ISSN 2087-3336 (Print) | 2721-4729 (Online)

TEKNOSAINS: Jurnal Sains, Teknologi dan Informatika
Vol. 13, No. 1, 2026, page. 137-143
http://jurnal.sttmcileungsi.ac.id/index.php/tekno
https://doi.org/10.37373/tekno.v13i1

Seawater evaporation using natural flow solar still

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Submitted: 28/5/2025 Revised: 05/09/2025 Accepted: 18/10/2025

ABSTRACT

One-third of the world's population, including coastal communities in Indonesia, experiences a shortage of clean water for daily needs. By 2050, it is estimated that around 25% of the world's population will be affected by the clean water crisis. This research is directed at examining the role of natural airflow in a solar still system in determining the evaporation rate during the seawater desalination process. Water temperature has a significant influence on solar still performance, where increasing water temperature and airflow velocity within the system will increase the evaporation rate. This research focuses on measuring the evaporation rate of seawater in a solar still device that relies on natural flow as its working mechanism. The desalination process is equipped with a condenser that functions to convert water vapor into liquid. In addition, there is a measurement system that includes temperature parameters and airflow velocity to ensure effective operation and precise data monitoring. Evaporation data was collected periodically every 15 minutes during a two-day observation period, to conduct a comprehensive analysis of the desalination system's performance. Research results show that the use of solar energy with natural flow can effectively accelerate the evaporation rate. The average experimental result is 231 grams and the theoretical result is 174 grams, with a percentage of 57%. This system has the potential to increase the efficiency of the desalination process, especially if developed according to local climate conditions that affect the overall performance of the device.

Keywords: Desalination; evaporation rate; natural flow.

1. Introduction

One third of the world's population lives in countries that lack clean water to meet their citizens' living needs [1]. Meeting the need for clean water, one of our daily activities, is a global challenge. According to WHO data (2000), approximately 2 billion people in 40 countries worldwide experience the impacts of water shortages every day. It is predicted that by 2050, one in four people worldwide will experience the impacts of clean water shortages [2]. Indonesia is a country surrounded by sea water, and the shortage of fresh water affects many people living on the coast [3]. People in coastal areas have to buy clean water every day to meet their consumption needs.

The clean water crisis is a serious problem that needs to be addressed immediately, one way is by utilizing the abundant sea water to be processed into clean water and salt [4][5]. Address this problem, desalination is used as a solution by removing salt and mineral content from seawater. Desalination is the process of treating seawater to produce fresh water [6]. A desalination device that uses the sun's heat to evaporate water and then condenses the steam to produce purified water [7][8]. Previous research on evaporation in desalination systems has been carried out extensively, such as sunlight intensity, pressure, and forced flow in solar still systems [9][10]. However, no research has yet been conducted under natural flow conditions in a solar still system. Increasing water temperature and air flow velocity in a natural flow solar still system directly impacts the evaporation rate. Furthermore, this process is also influenced by the surface area of the water, which serves as the evaporation medium.

Air pressure can be lowered by creating an air flow over the water's surface. In the working process of a solar still, water evaporation always involves a change in pressure between the water and the space above it [11]. The increase in water temperature and the intensity of air flow in a solar still system with natural flow has been proven to have a direct influence on increasing the evaporation rate, where this process is also influenced by the surface area of water available as an evaporation medium [12]. This study aims to evaluate the rate of seawater evaporation in a solar still-based desalination unit that utilizes natural flow mechanisms. This study focuses on the mechanism of seawater evaporation, which is influenced by ambient temperature, one of the main parameters in the desalination process.

2. Method

In Figure 1, the design of research equipment 1 (seawater tank), 2 (side glass), 3 (top glass), 4 (front glass), 5 (glass support pole), and 6 (condenser). The seawater desalination process uses a condenser shaped like a trunk. This allows water vapor from the evaporation area in the solar still to enter efficiently into the condenser section. This condenser is designed with a wider space to support a more effective condensation process. This research uses a laboratory-scale actual experimental method. The test was carried out in the Mechanical Engineering laboratory of Muhammadiyah University Prof. Dr. Hamka. The test was carried out using variables (T_{m1}) Inlet air temperature on the first day, (T_{m2}) Inlet air temperature on the second day, (T_{water1}) Sea water temperature on the first day, (T_{water2}) Sea water temperature on the second day, (T_{glass1}) Glass temperature on the first day, and (T_{glass2}) Glass temperature on the second day as in Figure 1.

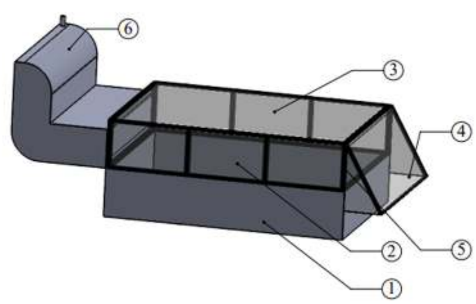

Figure 1. Research design tools

The desalination test scheme used in this study, as shown in Figure 2 for RH (air humidity), involves heating seawater in the main container using a 1000-watt halogen lamp, with a heat intensity of 1200 W/m² during the evaporation process. The resulting water vapor is directed toward a steam funnel before entering the condenser. This evaporation process takes place under the light radiation of the lamp, which causes the seawater in the reservoir to evaporate and move to the condenser. To maintain a stable water level in the condenser, the condenser container is designed with a specific depth and is equipped with a water circulation system that utilizes a pump for the cooling process. Thus, the water level in the control container remains constant, while the volume of seawater in the reservoir gradually decreases due to evaporation.

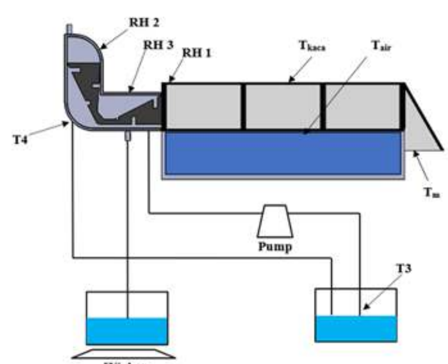

Figure 2. Research tool scheme

In this study, air flow was directed from only one direction, namely at the front of the tank mouth, to ensure the optimal rate of seawater evaporation during the desalination process. This airflow regulation is expected to increase the efficiency of the evaporation process. The tools and materials used in this study can be seen in Table 1.

Table 1. Research tools and materials

Name	Specification
Digital thermometer	-50°C-110°C, resolution 0.1°C, accuracy ±0.1°C
GM816 Anemometer	0 – 30 m/s, resolusi 0,1 m/s
Digital hygrometer	10% - 99%, resolution 1%, accuracy ± 1%
Philips halogen lamp	1000watt
Digital scales	0 kg – 20 kg
Aluminum	Aluminum plate 2 mm
Styrofoam	Styrofoam 100×50×2 cm
Aquaproof	1 kg gray

Water evaporation is the process of transformation from a liquid to a gaseous phase, triggered by the difference in pressure between the water surface and the air above it. Seawater desalination is achieved by evaporating the water, forming water vapor, while the salt content remains separate due to differences in physical characteristics. The water vapor is then condensed to produce fresh water. The following is the equation for water evaporation [13].

$$Elp = (0{,}37 + 0{,}0041\,\bar{u})(P_s - P_w)^{0{,}88} \tag{1}$$

Keterangan:
Elp = Evaporation rate, in/day
$\bar{U}$ = Wind movement, miles/day
P_s = Saturated vapor pressure of water, inHg.
P_w = Actual vapor pressure of air at given temperature and humidity conditions, inHg
The rate of evaporation of mass per unit area is calculated using the following formula [14]:

$$\frac{m_w}{A} = \frac{Elp}{12}\rho_w \tag{2}$$

Where:
ρ_w = Water density, lb/ft³

Pressure plays an important role in the rate of evaporation, which occurs when the air pressure above the water surface is lower than the water vapor pressure, so it is necessary to calculate the pressure using the following equation [15]:

$$P_w = \exp[25.317 - \frac{5144}{T_w + 273}] \tag{3}$$

$$= \exp\left[25{,}317 - \frac{5144}{29{,}1 + 273}\right]$$

$$= 8{,}28\ Pa$$

Where:
Pw = water pressure (Pa)
Tw = temperature (C)

3. Result and Discussion

This study involved testing six data sets: T_{m1}, T_{m2}, T_{water1}, T_{water2}, T_{glass1}, and T_{glass2}. The tank was heated to 27°C. Data collection began at 8:00 a.m. and continued until 5:00 p.m. WIB with 15-minute intervals. The method was applied for two days. The desalination process can be seen in Figure 3.

Figure 3. Desalination process

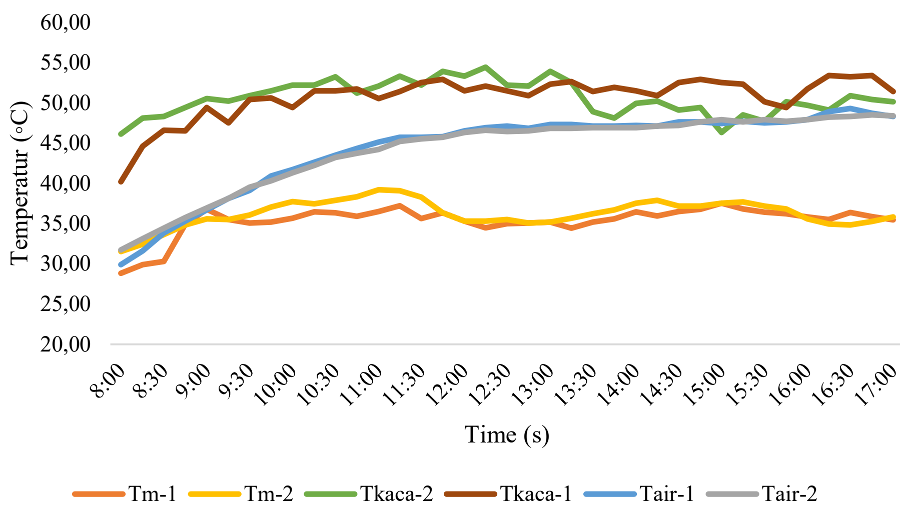

Figure 4. Evaporation temperature

Figure 4 presents data on temperature changes over time from 8:00 AM to 5:00 PM for six different parameters, namely T_{m1}, T_{m2}, T_{water1}, T_{water2}, T_{glass1}, and T_{glass2}. The results show that all parameters experienced a significant increase in temperature between the morning and approximately 12:00 PM, then stabilized or experienced mild fluctuations until the end of the observation period. Parameters T_{glass1} and T_{glass2} showed the highest temperature values throughout the observation period, with a range between 45°C and 55°C. This trend indicates that the locations or components represented by T_{glass1} and T_{glass2} experienced more intensive heating compared to parameters T_{water1} and T_{water2}. Meanwhile, parameters T_{water1} and T_{water2} showed a more gradual increase pattern, with initial temperatures around 30°C and reaching over 45°C towards the afternoon. This indicates a relatively stable heat accumulation. Parameters T_{glass1} and T_{glass2} recorded the lowest temperatures, ranging from 30°C to 40°C, and showed mild fluctuations throughout the day. Significant differences between T_m, T_{glass}, and T_{water} parameters indicate thermal variations likely caused by differences in environmental conditions, media, or measurement locations. Overall, these data reflect a consistent heating pattern over time, with a temperature peak occurring at midday and a steady trend in the afternoon. Variations between parameters demonstrate the importance of considering the characteristics of each measurement point in thermal analysis.

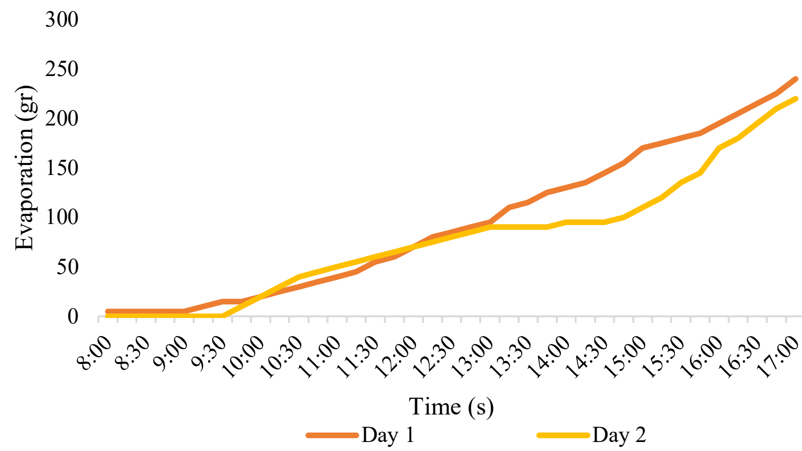

Figure 5. Evaporation

Figure 5 shows the relationship between time and evaporation volume in a two-day natural flow solar still experiment (Day 1 and Day 2). The horizontal axis shows the observation time from 8:00 AM to 5:00 PM with 30-minute intervals, while the vertical axis represents the evaporation volume. On Day 1, the evaporation rate increased significantly at 5:00 PM, reaching 240 grams. Conversely, on Day 2, although a similar increase pattern was observed, the evaporation volume was slightly lower than on the first day at the same time, at 220 grams. This difference is influenced by external factors, such as sunlight intensity, temperature, or humidity. Overall, this graph shows that evaporation occurs consistently and optimally, with the greatest increase occurring during the day when sunlight intensity is higher.

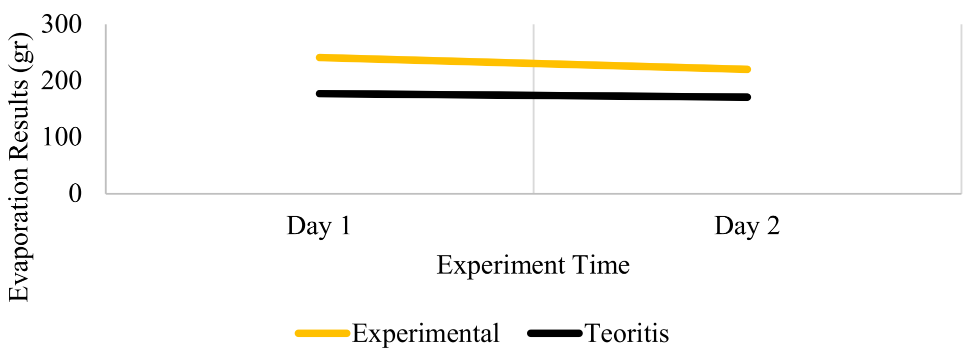

Figure 6. Experimental and theoretical graphs

Figure 6 displays a comparison graph between experimental and theoretical data for two days. The horizontal axis represents days 1 and 2, while the vertical axis shows the measured values. The actual evaporation rate on day 1 yielded 241 grams, and on day 2 it yielded 220 grams. The theoretical evaporation rate was also calculated on day 1 and yielded 177 grams, and on day 2 it yielded 171 grams.

Figure 6 shows the average experimental value for days 1 and 2 was 231 grams, while the average value was 174 grams. Therefore, the difference between the experimental and theoretical values is 57%. The experimental results were unstable due to the use of natural airflow, which is unstable. This difference between the experimental results and theoretical predictions indicates that the experimental values are generally higher than the theoretical values.

4. Conclusion

The results of this study indicate that the seawater evaporation process in a solar still desalination unit operating on the natural flow principle plays a significant role, with a value of 241 grams on the first day, which then decreased to 220 grams on the second day at the same time. This decrease in evaporation rate occurred despite the temperature on the second day being higher, indicating the influence of other parameters such as air humidity or solar radiation intensity on evaporation efficiency.

These findings form the basis for the development of desalination technology that considers various environmental factors in optimizing the seawater purification process in coastal areas..

Acknowledgment

The team would like to express its deepest gratitude to the Renewable Energy Research Team, Faculty of Industrial Technology and Hamka, for the financial support provided for this research.

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