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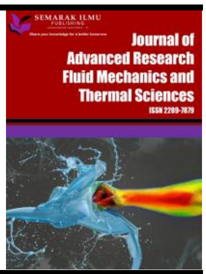

The Impact of Wind Speed on the Rate of Water Evaporation in a Desalination Chamber

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ABSTRACT

Water is very important to human life, and its use is increasing as the population grows. However, sources of fresh water on the earth's surface are limited, as seawater covers most of the earth. Therefore, seawater desalination is a potential solution to water shortages. Desalination is the process of removing salt from seawater to produce fresh water. Desalination is particularly useful approach in Indonesia because two-thirds of this nation's territory is ocean. Desalination involves two stages: evaporation and condensation. Wind speed affects the rate of evaporation. Thus, this study explores the effect of wind speed on the rate of evaporation. Wind speed was regulated using a fan, and wind speeds of 0 m/s, 0.6 m/s, 2.6 m/s, and 5 m/s were tested; the water temperature was kept constant at 60 ℃. The data were analyzed statistically to determine the effect of wind speed on the evaporation of seawater. The highest rate of evaporation occurred at a wind speed of 5 m/s and the lowest at a wind speed of 0 m/s. The highest amount of condensation occurred at a wind speed of 0.6 m/s and the lowest at a wind speed of 5 m/s.

1. Introduction

Water is very important for humans. Water consumption increases as the number of people on earth increases, and a global population increase of 15% will reduce the quality and amount of clean water by 40% [1-3]. Clean water shortages occur all over the world, including in Indonesia. In fact, in several places in Indonesia lack clean water and must buy it from other areas [4,5]. Even though Indonesia is the largest archipelagic country in the world and two-thirds of its area (3,288,683 km^2) consists of ocean, shortages of clean water occur in many places, especially in coastal regions, only 66.54% have access to clean water [6-8]. This is a serious concern; only 2.8% of water on the earth's surface is fresh, while the rest is advance water [9]. Therefore, seawater is a potential source of clean water, and due to the abundance of seawater in Indonesia, desalinating seawater to convert it to clean water could help address the nation's water problems [10,11].

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Desalination is the process of removing the salt from seawater to produce fresh water that uses two processes to separate salt from water: evaporation and condensation [12-16]. The resulting fresh water can be used for various human needs, including drinking, washing, and cooking [17]. In addition to converting seawater into fresh water, the desalination process also produces salt through the separation of seawater content. The salt produced through this process has potential as a valuable product. However, modern desalination equipment is fairly inefficient due to ineffective evaporation processes [18].

Many studies on evaporation have been conducted. Some study that has been explored include the effect of pressure and material on evaporation, the impact of the angle of the glass roof and the mirror at the base of the basin on evaporation; the effect of sunlight on evaporation; the effect of water level on evaporation; the effect of temperature on evaporation; and the use of mist sprayed from a nozzle to evaporate water [19-35]. However, no previous study has explored the effect of wind speed on the evaporation of sea water in desalination chamber.

Therefore, the present study aimed to determine the effect of wind speed on the evaporation of seawater in a desalination device. This study has analysed the impact of various wind speeds on the evaporation of seawater at a constant temperature. This research is believed to be beneficial for traditional salt-making farmers who still take advantage of natural conditions in the salt-making process. Evaporation in salt fields depends on wind speed and solar heat. The results of this study can be used to improve salt industry facilities in order to increase their efficiency.

1.1 Mass Transfer

Mass transfer is the transfer of a substance in a mixture from one location to another [36,37]. Mass transfer can also be interpreted as the driving force that causes the movement of molecules in liquid [38-41]. The mechanism of mass transfer is largely due to the dynamics of liquids [42]. Many physical and chemical processes involve mass transfer, including adsorption, evaporation, precipitation, membrane filtration, desalination and drying [43]. Engineers use mass transfer to describe physical processes involving molecular diffusion and the convection transfer of chemical species within a system. Previous studies have shown that number of mass transfer can vary depending on the physical and chemical parameters of the system, such as temperature, pressure, viscosity, and flow rate [44,45].

Evaporation is the process by which water transforms into water vapour or gas. It is caused by the difference in pressure between the surface of the water and the air above it [46]. Evaporation can be affected by several physical parameters, including humidity, wind speed and air temperature [47]. There are various methods for measuring evaporation [48].

Evaporation rate calculation:

According to Yuga *et al.,* [49], the rate of evaporation is defined as

$$\mathrm{E_{lp}} = (0.37 + 0.0041\,\bar{\mathrm{u}})(\mathrm{p_s} - \mathrm{p_w})^{0.88} \tag{1}$$

where

$\mathrm{E_{lp}}$ = evaporation rate, in/day
$\bar{\mathrm{u}}$ = wind movement, mi/day
$\mathrm{p_s}$ = saturation vapor pressure at air temperature water vapor, in Hg, and
$\mathrm{p_w}$ = actual vapor pressure of air under conditions of temperature and humidity, in Hg.

To calculate the mass evaporation rate per unit area, uses the following equation [50]

$$\frac{\dot{m}_w}{A} = \frac{E_{lp}}{12}\rho_w \tag{2}$$

where
E_{lp} = mass evaporation rate per unit area, $kg/h \cdot m^2$ and
ρ_w = water density, lb/ft^3.

To determine the efficiency of the condenser in a desalination system, condensation efficiency is calculated using the following equation [51]

$$(\eta) = \frac{\text{condensation results}}{\text{evaporation result}} \times 100\% \tag{3}$$

1.2 Pressure

Pressure is one of the primary factors impacting the rate of evaporation [52]. Therefore, it is necessary to determine the pressure in the water and on its surface because evaporation occurs when the air pressure above the water is lower than the surface water pressure. When the air pressure is low, water molecules evaporate into the atmosphere, leaving water behind. During evaporation, water molecules draw heat from the environment, which causes the temperature of the water to decrease and reduces the concentration of water molecules in the water.

The following equation is used to calculate water pressure [53]

$$P_w = \exp\left[25.317 - \frac{5144}{T_w + 273}\right] \tag{4}$$

where
P_w = water pressure (Pa) and
T_w = water temperature (°C).

2. Methods

In this study, a temperature of 60°C was maintained in the main water container. Several wind speeds (0 m/s, 0.6 m/s, 2.6 m/s, and 5 m/s) were obtained using an adjustable fan to compare the rate of seawater evaporation during desalination at different wind speeds. High wind speeds can help remove the water vapor from the surface of the desalination device and reduce the pressure, thus accelerating evaporation. However, wind speeds that are too high can cause vortices and energy losses [54].

Thus, various wind speeds were compared in this study to help determine the optimal conditions to maximize the evaporation rate of seawater during desalination. The following tools were used as shown in Table 1.

Table 1
Measurement tools

No	Tools	Function	Specifications
1	Thermostat XH-W3001	Temperature	-50℃ -110℃, ±0.1℃.
2	Anemometer GM816	Wind speed	0 – 30 m/s, 0.1 m/s,
3	Digital thermometer	Water temperature	-50℃ -110℃, ±0.1℃
4	Digital hygrometer	Humidity	10% – 99%, ±1%
5	Digital scale 40 kg	Water mass	0 – 40 kg, 0.005 kg
6	Digital scale 5 kg	Condensed water mass	0 – 5 kg, 1 gr

Figure 1 shows the design of the research tool. The study was conducted in the mechanical engineering laboratory of the Faculty of Industrial and Informatics Technology at the Universitas Muhammadiyah Prof. Dr. HAMKA from March to August 2022.

Figure 2 shows a schematic of a desalination device used in this study. In this device, seawater in the main container is heated to maintain the water temperature at 60℃. As the water evaporates, water vapour moves towards the steam funnel and through it to the condenser. Wind speeds of 0 m/s, 0.6 m/s, 2.6 m/s and 5 m/s were tested. Seawater in the holding container is channelled to the condenser by a pump. Water from the condenser flows into the control container through the condenser outlet. To maintain the water level at a certain level, the control container has an overflow into the holding container. Therefore, the water level in the control container remains constant, while the water level in the holding container decreases due to evaporation. So that the rate of evaporation is measured by the mass of the water in the holding container. Every 15 minutes, the mass of the water in the holding container is measured using a digital scale to determine whether the water mass has reduced due to evaporation. In Figure 2, data are collected at RH1, RH2, T1 and T2. Where T1 is temperature of the incoming air above the seawater in the main container, T2 is temperature of the outgoing air over the seawater in the main container, RH1is humidity of the incoming air over the seawater in the main container and RH 2 is humidity of the outgoing air over the seawater in the main container.

This study was conducted indoors to minimise of uncontrollable variables such as wind speed and solar radiation

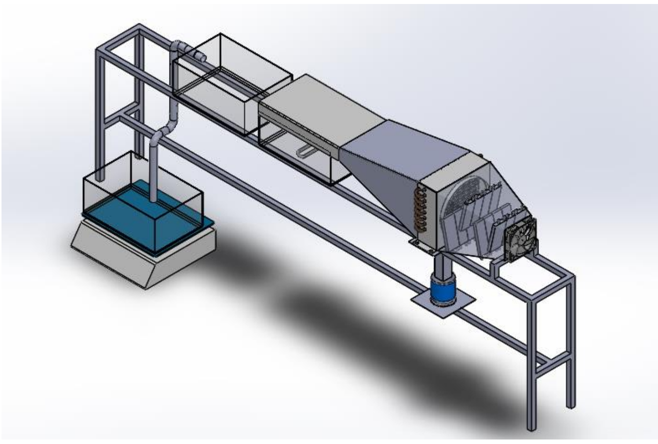

Fig. 1. Experimental rig

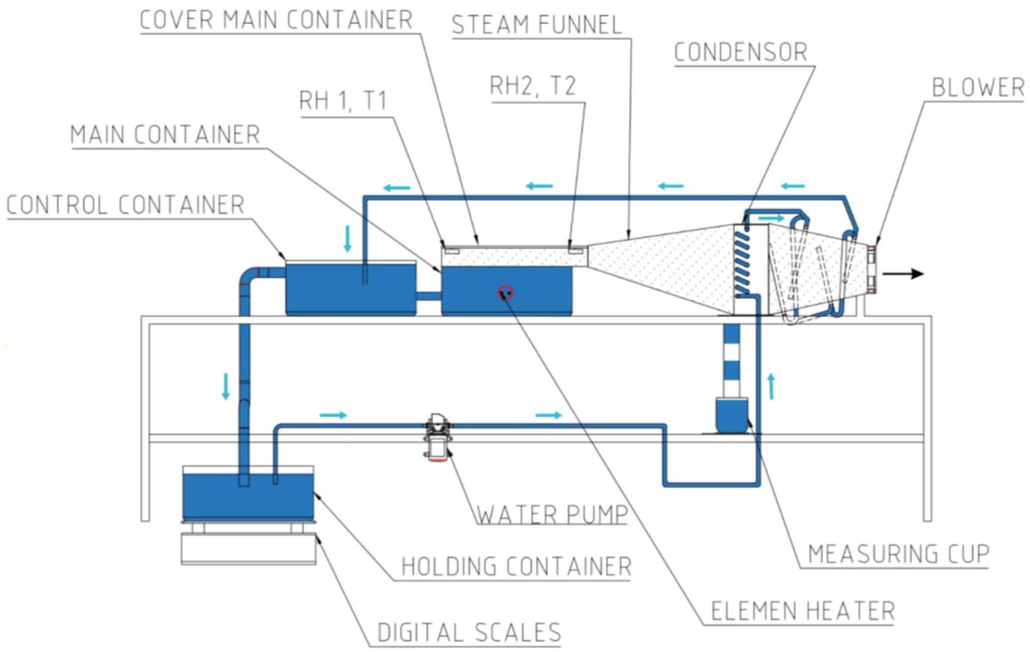

Fig. 2. Experimental setup

3. Results

In this study, four variables were tested: wind speeds of 0 m/s, 0.6 m/s, 2.6 m/s and 5 m/s. Other data collected were water and air temperature, relative humidity, mass of water in holding container to measure evaporation results and mass of measuring cup to measure condensation results.

Figure 3 shows the evaporation and condensation data collection processes. Seawater in the main container is heated using a heater which is regulated by a thermostat to maintain a constant temperature of 60℃. Data collection begins when seawater in the holding container is pumped into the condenser, from there to the heat exchanger, and from there to the control container, which is connected to the main container. This ensures a constant level of seawater in the main container. Data were collected every 15 minutes for two hours.

Fig. 3. Desalination equipment

3.1 Total Evaporation

To determine how much seawater evaporates under four different wind speeds, it is necessary to measure the reduction in mass of water in the holding container. This was measured using digital scales to determine how much seawater evaporated during desalination.

Using Eq. (1) and Eq. (2), the theoretical and measured evaporation rates per unit area over two hours were calculated; the results are shown in Table 2.

The values shown in Table 2 are plotted in Figure 4 to illustrate the correlation between the experimental and theoretical evaporation.

Table 2
Experimental and theoretical evaporation

	Experimental	Theoretical
V = 0 m/s	335 ml	360.5 ml
V = 0.6 m/s	455 ml	496.3 ml
V = 2.6 m/s	530 ml	549.8 ml
V = 5 m/s	715 ml	763.5 ml

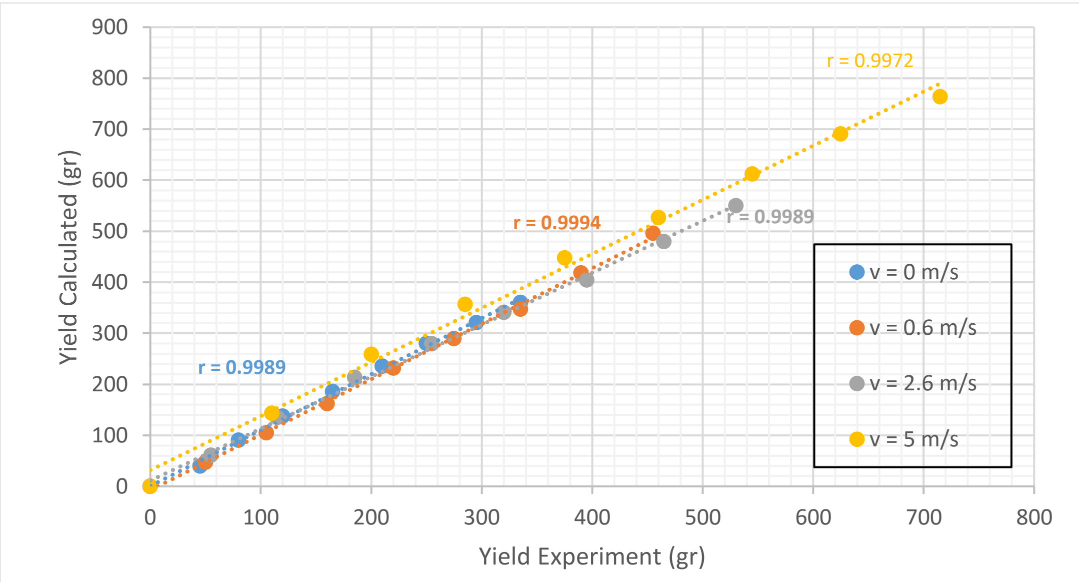

Fig. 4. Correlation of experimental and theoretical evaporation rates

The experimental results show the actual evaporation rates at various wind speeds over a period of two hours. These results show that higher wind speeds led to higher evaporation rates. At a wind speed of 0 m/s, the actual evaporation rate is 335 ml, while at a wind speed of 0.6 m/s, the actual evaporation rate increases to 445 ml. At a wind speed of 2.6 m/s, the actual evaporation rate is 530 ml, and at a wind speed of 5 m/s, the actual evaporation rate reaches 715 ml. The theoretical evaporation rates at these wind speeds were also calculated. The theoretical evaporation rate at a wind speed of 0 m/s is 360.505 ml, while at a wind speed of 0.6 m/s, the theoretical evaporation rate increases to 496.3 ml. At a wind speed of 2.6 m/s, the theoretical evaporation rate is 549.8 ml, and at a wind speed of 5 m/s, the theoretical evaporation rate reaches 763.5 ml. The results of this study show that wind speed significantly impacts the evaporation rate. Increased wind speed causes a decrease in air pressure above the basin, accelerating the evaporation process [55].

It can therefore be concluded from these findings that wind speed affects the rate of evaporation. However, it should be noted that the theoretical evaporation rate may differ from the actual evaporation rate due to other factors not measured in this study. The results of this study can be used as a reference for calculating the evaporation rate in a given location based on wind speed.

The correlation between measured and theoretical evaporation rates ranges from 0.9972 to 0.9994 (Figure 4), which means it is between 0.99 and 1. This indicates a strong correlation between actual and theoretical evaporation rates in the present study and the future similar studies can be predicted using this calculation [56]. Thus, it can be concluded that wind speed significantly affects evaporation, and this study shows that the measured evaporation rates correlate strongly with theoretical calculations. These findings can be used as a basis for developing a model to predict evaporation rates.

Pressure is one of the main factors impacting evaporation; therefore, in the present study, it was necessary to measure the pressure in the water vapor and the surface pressure of the water [57]. This is because evaporation is caused by pressure differences. The vapour properties were used to measure the air pressure above the basin as shown in Table 3 [58]. Water pressure was calculated as 19,331.67 Pa using Eq. (4). Thus, the air pressure above the surface of the water is lower than the water pressure; this difference in pressure causes evaporation [59].

As seen in Figure 5, the temperature of the air entering the basin (T1) is always lower than the temperature of the air leaving the basin (T2). This is because, during evaporation, water draws heat energy and transforms into water vapor [60]. Therefore, the air leaving the basin has a higher temperature because it has heat energy.

As shown in Figure 5, higher wind speeds decrease the air temperature. Thus, increasing the wind speed increases the rate of evaporation because the wind carries the newly formed water vapor away from the surface of the water and replaces it with drier air. Increasing the wind speed also increases the rate at which heat is transferred from the surface of the water to the surrounding air, decreasing the air temperature further.

Relative humidity (RH) is a ratio of the humidity ratio of a particular water-air mixture compared to the saturation humidity ratio at a given temperature (dry-bulb) [61]. As wind speed increases, the pressure of partial water vapour decreases, causing RH to decrease. This is shown in Table 3; higher wind speeds lead to lower pressure in the partial water vapour. As shown in Figure 5, increasing the wind speed decreases the humidity. Previous studies have also shown that higher wind speeds lead to lower RH [62]. The decrease in humidity from the time of entry (RH1) to exit (RH2) depends on wind speed; faster wind speeds bring water vapour, decreasing air humidity, which accelerates evaporation [63].

Table 3
Air pressure over the basin

Air pressure over the basin			
v = 0 m/s	v = 0.6 m/s	v = 2.6 m/s	v = 5 m/s
10433 Pa	6159 Pa	5154 Pa	5123 Pa

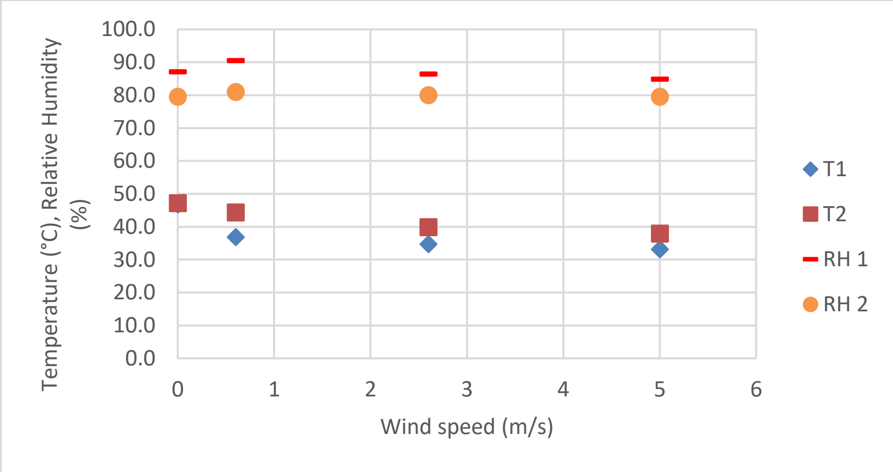

Fig. 5. Temperature (T1, T2) and relative humidity (RH1, RH2)

3.2 Amount of Condensed Water Produced

The largest condensation results are produced by a speed of 0.6 m/s as can be seen in Figure 6. In the same figure it can also be seen that the smallest condensation results are at speeds of 0 m/s and 5 m/s, namely 9 ml in two hours because the speed wind for (V) < 0.9 m/s, convection heat transfer and condensation rate increase with a large increase in gradient [64]. So that with increasing wind speed the evaporation rate increases but the heat transfer from water vapor to the condenser does not have enough time to turn into a liquid phase because wind speeds above the range of 5-7 mph will reduce the condensation rate [65].

Eq. (3) was used to calculate the condensation efficiency of the desalination device. At a wind speed of 0 m/s, the device's efficiency is 2.69%; at a wind speed of 0.6 m/s, it is 14.28%; at a wind speed of 2.6 m/s, it is 8.87%; and at a wind speed of 5 m/s, it is 1.26%. These results indicate that changing the condenser would improve the efficiency of condensation [66].

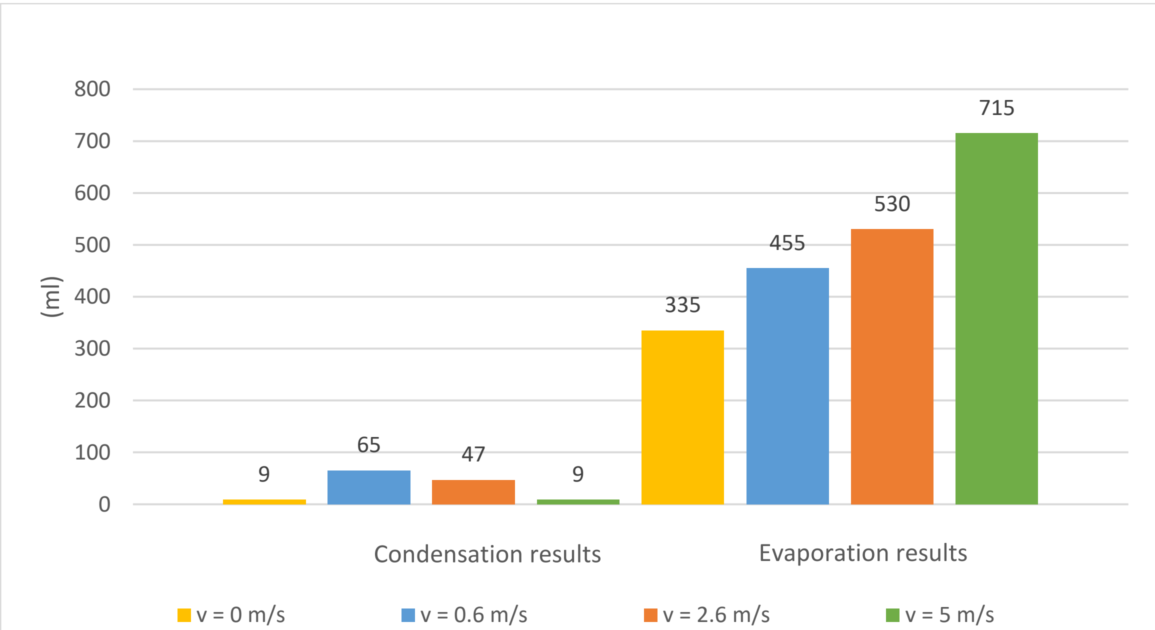

Fig. 6. Evaporation vs condensation over a two-hour period

4. Conclusions

Based on the results of the study, it can be concluded that wind speed significantly impacts the rate of seawater evaporation during desalination. The present study has demonstrated that increasing the wind speed accelerates evaporation. Over a period of two hours, the highest amount of water evaporated (715 ml) with a wind speed of 5 m/s; the lowest amount of water evaporated (335 ml) with a wind speed of 0 m/s. However, higher wind speeds also decrease condensation because wind causes the water vapour to exit the condenser more quickly, before it can condense. Therefore, the condenser used in this research should be improved to support more efficient desalination.

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