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Effect of wind speed on evaporation rate in air conditioner based desalination units

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ABSTRACT

Due to environmental changes, ensuring access to clean water is challenging for many regions. This study examines how wind speed influences seawater evaporation rates in a desalination system. Conducted indoors, the research varied wind speeds (0.6 m/s, 0.7 m/s, and 0.8 m/s) while maintaining a consistent temperature. A modified window Air Conditioner (AC) served as the evaporation unit, with its condenser immersed in water to utilize released heat, and its evaporator used as a condenser. Water temperature was maintained at 60-70°C. Results demonstrated a significant increase in evaporation rates with higher wind speeds. The strong correlation between experimental and theoretical results underscores wind speed as a critical factor in enhancing freshwater production efficiency from seawater. These insights inform the design of more effective desalination systems, offering potential solutions to water scarcity challenges in vulnerable regions.

Keywords: Water; desalination; wind velocity; evaporation.

1. INTRODUCTION

Water is essential for life on Earth, playing a crucial role in the survival and well-being of all living organisms [1]. For humans, water is necessary to drink to stay hydrated, support bodily functions, and maintain overall health. Without adequate water, both humans and animals would be unable to sustain life, highlighting its fundamental importance in maintaining the delicate balance of ecosystems on our planet. Water is also used for cooking, cleaning, and various other daily purposes [2]. Water is found on the surface of the earth and in the ground [3]. Water on the earth's surface consists of seawater, rivers, and lakes however, not all regions in Indonesia have clean water sources [4]. Communities often face difficult problems when clean water resources are limited and water demand increases [5]. Coastal areas and small islands in the middle of the sea are areas where clean water sources are very rare. Water sources in coastal areas generally have poor quality, such as groundwater that is brackish or salty [6]. Approximately 16.42 million Indonesians live in coastal areas [7].

Given this reality, researchers worldwide have made various efforts to convert saltwater or brackish water into fresh water using different technologies, including the desalination process [8]. Desalination refers to the process of changing salt water into fresh water that is suitable for various human needs and industrial purposes [9]. This process can remove salt and other impurities from the water, making it safe and usable [10]. One commonly used method for desalination is evaporation. In this process, water is heated until it evaporates, causing the water molecules to change from a liquid to a gas state. As the water vapor rises, it leaves behind impurities and salt, resulting in purified water. This vapor is then condensed back into liquid form, providing fresh, desalinated water [11].

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Much research has been conducted on the process of evaporation, focusing on various factors that influence the rate of water evaporation. Numerous experiments have explored the impact of different variables, such as pressure, temperature, and airflow, on the efficiency of the evaporation process. These studies aim to optimize the conditions under which evaporation occurs to enhance the effectiveness of desalination and other applications [12], the effect of evaporation on the angle of the glass roof and mirror at the bottom of the basin [13], the effect of evaporation on sunlight [14], the effect of evaporation on temperature [15], and the effect of evaporation on the mist sprayed from the nozzle [16]. However, no previous research has looked at how wind speed affects seawater evaporation in a desalination chamber, especially when combined with air conditioning (AC).

Therefore, this research aims to determine the effect of wind speed on seawater evaporation in a desalination device that uses an AC condenser as a heat source in the evaporation area. The study focuses on the process of seawater evaporation at a constant temperature and varying wind speeds. Additionally, utilizing wind energy can significantly reduce operational costs by harnessing free and abundant resources to power various processes involved in water treatment [17]. Overall, the benefits of the evaporation desalination process influenced by wind speed include increased freshwater production, enhanced environmental sustainability, and improved cost-effectiveness [18].

2. METHOD

Wind Velocity: Wind speed is a fundamental meteorological parameter that quantifies the velocity at which air molecules move in the atmosphere [19]. High wind speeds have a significant impact on increasing the evaporation rate of seawater, thereby enhancing freshwater production in the desalination process [20]. Wind speed plays a crucial role in transferring water vapor from the sea surface into the air, thereby accelerating the rate of water evaporation [21].

Mass Transfer: Mass transfer involves the process by which components or substances move within a system, typically from areas of high concentration to low concentration [22]. This movement can occur through various mechanisms such as diffusion, convection, and molecular or convective flow. Mass transfer can be described as the movement or transfer of substances from one location to another [23]. Particles in liquid substances remain closely packed together but can move and flow freely past one another. Large movements of mass occur primarily due to the complex and dynamic nature of liquids in the field of chemistry. Many physical and chemical changes involve the movement of matter from one location to another. According to conducted research, various methods used for water purification include adsorption, evaporation, precipitation, desalination, membrane filtration, and drying. Previous research indicates that the temperature and physical and chemical characteristics of a system significantly influence the movement of particles within that system. The influence on fluid movement can be determined using pressure, viscosity, and flow velocity [24].

Evaporation: Evaporation is a process where the pressure difference between the surface of water and air changes water into water vapor or gas, called evaporation [25]. Humidity, wind speed, and air temperature are some physical factors that can affect evaporation [26].

Evaporation Rate Calculation: The evaporation rate is defined as.

$$Elp = (0.37 + 0.0041\bar{u})(ps - pw)0.88 \quad (1)$$

Where:
Elp = Evaporation rate, in/day
$\bar{u}$ = Wind movement, in/day
ps = Saturation vapor pressure at air temperature of water vapor, in Hg.
pw = The actual vapor pressure of air under conditions of temperature and humidity, in Hg.

To calculate the mass evaporation rate per unit area, the following equation is used:

$$\frac{\dot{m}}{A} = \frac{Elp}{12} pw \quad (2)$$

Where:
Elp = Evaporation rate, in/day
Pw = Water Density, lb/ft 3

To determine the efficiency of the condenser in the desalination system, the efficiency is calculated using the following equation.

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

Pressure: One of the main factors that influences the rate of evaporation is pressure [27]. Therefore, the pressure inside the water and at its surface must be determined because evaporation occurs when the air pressure above the water is lower than the water pressure at its surface [28]. When air pressure is low, water molecules evaporate and leave water behind [29]. During the evaporation process, water molecules attract heat from the environment, which results in a decrease in the temperature of the water and a reduction in the concentration of water molecules in it [30]. The following equation is used to calculate water pressure:

$$Pw = exp\left[25{,}317 - \left[25{,}317 - \frac{5.144}{Tw}\right]\right] \tag{4}$$

Where:
Pw = Water Pressure
Tw = Water Temperature

This research was conducted indoors to mitigate uncontrollable variables such as wind speed and solar radiation. The procedures followed in the research process are outlined below:

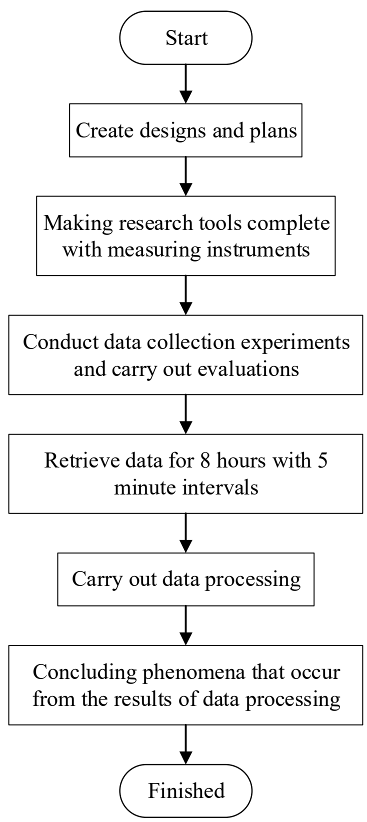

Figure 1. Flow diagram.

a. Tools and materials

The data collection method involved taking measurements at 5-minute intervals over 8 hours. Several wind speeds (0.6 m/s, 0.7 m/s, and 0.8 m/s) were applied. To collect evaporation data, the reduction in mass of the holding container was measured using a 30 kg scale. Therefore, this study compared various wind speeds to identify optimal conditions for maximizing seawater evaporation rates in the desalination process. The experimental setup included controlled indoor conditions to eliminate variables like wind speed and solar radiation. The tools used in this study are detailed in Table *1*.

Table 1. Tools and material.

NO	TOOL	FUNCTION	SPECIFICATION
1	Thermostat XH-W3001	Measuring temperature	-50°C - 110°C, Temperature accuracy 0.1°C
2	GM816 anemometer	Measuring wind speed	0 – 30 m/s, Resolution 0.1 m/s
3	Digital Thermometer	Measuring water temperature	-50°C - 110°C, resolution 0.1°C, accuracy ±0.1°C
4	Digital Hygrometer	Measuring humidity	10% - 99%, 1% resolution, ±1% accuracy
5	30 kg digital scale	Calculate the mass of water	0 - 40 kg, resolution 0.005 kg
6	20 kg digital scale	Calculate the mass of water resulting from condensation	0 - 20 kg, resolution 1 gr

b. Tool design

This research was conducted indoors to maintain controlled environmental conditions. The research tool utilized in this study was a modified air conditioner (AC), as depicted in Figure *2*. Experimental equipment.. The experimental setup was situated in the mechanical engineering laboratory of the Faculty of Industrial Technology and Information Technology, Muhammadiyah University, Prof. Dr. Hamka, during the period from September to December 2023.

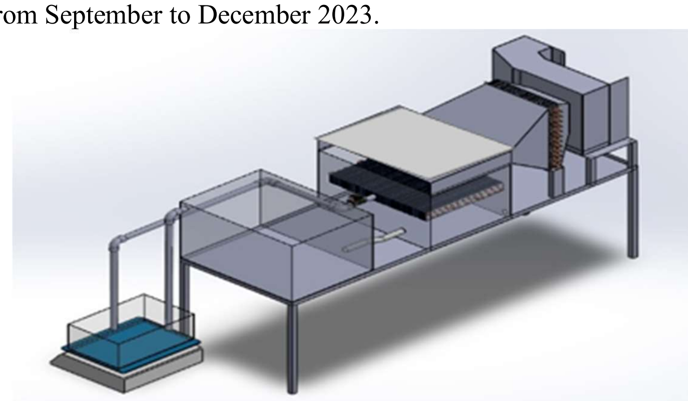

Figure 2. Experimental equipment.

In this research setup, Figure 2, seawater within the evaporation container is maintained at a consistent temperature of 60°C to facilitate evaporation. As water evaporates, vapor moves through a steam funnel to the condenser, driven by varying wind speeds of 0.6 m/s, 0.7 m/s, and 0.8 m/s. Sea water from the storage container is pumped into the control container, which then feeds the evaporation container via a pipeline. To regulate water levels, excess water from the control container overflows into the holding container, ensuring a constant level in the former while allowing the latter's water level to decrease due to evaporation. The evaporation rate is monitored by measuring the mass of water in the holding container every 5 minutes using a digital scale. Data collection includes temperatures (T1-T11), such as those of water and air at various points in the system, and air velocities (A1-A2) and relative humidity (R1-R4), providing comprehensive insights into the evaporation dynamics influenced by wind speed and controlled environmental conditions. Where T1 is the temperature of the water below the evaporator in the evaporation container, T2 is the temperature of the water above the evaporator in the evaporation container, T3 is the temperature in the condenser, T4 is the temperature on the wall of the copper pipe where the freon flows, T5 is the temperature of the exit air which has passed through condenser, T6 is the temperature of the air in the environment, T7 is the temperature of the air entering the steam funnel towards the condenser, T9 is the temperature of the air entering above sea water in the evaporation container, T10 is the temperature of the water in the holding container which is on the scale, T11 is the temperature of the water in the control container, A1 is the air velocity entering the evaporation container while A2 is the exit air velocity, R1 is the air humidity in the environment, R2 is the air humidity in the steam funnel, R3 is the exit air humidity, R4 is the air humidity enter above sea water in the evaporation container. Figure 3 is a schematic of the desalination tool, which in Figure 3 shows the locations of the sensors and measuring instruments used for data collection in this research.

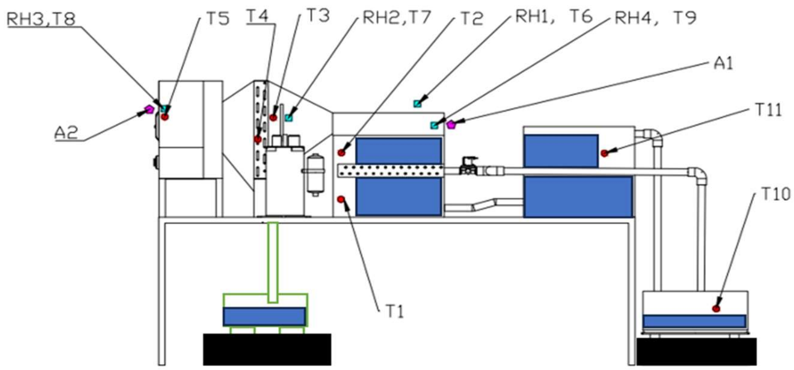

Figure 3. Experimental setup.

3. RESULTS AND DISCUSSION

In this study, three different wind speeds were tested: 0.6 m/s, 0.7 m/s, and 0.8 m/s. The goal was to quantify the amount of seawater evaporation under these varying conditions by measuring the reduction in water mass within the container. Evaporation rates were monitored using a digital scale immersed in a water bath, providing precise data on the water loss throughout the desalination process.

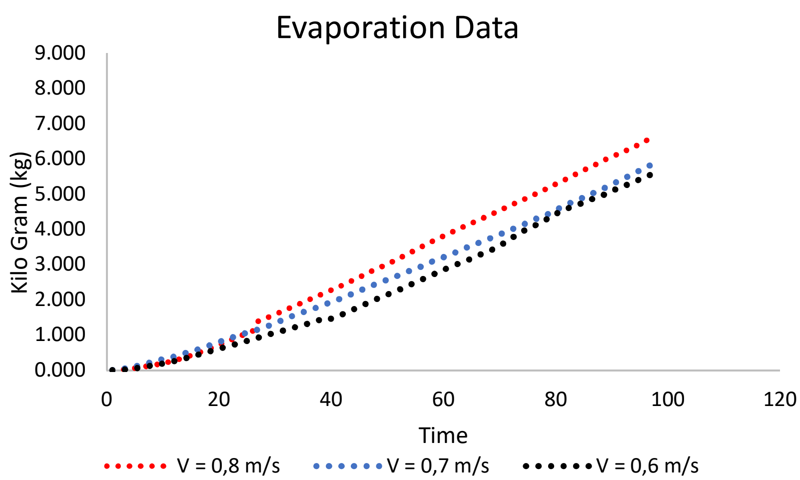

Figure 4. Experimental data evaporation rate.

Based on Figure 4, the research findings demonstrate the actual evaporation rates at various wind speeds over eight hours. The results reveal that higher wind speeds lead to increased evaporation rates. Specifically, at a wind speed of 0.6 m/s, the actual evaporation rate measures 5.553 kg, which increases to 5.828 kg at 0.7 m/s, and further rises to 6.592 kg at 0.8 m/s. Theoretical calculations also indicate corresponding rates: 4.888 kg at 0.6 m/s, 5.772 kg at 0.7 m/s, and 6.163 kg at 0.8 m/s. These findings underscore the significant influence of wind speed on evaporation rates, attributed to the reduction in air pressure above the water surface that accelerates the evaporation process [31]. Based on theoretical and empirical data from the field, the average evaporation rates over eight hours were calculated and are presented in Table 2.

Table 2. Experimental and theoretical evaporation rates.

Experimental and Theoretical Evaporation Rate		
Wind Velocity	**Experiment**	**Theoretical**
V = 0.6 m/s	5,553 kg	4,888 kg
V = 0.7 m/s	5,828 kg	5,772 kg
V = 0.8 m/s	6,592 kg	6,162 kg

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The correlation between theoretical and actual evaporation rates ranges from 0.8844 to 0.9650 kg, indicating a strong correlation between the measured and theoretical evaporation rates. The difference in evaporation rates between wind speeds of 0.6 m/s and 0.7 m/s is 0.04952 kg, and it increases by 0.13109 kg between wind speeds of 0.7 m/s and 0.8 m/s. Thus, wind speeds significantly influence evaporation, and this study demonstrates a strong correlation between measured and theoretical evaporation rates.

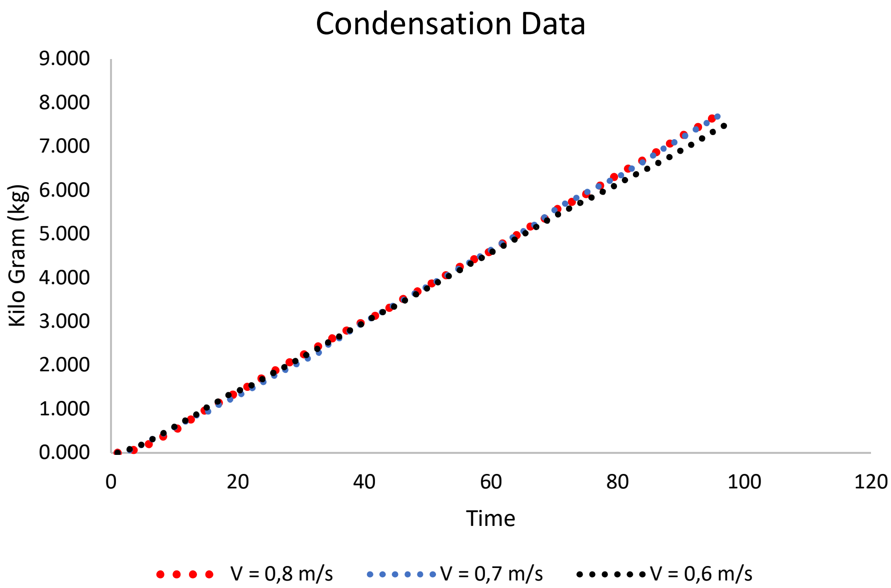

Figure 5. Condensation data.

Thus, these results indicate that wind speed indeed influences the evaporation rate. However, it is important to consider that theoretical and experimental evaporation rates may slightly differ due to unmeasured factors in this study. Nonetheless, this research provides valuable insights for estimating evaporation rates at specific locations based on wind speed. These findings serve as a foundation for developing predictive models of evaporation.

Figure 5 illustrates that higher wind speeds lead to increased condensation water production. Specifically, at a wind speed of 0.6 m/s, 7,498 kg of condensation water is produced, which increases to 7,797 kg at 0.7 m/s, and further to 7,833 kg at 0.8 m/s. Interestingly, the data shows that condensation results exceed evaporation results, primarily because condensation occurs not only within the evaporation tank but also within the modified Air Conditioner (AC) unit used in this study. Condensation in the AC unit occurs when the cold air it produces encounters warmer, more humid indoor air, resulting in moisture condensing.

The percentage of condensation relative to evaporation varies with wind speed. At a wind speed of 0.6 m/s, condensation amounts to 0.866 kg, which is 15% of the evaporation rate. At 0.7 m/s, condensation increases to 0.858 kg, comprising 17% of evaporation, while at 0.8 m/s, it decreases to 0.762 kg, representing 31% of evaporation. These percentages indicate an increasing trend in condensation relative to evaporation as wind speed increases.

4. CONCLUSION

Based on the findings of this study, it is evident that wind speed plays a crucial role in influencing the rate of seawater evaporation in desalination processes. The experiments conducted at wind speeds of 0.6 m/s, 0.7 m/s, and 0.8 m/s consistently demonstrated higher evaporation rates with increasing wind speeds: 5.553 kg, 5.828 kg, and 6.592 kg respectively. This underscores the significant impact of wind speed on enhancing evaporation efficiency. Moreover, the study revealed that as the wind speed increased, so did the production of condensation water, with amounts reaching 7.498 kg, 7.797 kg, and 7.833 kg respectively. The increasing percentage of condensation relative to evaporation further highlights the potential for optimizing the desalination process by controlling wind speeds. These findings suggest that managing wind conditions effectively can lead to improved operational efficiency in desalination technologies. This research contributes scientifically by providing empirical data on the impact of wind speed on evaporation rates, contributing to the optimization of desalination technologies for sustainable water management

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