiency and performance of desalination devices with various energy utilization methods. After testing, the highest solar intensity obtained on the test day reached 420.85 W/m², and the lowest solar intensity on the second day was 96.89 W/m². The highest evaporation heat transfer coefficient reaches 10.54 W/m²°C and the lowest is 4.42 W/m²°C. The highest convection heat transfer coefficient reaches 51.15 W/m²°C and the lowest heat conversion coefficient is 15.28 W/m²°C. The total absorbed energy reaches 6.26 kW and the lowest absorbed energy reaches 1.37 kW. Energy efficiency reaching 85% and the lowest energy efficiency is 35%.

1. Introduction
The development of seawater processing technology into clean water is based on the importance of clean water as a human need in everyday life and agricultural and industrial needs. About 97% to 97.5% of the water on the earth's surface is saltwater and about 2% is stored as ice in the polar region and 1% is freshwater available for the needs of plants, animals and human life [1, 2]. Every day the availability of drinking water from natural sources is shrinking due to the rapid growth of the human population and the poor processing of dirty water produced from industrial wastes using chemicals that pollute clean water sources [3]. Some desalination technologies have been developed including, Reverse Osmosis (RO), Thermal Vapor Compression (TVC) Mechanical vapor compression (MVC), multi-stage flash distillation (MSF), multi-effect distillation (MED) and Vacuum Desalination (VD) [3, 4]. But some researchers say the desalination process using solar energy is the most efficient, economical and environmentally friendly technology [3, 4, 5, 6]. In the last 40 years, desalination has been developed and produced ideas in developing the model and methods including single slope models and double slopes by the workings of passive and active systems [6, 7]. However, the amount of clean water produced from a single slope model desalination device is greater than the amount of...
water produced in the double slope model [3]. Tiwari et al. (2016) conducted a single slope and double slope desalination model experiments and obtained a number of clean water production on a single slope of 499.1 L/year, and the amount of clean water production on a double slope model 464.68 L/year or around 1.3 liters per day [3].

Many variations in the slope of the glass have also been carried out starting from 15°, 30° and 45° as well as the depth of seawater inside the evaporator ranging from 0.01 m, 0.02 m, 0.03 m, 0.04 m, 0.05 m, 0.08 m, 0.12 m, 0.16 m and 0.18 m [3, 8, 9, 10]. D.B. Singh (2016) conducted an experiment on the desalination of a single slope model of the total power system received by the evaporator 1159.43 kW and the amount of clean water production of 1739.15 kg/year or about 1.73 Kg per day [11]. In the following year, D.B.Singh (2017) added a copper and heter electric collector whose photovoltaic electricity flow to a single slope desalination model pasiv system and total energy obtained by 3389.00 kW and the amount of clean water production obtained 4519.54 kg/year or about 12.55 kg/day [12]. In addition to the use of solar energy, wind and geothermal energy are also considered to aim at efficiency and also the energy used is environmentally friendly [13, 14]. Of the three types of energy that are often used in desalination devices, namely the sun, wind and geothermal energy, solar energy is the most widely used up to 73% compared to other energy [15]. Before the development of the use of solar energy, the use of electrical energy was also carried out, around 10.000 tons of fuel was spent on the desalination process [16]. The energy received is very influential on the amount of the rate of production of clean water produced in desalination devices, it requires the use of good energy to reduce the amount of energy wasted during the process carried out. This study aims to review the overall heat energy absorbed by the single slope seawater desalination process by adding thickness and insulation material.

2. Method and equipment

Tests carried out for 8 days with the location of the evaporator and glass evaporator to the south to be able to receive heat energy from the sun perfectly. Six thermocouples were placed in areas that wanted to know the temperature, namely the temperature of the outer glass, the inner glass temperature, the basin temperature, the water temperature, and ambient temperature. The data was recorded every hour and was used to find the heat transfer coefficient and the total energy absorbed in the desalination device (Figure 1). The following are dimensions of the solar distillation device and the physical properties of the materials used. In Table 1 we can see the specifications and physical properties of the materials used in the desalination device.

**Table 1. Physical properties of distillation equipment [3]**

| Symbol | Value      | Symbol | Value     |
|--------|------------|--------|-----------|
| Ag     | 1 m²      | Li     | 0.02 m    |
| hbw/f  | 100 W/m² K| Ki     | 0.039 W/m °C |
| σ      | 5.67x 10⁻⁸ W/m² K⁻¹ | α_b   | 0.8       |
| Ab     | 1 x 1 m   | α_w   | 0.6       |
| L_g    | 0.003 m²  | α_g   | 0.05      |
| K_g    | 0.78 W/m² °C⁻¹ | ε_eff | 0.9048    |
| M_w    | 20 Kg     | ε_g & ε_w | 0.95 |
The dimensions of the desalination device are adjusted according to previous research D.B.Singh (2016). The workings of the desalination tool used are to open the inlet valve from the reservoir tank into the basin until the water level reaches 0.02 m from the bottom of the evaporator. After the water in the evaporator is filled enough, then operate the logger temperature data to start recording the temperature of the outer glass (Tgo), the temperature of the glass (Tgi), the water temperature (Tw), basin temperature (Tb), and ambient temperature (Ta), while the intensity data The sun is recorded using a solar intensity sensor. Test data obtained is stored and calculated using Excel 2010 M.S.Office.

The data obtained during the test are analyzed so that the calculation temperature of the outer glass and the inside of the glass are also known and also to calculate the amount of heat transfer coefficient that occurs during the test. There are two parts that will be calculated the heat transfer coefficient value on the evaporator, namely the heat transfer coefficient outside and the heat transfer coefficient inside. The outer heat transfer coefficient includes the convection heat transfer coefficient from the glass to the environment and the heat transfer coefficient from the glass environment. Whereas the heat transfer coefficient is in the convection, radiation and evaporation heat transfer coefficients. Calculating the temperature of the outer glass $T_{go}$ evaporator can follow the following equation [11, 17, 18].

$$T_{go} = \frac{K_g T_{go} + h_{tg}T_u}{L_g + h_{tg}}$$  \hspace{1cm} (1)

Calculating the temperature of the inner glass $T_{gi}$ can use the following equation [11, 17, 18].

$$T_{gi} = \frac{\alpha_g I_g(t)A_g + h_{tg}T_u A_b + U_{c,g}T_a A_g}{U_c g_u A_g + h_{tg} A_b}$$  \hspace{1cm} (2)

To get the total energy absorbed by the evaporator, first, calculate the heat transfer coefficient outside or inside. Calculating the convection transfer coefficient outside $h_{tg}$ the evaporator can use the following equation [3]
Wind speed is very influential on the large heat transfer coefficient of the evaporator because it relates to the environment. To calculate the heat transfer that occurs in the evaporator, $h_{eg}$ can use the following equation [3]

$$h_{eg} = \varepsilon_g \times \sigma \times \left( T_g^4 - T_{sky}^4 \right) \left( T_g - T_w \right)$$

After getting the total external heat transfer coefficient, it calculates the inner heat transfer coefficient. To calculate the amount of heat transfer coefficient outside the water evaporator $h_{ew}$ into the air in the evaporator, the following conditions can be used [3, 11, 12, 17, 18, 19]

$$h_{ew} = \varepsilon_{eff} \times \sigma \times \left[ \left( T_w + 273 \right)^4 + \left( T_{ew} + 273 \right)^4 \times \left( T_w + T_{gl} + 546 \right) \right]$$

Effective emissivity $\varepsilon$ and Stefan-Boltzmann numbers $\sigma$ can be obtained from table 1. To find the convection heat transfer coefficient in water $h_{cw}$ can use the following equation [3, 11, 12, 17, 18]

$$h_{cw} = 0.884 \left( T_w + T_{gl} \right)^{\frac{1}{5}} + \left( \frac{P_{gw} - P_{gw}}{268.9 \times 10^3 - P_w} \right) \left( T_w + 273 \right)^4$$

To calculate the amount of evaporation heat transfer coefficient that occurs in the evaporator $h_{ew}$ can use the following equation [3, 11, 12, 17, 18].

$$h_{ew} = 0.034 \times 5.67 \times 10^{-8} \left[ \left( T_{ew} + 273 \right) + \left( T_{ew} + 273 \right)^4 \times \left( T_{ew} + T_{gl} + 5546 \right) \right]$$

After getting the heat transfer coefficient outside and inside, we can find out the total energy absorbed by the evaporator every day. The energy received and absorbed by the evaporator every hour can be calculated using the following equation [3, 11, 12, 17, 18].

$$E_{nhour} = h_{ew} \left( T_{ew} - T_{gl} \right)$$

After getting a large amount of energy absorbed every hour, energy efficiency can be sought from the desalination device using the following equation [3, 11, 12, 17, 18].

$$\eta_{En} = \frac{\sum_{}\left( m_{ew} \right) \times L}{\left( A_g - I_s(t) \right) \times 3600} \times 100$$

The above equation is used to find the efficiency of the evaporator.

3. Results and discussion

The test was carried out for 7 days by observing the temperature of the glass evaporator outside and also the temperature of the water and air in the evaporator by recording the clock. There are 6 thermocouples installed on each side that you want to observe the temperature.

After analyzing the test data, it was found that the heat transfer coefficient in the average evaporator can be seen in Figure 2 below. From Figure 2 can be seen on the fifth day the test of solar intensity is very high, which is 420.85 W/m² so that the evaporation heat transfer coefficient that occurs on that day is very high compared to the previous day which reached 10.54 W/m² °C, this is
due to heat energy enter high and absorbed by water so that the water evaporates faster. While on the second day the intensity of the sun looks low only reaching 96.89 W/m² and the evaporation heat transfer coefficient also looks low only reaching 4.42 W/m²°C this is because the intensity of the sun is very low so that the energy entering and absorbing also causes the evaporation rate the water in the evaporator is not as fast as on the fifth day. With the same solar intensity, the convection coefficient obtained on the fifth day is 1.32 W/m²°C and the lowest convection coefficient on the second day is 1.16 W/m²°C. While the radiation coefficient obtained the highest data on the fifth day which is 6.58 W/m²°C and the lowest on the second day is 5.7 W/m²°C, while the glass temperature is low, the rate of evaporation in water is very fast.

The solar intensity and the wind speed during the test greatly affect the rate of heat transfer from the glass of the environment, the heat transfer coefficient that occurs on the outside of the evaporator can be seen in Figure 3.

**Figure 2.** Graph of the solar intensity of the heat transfer coefficient in the evaporator.

In the picture above, it can be seen that the highest convection coefficient occurs on the fourth day which is 51.15 W/m²°C and the lowest coefficient is seen on the sixth day 15.28 W/m²°C. The high solar intensity affects the magnitude of the convection coefficient from the outer glass surface to the environment, this is also because the wind speed on the fourth day is much higher, reaching up to 14.11 m/s compared to the wind speed on the sixth day only reaching 2.76 m/s. While the highest radiation heat transfer coefficient was seen on the second day at 13.25 W/m²°C and the lowest on the seventh day 8.62 W/m²°C.

**Figure 3.** Graph of the solar intensity of the heat transfer coefficient outside the evaporator
Even though the amount of energy absorbed by the water inside the evaporator is large, then the rate of consumption of water will be greater and this is expected to increase the amount of clean water production. The amount of energy absorbed must be in accordance with the amount of water produced to minimize losses due to wasted energy. The total energy absorbed by water and energy efficiency in the evaporator can be seen in Figure 4 below.

![Figure 4. Graph of energy towards energy efficiency absorbed by the evaporator](image)

The highest total absorbed energy was seen on the fifth day of 6.28 kWh and the lowest total absorbed energy on the second day was 1.37 kWh according to the high intensity of the sun shown in Figure 2 and Figure 3. The highest energy efficiency was also obtained on the fifth day to 58.89% and the lowest efficiency obtained on the second day is 34.05%.

4. Conclusion

With the highest solar intensity 420.85 W/m² obtained by total heat transfer coefficient in the evaporator by summing the evaporation heat transfer coefficient, convection heat transfer coefficient and radiation heat transfer coefficient which is 18.44 W/m² °C, and total heat transfer coefficient in the lowest evaporator with sun intensity 96.89 W/m² which is 11.31 W/m² °C. While the total heat transfer coefficient is 62.63 W/m² °C and the lowest total heat transfer coefficient is 25.57 W/m² °C. The highest energy absorbed by the evaporator was obtained on the fifth day of 6.28 kWh and the lowest energy was absorbed by the evaporator on the second day, namely 1.37 kWh. The highest efficiency on the fifth day is reaching 58.89% and the lowest energy efficiency on the second day is 34.05%.

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