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Improving the Performance of a Forced-flow Desalination Unit Using a Vortex Generator

Oktarina Heriyani[1], Dan Mugisidi[1,*]

[1] Mechanical Engineering, Faculty of Industrial Technology and Informatics, Universitas Muhammadiyah Prof. Dr HAMKA, Jakarta, Indonesia

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ABSTRACT

Water is a primary need for living creatures, and water scarcity can trigger a crisis. Water scarcity is becoming an issue in Indonesia, especially in coastal village areas, including salt-producing areas. Salt production involves evaporating large amounts of seawater in concentration ponds. Using evaporated seawater as a source of clean water would reduce the risk of water scarcity. Therefore, this study aims to obtain fresh water by condensing water vapour that evaporates in a desalination unit. More specifically, the study uses a vortex generator to increase the rate and efficiency of evaporation in a forced-flow desalination unit. This research was conducted indoors to reduce uncontrollable variables. An evaporation container with a volume of 0.35 m^3 was filled with seawater. The rate of evaporation in the desalination unit with a vortex generator was compared to that in a unit without a vortex generator. The results show that the vortex generator leads to faster evaporation. The rate of evaporation with a vortex generator was 13% higher than that without a vortex generator, and the gained output ratio increased 14% with the vortex generator. Therefore, it can be concluded that vortex generators can improve the performance of desalination equipment.

1. Introduction

Humans and other living creatures need water to live. As the global population increases, the need for water will increase as well; a global population increase of 15% will reduce the amount of available fresh water by 40% [1]. Without changes to the use and treatment of water, this will lead to water scarcity [2], which is predicted to impact half of the world’s population by 2025 [3]. Water is so important that it can raise issues related to human rights, politics and even racism [4]. Since physical water scarcity is often associated with agricultural production, growing human populations and state sovereignty, it is almost certain that water scarcity will trigger various crises [5]. In addition to being a global threat, water scarcity has become an urgent issue in specific parts of the world, including Indonesia.

Indonesia, an archipelagic country, has the longest coastline in the world, so many people live in coastal areas. Unfortunately, coastal village communities often experience severe water scarcity.

* *Corresponding author.*
E-mail address: *dan.mugisidi@uhamka.ac.id* *(Dan Mugisidi)*

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There are 12,827 coastal villages throughout Indonesia, and only 66.54% of these villages have regular access to clean water. Thus, coastal villagers use turbid and salty water for daily needs, such as washing and bathing, and buy drinking water; many members of these coastal village communities are salt farmers.

There is a high demand for salt in Indonesia. The Indonesian salt industry still uses traditional mining methods, which involve injecting seawater into ponds and evaporating it. The evaporation of seawater in concentration ponds is very dependent on water surface pressure and temperature [6]. Therefore, if the sun's heat is blocked or the wind is still, the rate of evaporation slows. However, making salt requires evaporating large amounts of water.

Sea water in the concentration pond, with a salinity of 30–45‰ or 3–4.5 °Be [7], is allowed to evaporate into the environment. To concentrate 1,000 litres of seawater to 30–45 °Be, about 900 litres of seawater must be evaporated. A concentration pool for salt mining can contain up to 10,000 litres of seawater, which undergoes a concentration process lasting four to five days [7]. Collecting and condensing this evaporated seawater could provide 9,000 litres of clean water. A large amount of this water could then be used by villagers. Thus, the ability to collect and use water that evaporates from salt fields would significantly benefit Indonesia's coastal villages. However, recovering moisture from salt fields without reducing salt production is a challenge. Little research has been done on the use of desalination to produce fresh water and salt [8]. A simpler solution would be to evaporate the seawater in evaporation chambers similar to solar stills.

Solar still is a simple device that uses the greenhouse effect [9] to convert salt water or wastewater into clean water by evaporating and condensing it [10]. Even though its productivity is low, because its operation is easy and economical, various studies have explored ways to increase the productivity of solar distillation equipment [11]. Methods for increasing the production of solar still fall into four categories: hybrid solar stills, stills with reflectors and concentrators, stills with condensers and stills with absorbers. Several types of absorbers can increase the productivity of solar stills. These approaches include changing the type of heat absorber [12, 13] using a wick [14-17], using fins [18-20], adding reflectors [21-23] and adding a heat collector. Furthermore, according to Nasri [24], solar still heat absorbers can use materials such as gravel, sand or polyurethane, and it is easy to add such materials to speed the evaporation process. The expansion of the absorber increases the water temperature, while the addition of a condenser increases the heat absorption capabilities of the water vapour. Increasing the rate of air flow over the surface of the water also increases the rate of evaporation. The air flow causes the pressure above the water surface to decrease, resulting in evaporation [25]. Some studies have used increased air flow in solar stills to increase the rate of evaporation [26, 27] but so far, few solar stills have used vortex generators to increase the rate of evaporation.

A vortex generator reduces air pressure, thereby increasing the difference in pressure between the surface of the water and the air above it. This pressure difference is the driving force for evaporation [28]. A vortex generator also increases heat transfer [29] by creating turbulence and vortices [30]. Vortex generators can increase heat transfer in cooling tower ducts [31] by increasing the speed of air flow around the tip of the vortex generator [32]. An increase in flow velocity creates vortices, lowering the surface pressure of the water and increasing the rate of evaporation. Thus, the present study aims to explore the impact of air flow on evaporation and condensation in salt field desalination units using a vortex generator. Therefore, various amounts of air flow were tested with constant heat. Each variation in air flow underwent two treatments: one without a vortex generator and one with a vortex generator. In addition, a condenser is used to condense water vapour; previous studies have proven that the addition of internal and external condensers has been shown to increase the efficiency of solar stills [33-40]. Solar still efficiency can also be increased by expanding the condensation surface [41]; increasing the condensation surface by 7.5 times increases freshwater production by more than 50% [42]. Specifically, this paper examines the impact of a vortex generator on the rate of evaporation in a forced-flow desalination unit.

2. Methodology
2.1 Experimental Setup

This research was conducted indoors to reduce uncontrolled variables [43], as shown in Figure 1. Three lamp units with a total power of 3,000 watts were used to maintain a constant solar radiance at 500 watts/m^2. As shown in the research scheme in Figure 2, water was pumped from the water

Fig. 1. Forced-flow desalination experimental rig

reservoir to the water level control, which was connected to the evaporation chamber. Thus, the water level in the evaporation chamber remained the same as that in the water level control. The evaporation chamber holds 350 litres of water. Water level control has an overflow channel, and the water level is determined by the height of the overflow. The water emerging from the overflow flows back into the seawater reservoir. When evaporation occurs in the evaporation chamber, water from the water level control flows into the evaporation chamber to equalize the level. Because the water level is maintained by the overflow, the reduction in water volume or weight in the seawater reservoir is proportional to the volume of water that evaporates in the evaporation chamber. In addition to water circulation, the system also includes air flow. The direction of the air flow is shown by the arrow in Figure 1. The air flow at a rate of 2 m/s is caused by fan suction. Air flow was tested in a desalination unit with (D-VG) and without a vortex generator (D-NVG). The vortex generator was attached to the top cover of the evaporation container so that it could be removed and replaced with a cover that did not include a vortex generator. The vortex generator was 9.4 mm high and mounted on the inside of the glass cover. The ratio of the height vortex generator to that of the glass cover is 0.47 [44]; the width of the vortex generator is the same as that of the glass cover. The first vortex generator was placed 286 mm from the air inlet, and the second vortex generator was placed 286 mm from the first. Thus, the longitudinal pitch ratio of the distance between the vortex generators and the length of the cover was 0.2 [45]. Four vortex generators were used, all placed 286 mm apart. A schematic of forced-flow desalination is shown in Figure 2. Data were collected every five minutes. A simulation of the system was also conducted using computational fluid dynamics (CFD).

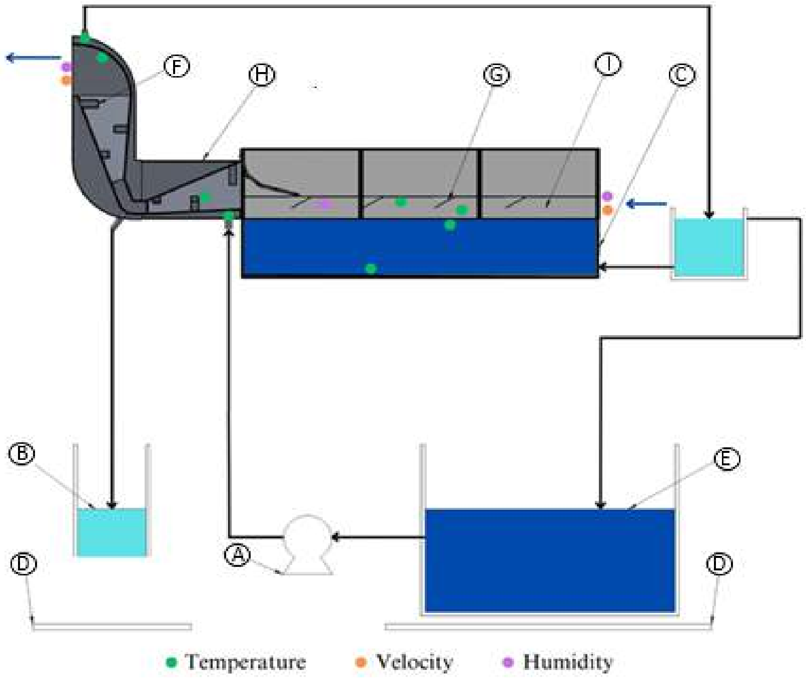


Fig. 2. Schematic of the forced-flow desalination experimental rig. (A) Circulation pump, (B) Freshwater reservoir, (C) Sea water, (D) Scale, (E) Condenser cooling water reservoir, (F) Vortex generator in condenser, (G) Vortex generator, (H) Condenser, (I) Evaporation chamber. The coloured dots show the locations of the sensors; the arrows show the direction of air flow

Many previous studies have included CFD simulations [46-49]. In the present study, a simulation was created using Cradle CFD software by Hexagon. There are three governing equations in fluid dynamics: the continuity equation, the momentum equation and the energy equation.

Integral form continuity equation:

$$\frac{\partial}{\partial t}\iiint_{V} \rho dV + \iint_{A} \rho\vec{V} \cdot d\vec{A} = 0 \quad (1)$$

Differential form continuity equation:

$$\frac{\partial \rho}{\partial t} + \rho\vec{\nabla} \cdot \vec{V} = 0 \quad (2)$$

Momentum equation in the x-axis direction:

$$\frac{\partial(\rho u)}{\partial t} + \vec{\nabla} \cdot \left(\rho u\vec{V}\right) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \quad (3)$$

The momentum equation in the y-axis direction:

$$\frac{\partial(\rho v)}{\partial t} + \vec{\nabla} \cdot \left(\rho v\vec{V}\right) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \quad (4)$$

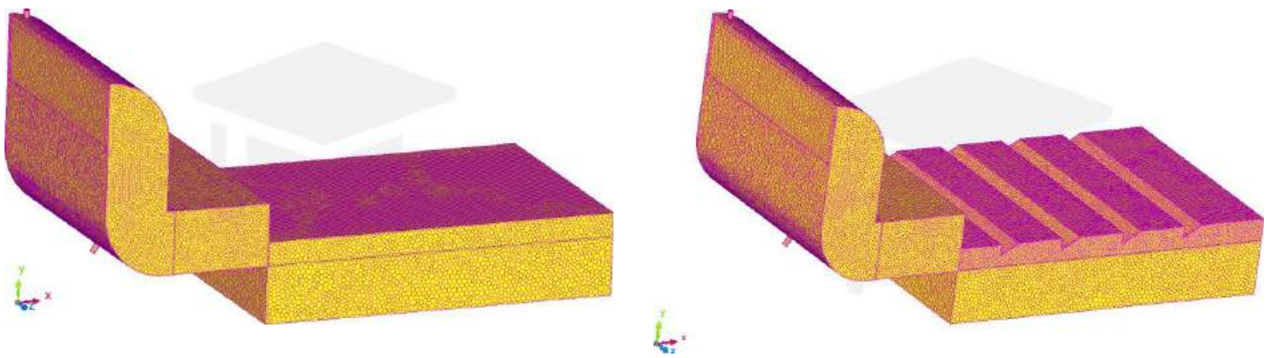
The momentum equation in the z-axis direction:

$$\frac{\partial(\rho w)}{\partial t} + \vec{\nabla} \cdot \left(\rho w \vec{V}\right) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \quad (5)$$

The energy equation is written in the form of internal energy:

$$\frac{\partial}{\partial t}\left[\rho\left(e + \frac{V^2}{2}\right)\right] + \vec{\nabla} \cdot \left[\rho\left(e + \frac{V^2}{2}\right)\vec{V}\right] = \rho\dot{q} - \frac{\partial(\rho p)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} + \rho\vec{f} \cdot \vec{V} \quad (6)$$

In CFD, meshing or discretization is used to convert a continuous fluid domain into a discrete computational domain. This approach allows fluid equations to be solved using numerical methods. An efficient mesh is very important in multiphase simulations because it impacts the accuracy of the simulation [50]. A hexahedron mesh was used here; this mesh has good resolution and high computational efficiency. For more detailed analyses, a polyhedral mesh was used in the present study, which can simulate the movements of objects along a high curvature (Figure 3). When creating a CFD simulation, it is also necessary to conduct a grid independence test [51, 52] as shown in Figure 4.



(a) (b)

Fig. 3. A CFD hexahedron mesh (a) without vortex generator (b) using vortex generator

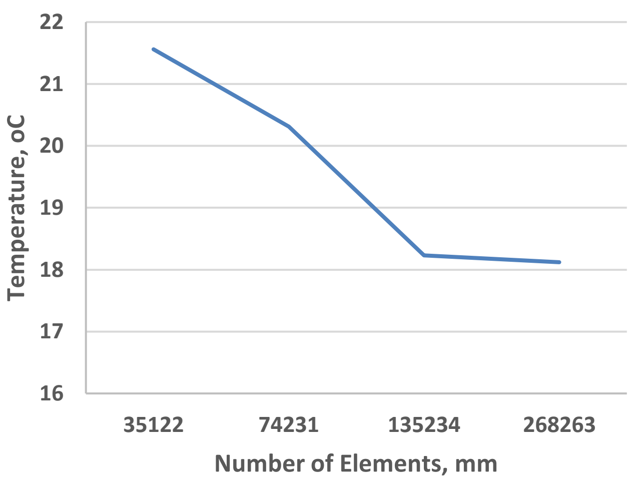


Fig. 4. Grid independence test

Data were collected using the tools listed in Table 1.

Table 1
Tools used in the study

No.	Factor	Tools	Specification
1	Temperature	Thermometer	40–400 °C, 0.09%
2	Solar radiance	Solar meter	0–2000 W/m^2
3	Wind velocity	Wind meter	0–30 m/s
4	Relative humidity	Hygrometer	10%–99%
5	Weight	Digital balance	0–20 kg ± 0,1

3. Results

The temperature of the water and the air flowing over the water significantly impact the rate of evaporation, while the condenser temperature determines the amount of water vapour that can be condensed, as shown in Figure 5.

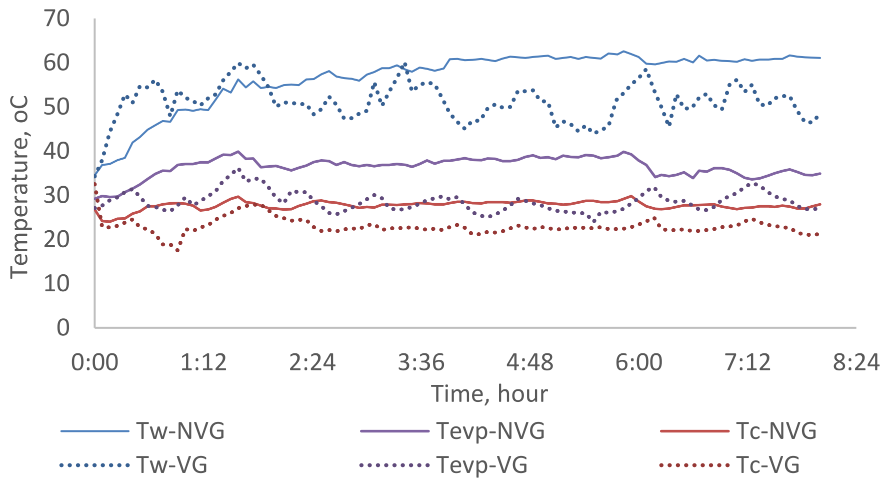


Fig. 5. Water temperature (Tw), air flow temperature (Tev) and condenser temperature (Tc) in the desalination units with (Tw-VG, Tev-VG and Tc-VG) and without a vortex generator (Tw-NVG, Tev-VG and Tc-VG)

As shown in Figure 5, the water temperature was lower with a vortex generator (Tw-VG) than without it (Tw-NVG). The average Tw-VG and TW-NVG were 51.42 °C and 58.06 °C, respectively. The air flow temperature is a mix of the temperature of the air entering from outside and the temperature of the evaporated water vapour. The air flow temperature was generally lower with the vortex generator (Tev-VG) than without it (Tev-NVG). Although Tev-VG was lower than Tev-NVG, the difference between the temperature of the water and that of the vapour in the D-VG was greater than the difference between the temperature of the water and the vapour in the D-NVG; these differences were 25.72 °C and 21.18 °C, respectively. This temperature difference is proportional to the pressure difference [28] and promotes evaporation. Tc-VG was lower than Tc-NVG; the average difference between these temperatures was 2.36 °C because Tev-VG entering the condenser is lower than Tev-NVG. The temperature during evaporation predicted by the simulation did not differ much from the temperature recorded in the experiment, as shown in Figure 6.

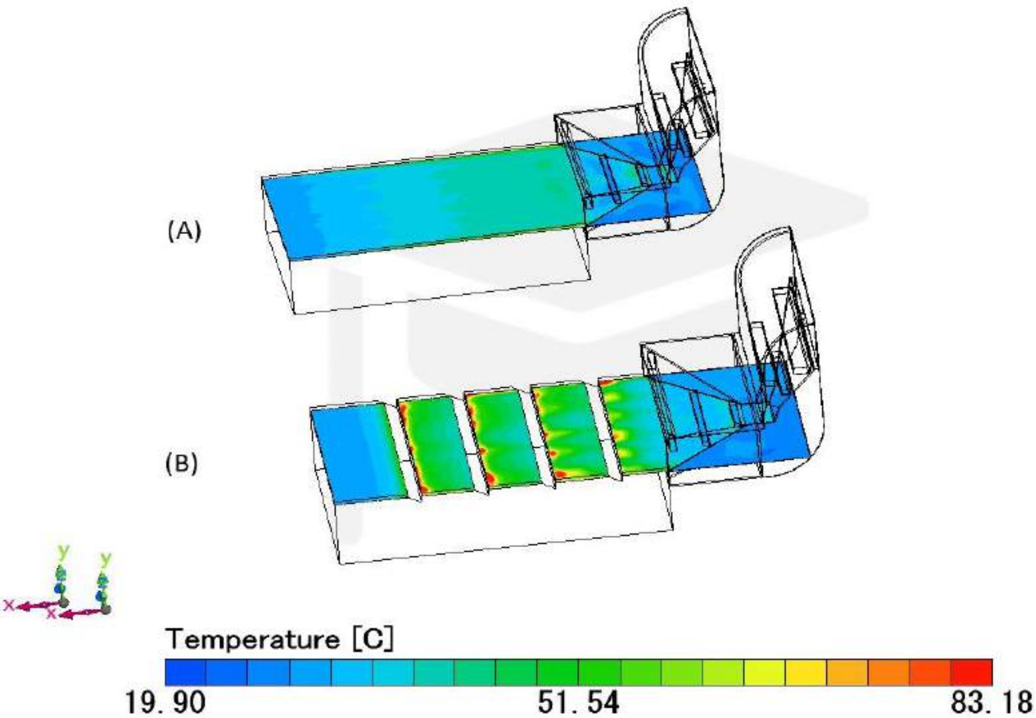


Fig. 6. Temperature distribution (A) without vortex generator (B) with a vortex generator

As shown in Figure 6, the temperature of the water surface with a vortex generator is about 50 °C; it is about 55 °C without the vortex generator. The speed of air flow increases around the tip of the vortex generator, thus reducing the water temperature. This increase in air flow speed can be seen in Figure 7.

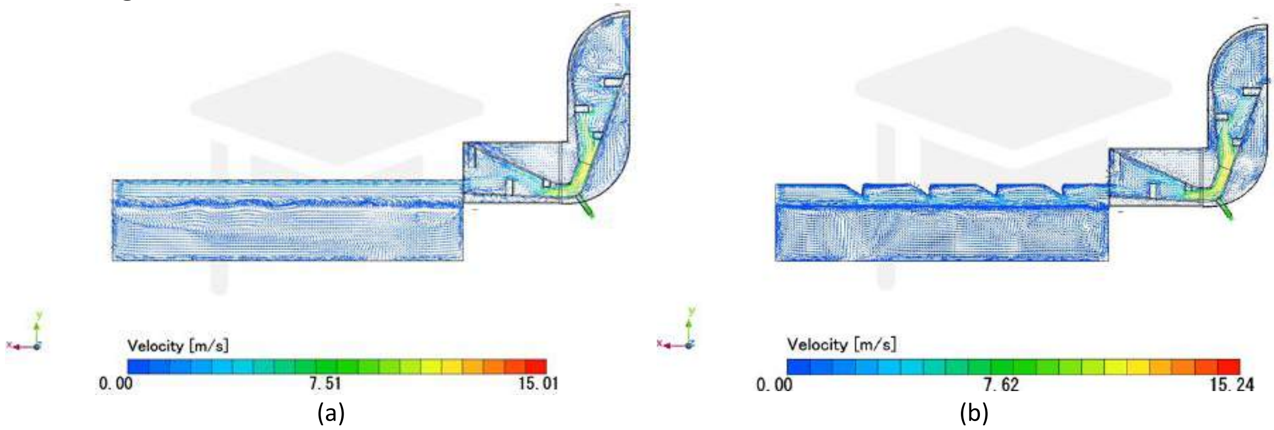


Fig. 7. Air flow velocity (a) without vortex generator (b) with a vortex generator

As shown in Figure 7, the rate of air flow without the vortex generator was about 2.28 m/s; without the vortex generator, the air speed tends to remain constant throughout the evaporation chamber. With a vortex generator, the air flow speed increases around the tip of the vortex generator. This increase in speed causes a drop in air pressure at the tip of the vortex generator; this drop does not occur without the vortex generator [53]. This shift increases the difference in air pressure, encouraging faster evaporation, as shown in Figure 8.

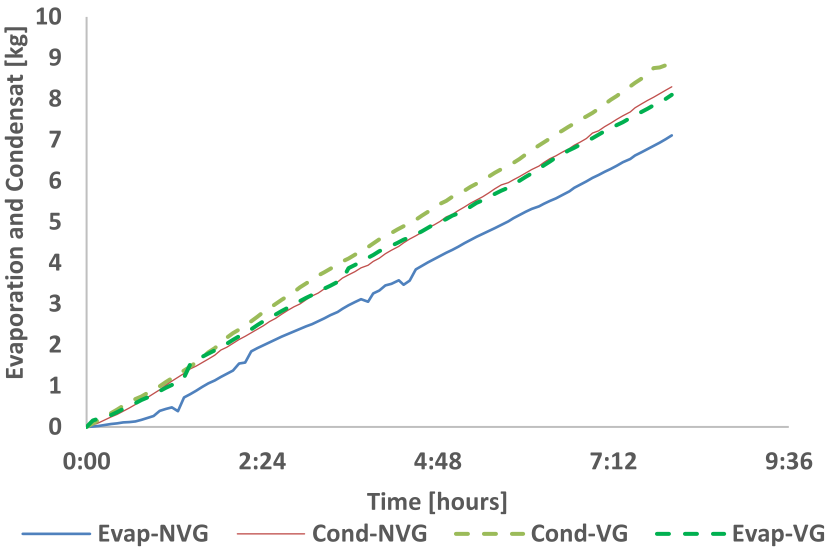


Fig. 8. Evaporation and condensation with (Evap-VG and Cond-VG) and without (Evap-NVG and Cond-NVG) a vortex generator

Figure 8 illustrates evaporation and condensation with (Evap-VG and Cond-VG) and without (Evap-NVG and Cond-VG) vortex generators. Evap-VG was consistently greater than Evap-NVG; on average, the difference was 1.13 times greater. Condensation was also greater with the vortex generator; the average relative humidity after evaporation was 56.5% without the vortex generator and 67.6% with it. With the vortex generator, 91% of the condensation evaporated; without it, only 86% of the condensation evaporated. Thus, the D-VG created more water vapour than the D-NVG. The Reynolds number (Re) was also higher with a vortex generator than without it. The Reynolds number is calculated as follows:

$$Re = \frac{\rho V x}{\mu}, \tag{7}$$

Where the dynamic viscosity μ, density of air ρ and length x were taken as 1.954×10^{-5} kg/ms, 1.09 kg/m^3 and 0.025 m, respectively. The evaporation coefficient (h_{ew}) and convection coefficient (h_{cw}) can be calculated based on evaporation [54]; the results of evaporation per hour (m_w) for a solar still are [55] as follows:

$$m_w = \frac{h_{ew}\,(T_w - T_{evp})}{h_{fg}}\ x\ 3600, \tag{8}$$

where the latent heat of evaporation (h_{fg}) were taken as 2.372.099. The convection coefficient was obtained from the following equation:

$$h_{e,w-gi} = 0{,}0163\ x\ h_{cw}\left[\frac{P_w - P_{evp}}{T_w - T_{ev}}\right], \tag{9}$$

Where P_w and P_{evp} are partial vapour pressure at the water surface temperature and partial vapour pressure at the evaporation chamber, respectively. The results can be seen in Table 2.

Table 2
Reynolds Number (Re), evaporation coefficient (h_{ew}) and convection coefficient (h_{cw})

	Re	h_{ew}	h_{cw}
Without vortex generator	6,626.29	1,148.92	124.76
With vortex generator	7,729.21	3,543.10	560.74

Without a vortex generator, Re was 6.626.29; with it, Re was 7,731.12, 1.15 times greater. A higher Reynolds number indicates more counter-rotating vortices [56] and also leads to an increase in the mass transfer coefficient [57], hence increasing the convection and evaporation rate, which is indicated by increasing the convection coefficient (h_{cw}) and evaporation (h_{ew}).

As mentioned above, greater evaporation leads to higher condensation. This finding also aligns with the simulation. Since the yield of water vapour was higher with the vortex generator than without it, the D-VG was more efficient than the D-NVG (Table 3).

The efficiency of the system is measured by the gained output ratio (GOR), which can be expressed as [58]:

$$GOR = \frac{\sum m_w \cdot h_{fg}}{Q_{in}} \tag{10}$$

Table 3
System efficiency and comparison

	GOR	η	
Flat plate evaporator	4.49		[59]
Thermal collector–evaporator	3.99		[60]
With vortex generator	1.53	76.1%	
Without vortex generator	1.34	66.4%	
Air heating counter flow	0.62		[61]
Air motion in solar still		55.6%	[62]
Natural circulation loop		45.15%	[63]

As shown in Table 3, efficiency or can be measured as GOR [64, 65]; the D-VG is 1.14 times more efficient than the D-NVG. Although several studies show higher GOR values, the system used is different and can be used in further research. However, when compared with solar desalination, the efficiency of using a vortex generator is higher. Therefore, a vortex generator is very useful for increasing the rate of evaporation.

4. Conclusions

The results of this study show that a vortex generator increases the rate of evaporation. In the unit with a vortex generator, evaporation occurred 1.13 times faster than without a vortex generator. This means that more fresh water was produced. Thus, a vortex generator can increase the efficiency of a desalination unit. In this study, GOR or efficiency increased from 1.53 in a unit without a vortex generator to 1.34 in a unit with a vortex generator. Therefore, it can be concluded that vortex generators can improve the performance of desalination equipment.

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References

[1] Schewe, Jacob, Jens Heinke, Dieter Gerten, Ingjerd Haddeland, Nigel W. Arnell, Douglas B. Clark, Rutger Dankers *et al.,* "Multimodel assessment of water scarcity under climate change." *Proceedings of the National Academy of Sciences* 111, no. 9 (2014): 3245-3250. https://doi.org/10.1073/pnas.1222460110
[2] Sivakumar, Bellie. "Water crisis: from conflict to cooperation—an overview." *Hydrological Sciences Journal* 56, no. 4 (2011): 531-552. https://doi.org/10.1080/02626667.2011.580747
[3] UNICEF, "Water scarcity," 2020. Accessed: Aug. 05, 2022.
[4] Pauli, Benjamin J. "The Flint water crisis." *Wiley Interdisciplinary Reviews: Water* 7, no. 3 (2020): e1420. https://doi.org/10.1002/WAT2.1420
[5] Bond, Nick R., Ryan M. Burrows, Mark J. Kennard, and Stuart E. Bunn. "Water scarcity as a driver of multiple stressor effects." In *Multiple stressors in river ecosystems*, pp. 111-129. Elsevier, 2019. https://doi.org/10.1016/B978-0-12-811713-2.00006-6
[6] Guntur, G., A. A. Jaziri, A. A. Prihanto, D. M. Arisandi, and A. Kurniawan. "Development of salt production technology using prism greenhouse method." In *IOP Conference Series: Earth and Environmental Science*, vol. 106, no. 1, p. 012082. IOP Publishing, 2018. https://doi.org/10.1088/1755-1315/106/1/012082
[7] Sartono, Cinthia Morris, Prijadi Soedarsono, and Max Rudolf Muskanonfola. "Konversi tonase air dengan berat garam yang terbentuk di areal pertambakan Tanggultlare Jepara." *Management of Aquatic Resources Journal (MAQUARES)* 2, no. 3 (2013): 20-26. https://doi.org/10.14710/marj.v2i3.4177
[8] Xu, Jiale, Zizhao Wang, Chao Chang, Benwei Fu, Peng Tao, Chengyi Song, Wen Shang, and Tao Deng. "Solar-driven interfacial desalination for simultaneous freshwater and salt generation." *Desalination* 484 (2020): 114423. https://doi.org/10.1016/j.desal.2020.114423
[9] Kalogirou, Soteris A. "Solar thermal collectors and applications." *Progress in energy and combustion science* 30, no. 3 (2004): 231-295. https://doi.org/10.1016/j.pecs.2004.02.001
[10] Kabeel, A. E., and S. A. El-Agouz. "Review of researches and developments on solar stills." *Desalination* 276, no. 1-3 (2011): 1-12. https://doi.org/10.1016/j.desal.2011.03.042
[11] Rabhi, Kamel, Rached Nciri, Faouzi Nasri, Chaouki Ali, and Habib Ben Bacha. "Experimental performance analysis of a modified single-basin single-slope solar still with pin fins absorber and condenser." *Desalination* 416 (2017): 86-93. https://doi.org/10.1016/j.desal.2017.04.023
[12] Srivastava, Pankaj K., and S. K. Agrawal. "Experimental and theoretical analysis of single sloped basin type solar still consisting of multiple low thermal inertia floating porous absorbers." *Desalination* 311 (2013): 198-205. https://doi.org/10.1016/j.desal.2012.11.035
[13] Mugisidi, Dan, Berkah Fajar, Syaiful Syaiful, Tony Utomo, Oktarina Heriyani, Delvis Agusman, and Regita Regita. "Iron Sand as a Heat Absorber to Enhance Performance of a Single-Basin Solar Still." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 70, no. 1 (2020): 125-135. https://doi.org/10.37934/arfmts.70.1.125135
[14] Haddad, Zakaria, Abla Chaker, and Ahmed Rahmani. "Improving the basin type solar still performances using a vertical rotating wick." *Desalination* 418 (2017): 71-78. https://doi.org/10.1016/j.desal.2017.05.030
[15] Hansen, R. Samuel, C. Surya Narayanan, and K. Kalidasa Murugavel. "Performance analysis on inclined solar still with different new wick materials and wire mesh." *Desalination* 358 (2015): 1-8. https://doi.org/10.1016/j.desal.2014.12.006
[16] Pal, Piyush, Pankaj Yadav, Rahul Dev, and Dhananjay Singh. "Performance analysis of modified basin type double slope multi–wick solar still." *Desalination* 422 (2017): 68-82. https://doi.org/10.1016/j.desal.2017.08.009
[17] Sharshir, Swellam W., M. R. Elkadeem, and An Meng. "Performance enhancement of pyramid solar distiller using nanofluid integrated with v-corrugated absorber and wick: an experimental study." *Applied Thermal Engineering* 168 (2020): 114848. https://doi.org/10.1016/j.applthermaleng.2019.114848
[18] Jani, Hardik K., and Kalpesh V. Modi. "Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins." *Solar Energy* 179 (2019): 186-194. https://doi.org/10.1016/j.solener.2018.12.054

[19] El-Sebaii, A. A., and E. El-Bialy. "Advanced designs of solar desalination systems: A review." *Renewable and Sustainable Energy Reviews* 49 (2015): 1198-1212. https://doi.org/10.1016/j.rser.2015.04.161

[20] Mevada, Dinesh, Hitesh Panchal, Kishor kumar Sadasivuni, Mohammad Israr, M. Suresh, Swapnil Dharaskar, and Hemin Thakkar. "Effect of fin configuration parameters on performance of solar still: a review." *Groundwater for Sustainable Development* 10 (2020): 100289. https://doi.org/10.1016/j.gsd.2019.100289

[21] Estahbanati, MR Karimi, Amimul Ahsan, Mehrzad Feilizadeh, Khosrow Jafarpur, Seyedeh-Saba Ashrafmansouri, and Mansoor Feilizadeh. "Theoretical and experimental investigation on internal reflectors in a single-slope solar still." *Applied energy* 165 (2016): 537-547. https://doi.org/10.1016/j.apenergy.2015.12.047

[22] Omara, Z. M., A. E. Kabeel, A. S. Abdullah, and F. A. Essa. "Experimental investigation of corrugated absorber solar still with wick and reflectors." *Desalination* 381 (2016): 111-116. https://doi.org/10.1016/j.desal.2015.12.001

[23] Tanaka, Hiroshi. "Analyzing the effect of an enlarged flat plate reflector (FPR) on a vertical multiple-effect diffusion solar still's (VMEDS) performance." *Applied Thermal Engineering* 142 (2018): 138-147. https://doi.org/10.1016/j.applthermaleng.2018.06.054

[24] Nasri, B., A. Benatiallah, S. Kalloum, and D. Benatiallah. "Improvement of glass solar still performance using locally available materials in the southern region of Algeria." *Groundwater for Sustainable Development* 9 (2019): 100213. https://doi.org/10.1016/j.gsd.2019.100213

[25] Wirangga, Ristanto, Dan Mugisidi, Adi Tegar Sayuti, and Oktarina Heriyani. "The Impact of Wind Speed on the Rate of Water Evaporation in a Desalination Chamber." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 106, no. 1 (2023): 39-50. https://doi.org/10.37934/arfmts.106.1.3950

[26] Fath, Hassan ES, Samy Elsherbiny, and Ahmad Ghazy. "A naturally circulated humidifying/dehumidifying solar still with a built-in passive condenser." *Desalination* 169, no. 2 (2004): 129-149. https://doi.org/10.1016/j.desal.2004.08.014

[27] Boutriaa, Abdelouahab, and Ahmed Rahmani. "Thermal modeling of a basin type solar still enhanced by a natural circulation loop." *Computers & Chemical Engineering* 101 (2017): 31-43. https://doi.org/10.1016/j.compchemeng.2017.02.033

[28] Sellami, M. Hassen, R. Touahir, S. Guemari, and K. Loudiyi. "Use of Portland cement as heat storage medium in solar desalination." *Desalination* 398 (2016): 180-188. https://doi.org/10.1016/j.desal.2016.07.027

[29] Yang, Jae Sung, Myunggeun Jeong, Yong Gap Park, and Man Yeong Ha. "Numerical study on the flow and heat transfer characteristics in a dimple cooling channel with a wedge-shaped vortex generator." *International Journal of Heat and Mass Transfer* 136 (2019): 1064-1078. https://doi.org/10.1016/j.ijheatmasstransfer.2019.03.072

[30] Fiebig, M. "Vortices, generators and heat transfer." *Chemical Engineering Research and Design* 76, no. 2 (1998): 108-123. https://doi.org/10.1205/026387698524686

[31] Mugisidi, Dan, Oktarina Heriyani, Pancatatva Hesti Gunawan, and Dwi Apriani. "Performance Improvement of a Forced Draught Cooling Tower Using a Vortex Generator." *CFD Letters* 13, no. 1 (2021): 45-57. https://doi.org/10.37934/cfdl.13.1.4557

[32] Md Salleh, Mohd Fahmi, Ahmadali Gholami, and Mazlan A. Wahid. "Numerical evaluation of thermal hydraulic performance in fin-and-tube heat exchangers with various vortex generator geometries arranged in common-flow-down or common-flow-up." *Journal of Heat Transfer* 141, no. 2 (2019): 021801. https://doi.org/10.1115/1.4041832

[33] Kabeel, A. E., Z. M. Omara, and F. A. Essa. "Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach." *Energy conversion and management* 78 (2014): 493-498. https://doi.org/10.1016/j.enconman.2013.11.013

[34] Essa, F. A., Mohamed Abd Elaziz, and Ammar H. Elsheikh. "An enhanced productivity prediction model of active solar still using artificial neural network and Harris Hawks optimizer." *Applied Thermal Engineering* 170 (2020): 115020. https://doi.org/10.1016/j.applthermaleng.2020.115020

[35] El-Samadony, Y. A. F., A. S. Abdullah, and Z. M. Omara. "Experimental study of stepped solar still integrated with reflectors and external condenser." *Experimental heat transfer* 28, no. 4 (2015): 392-404. https://doi.org/10.1080/08916152.2014.890964

[36] Al-Hamadani, Ali AF, and S. K. Shukla. "Performance of single slope solar still with solar protected condenser." *Distributed Generation & Alternative Energy Journal* 28, no. 2 (2013): 6-28. https://doi.org/10.1080/21563306.2013.10677548

[37] Sivaram, P. M., S. Dinesh Kumar, M. Premalatha, T. Sivasankar, and A. Arunagiri. "Experimental and numerical study of stepped solar still integrated with a passive external condenser and its application." *Environment, Development and Sustainability* 23 (2021): 2143-2171. https://doi.org/10.1007/s10668-020-00667-4

[38] Belhadj, Mohamed Mustapha, Hamza Bouguettaia, Yacine Marif, and Moussa Zerrouki. "Numerical study of a double-slope solar still coupled with capillary film condenser in south Algeria." *Energy Conversion and Management* 94 (2015): 245-252. https://doi.org/10.1016/j.enconman.2015.01.069

[39] Tiwari, G. N., A. Kupfermann, and Shruti Aggarwal. "A new design for a double-condensing chamber solar still." *Desalination* 114, no. 2 (1997): 153-164. https://doi.org/10.1016/S0011-9164(98)00007-1
[40] El-Bahi, A., and D. Inan. "Analysis of a parallel double glass solar still with separate condenser." *Renewable energy* 17, no. 4 (1999): 509-521. https://doi.org/10.1016/S0960-1481(98)00768-X
[41] Xiong, Jianyin, Guo Xie, and Hongfei Zheng. "Experimental and numerical study on a new multi-effect solar still with enhanced condensation surface." *Energy conversion and management* 73 (2013): 176-185. https://doi.org/10.1016/j.enconman.2013.04.024
[42] Bhardwaj, R., M. V. Ten Kortenaar, and R. F. Mudde. "Maximized production of water by increasing area of condensation surface for solar distillation." *Applied energy* 154 (2015): 480-490. https://doi.org/10.1016/j.apenergy.2015.05.060
[43] Tiwari, Anil Kr, and G. N. Tiwari. "Effect of the condensing cover's slope on internal heat and mass transfer in distillation: an indoor simulation." *Desalination* 180, no. 1-3 (2005): 73-88. https://doi.org/10.1016/j,desa1.2004.12.029
[44] Han, Zhimin, Zhiming Xu, and Hongwei Qu. "Parametric study of the particulate fouling characteristics of vortex generators in a heat exchanger." *Applied Thermal Engineering* 167 (2020): 114735. https://doi.org/10.1016/j.applthermaleng.2019.114735
[45] Dietz, C. F., M. Henze, S. O. Neumann, and Jens von Wolfersdorf. "The effects of vortex structures on heat transfer and flow field behind arrays of vortex generators." *Journal of Enhanced Heat Transfer* 16, no. 2 (2009). https://doi.org/10.1615/JEnhHeatTransf.v16.i2.60
[46] Nadgire, Anand R., Shivprakash B. Barve, and Prachi K. Ithape. "Experimental investigation and performance analysis of double-basin solar still using CFD techniques." *Journal of The Institution of Engineers (India): Series C* 101 (2020): 531-539. https://doi.org/10.1007/s40032-020-00561-y
[47] Khare, Vaibhav Rai, Abhay Pratap Singh, Hemant Kumar, and Rahul Khatri. "Modelling and performance enhancement of single slope solar still using CFD." *Energy Procedia* 109 (2017): 447-455. https://doi.org/10.1016/j.egypro.2017.03.064
[48] S. El-Sebaey, Mahmoud, Asko Ellman, Ahmed Hegazy, and Tarek Ghonim. "Experimental analysis and CFD modeling for conventional basin-type solar still." *Energies* 13, no. 21 (2020): 5734. https://doi.org/10.3390/en13215734
[49] Yan, Tiantong, Guo Xie, Hongtao Liu, Zhanglin Wu, and Licheng Sun. "CFD investigation of vapor transportation in a tubular solar still operating under vacuum." *International Journal of Heat and Mass Transfer* 156 (2020): 119917. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119917
[50] Hamad, A., Syed Mohammed Aminuddin Aftab, and Kamarul Arifin Ahmad. "Reducing flow separation in T-junction pipe using vortex generator: CFD study." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 44, no. 1 (2018): 36-46.
[51] Shoeibi, Shahin, Nader Rahbar, Ahad Abedini Esfahlani, and Hadi Kargarsharifabad. "Energy matrices, exergoeconomic and enviroeconomic analysis of air-cooled and water-cooled solar still: Experimental investigation and numerical simulation." *Renewable Energy* 171 (2021): 227-244. https://doi.org/10.1016/j.renene.2021.02.081
[52] Gnanavel, C., R. Saravanan, and M. Chandrasekaran. "CFD analysis of solar still with PCM." *Materials Today: Proceedings* 37 (2021): 694-700. https://doi.org/10.1016/j.matpr.2020.05.638
[53] Ramakrishnan, Ramkumar, and Ragupathy Arumugam. "Optimization of operating parameters and performance evaluation of forced draft cooling tower using response surface methodology (RSM) and artificial neural network (ANN)." *Journal of Mechanical Science and Technology* 26 (2012): 1643-1650. https://doi.org/10.1007/s12206-012-0323-9
[54] Dan Mugisidi, Dan Mugisidi, Abdul Rahman Abdul Rahman, Oktarina Heriyani Oktarina Heriyani, and Pancatatva Hesti Gunawan Pancatatva Hesti Gunawan. "Determination of the convective heat transfer constant (c and n) in a solar still." *Jurnal Ilmiah Sains dan Teknologi* 11, no. 1 (2021): 1-12. https://doi.org/10.22146/teknosains.50908
[55] Elango, C., N. Gunasekaran, and K. Sampathkumar. "Thermal models of solar still—A comprehensive review." *Renewable and Sustainable Energy Reviews* 47 (2015): 856-911. https://doi.org/10.1016/j.rser.2015.03.054
[56] Oyakawa, K., Y. Furukawa, T. Taira, I. Senaha, and T. Nagata. "Effects of vortex generators on heat transfer enhancement in a duct." In *Experimental Heat Transfer, Fluid Mechanics and Thermodynamics 1993*, pp. 633-640. Elsevier, 1993. https://doi.org/10.1016/b978-0-444-81619-1.50075-7
[57] Ali, H. M. "Effect of forced convection inside the solar still on heat and mass transfer coefficients." *Energy conversion and management* 34, no. 1 (1993): 73-79. https://doi.org/10.1016/0196-8904(93)90009-Y
[58] Kabeel, A. E., and Emad MS El-Said. "Applicability of flashing desalination technique for small scale needs using a novel integrated system coupled with nanofluid-based solar collector." *Desalination* 333, no. 1 (2014): 10-22. https://doi.org/10.1016/j.desal.2013.11.021

[59] Yu, Jing, Juan Yang, and Weidong Yan. "Characteristics and performance investigation of solar AES system with novel flat-plate collector-evaporator integrated unit capable of salinity wastewater thermal self-storage." *Desalination* 555 (2023): 116559. https://doi.org/10.1016/j.desal.2023.116559

[60] Yu, Jing, Juan Yang, and Weidong Yan. "Thermodynamic simulation and experiment research of the solar air evaporating separation system for saline wastewater treatment with thermal collector–evaporator integrated unit." *Energy Reports* 8 (2022): 6707-6728. https://doi.org/10.1016/j.egyr.2022.05.025

[61] Yu, Jing, Sumin Jin, and Yujiang Xia. "Experimental and CFD investigation of the counter-flow spray concentration tower in solar energy air evaporating separation saline wastewater treatment system." *International Journal of Heat and Mass Transfer* 144 (2019): 118621. https://doi.org/10.1016/j.ijheatmasstransfer.2019.118621

[62] Ali, H. M. "Experimental study on air motion effect inside the solar still on still performance." *Energy conversion and management* 32, no. 1 (1991): 67-70. https://doi.org/10.1016/0196-8904(91)90144-8

[63] Rahmani, Ahmed, Abdelouahab Boutriaa, and Amar Hadef. "An experimental approach to improve the basin type solar still using an integrated natural circulation loop." *Energy conversion and management* 93 (2015): 298-308. https://doi.org/10.1016/j.enconman.2015.01.026

[64] Rostamzadeh, Hadi, Amin Shekari Namin, Pejman Nourani, Majid Amidpour, and Hadi Ghaebi. "Feasibility investigation of a humidification-dehumidification (HDH) desalination system with thermoelectric generator operated by a salinity-gradient solar pond." *Desalination* 462 (2019): 1-18. https://doi.org/10.1016/j.desal.2019.04.001

[65] Yu, Jing, Liang Chen, Sumin Jin, and Weidong Yan. "Performance investigation of the double-stage solar air evaporating separation system for saline wastewater treatment." *Desalination* 515 (2021): 115194. https://doi.org/10.1016/j.desal.2021.115194

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

Ristanto Wirangga[1], Dan Mugisidi[1,*], Adi Tegar Sayuti[1], Oktarina Heriyani[1]

[1] Department of Mechanical engineering, Faculty of Industrial and Informatic Technology, Universitas Muhammadiyah Prof. Dr. HAMKA, Indonesia

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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 °C. 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].

* *Corresponding author.*
E-mail address: dan.mugisidi@uhamka.ac.id

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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

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

where

E_{lp} = evaporation rate, in/day

$\bar{u}$ = wind movement, mi/day

p_s = saturation vapor pressure at air temperature water vapor, in Hg, and

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]

$$\frac{\dot{m}_w}{A} = \frac{E_{lp}}{12} \rho_w \quad (2)$$

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]

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

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]

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

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°C -110°C, ±0.1°C.
2	Anemometer GM816	Wind speed	0 – 30 m/s, 0.1 m/s,
3	Digital thermometer	Water temperature	-50°C -110°C, ±0.1°C
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°C. 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

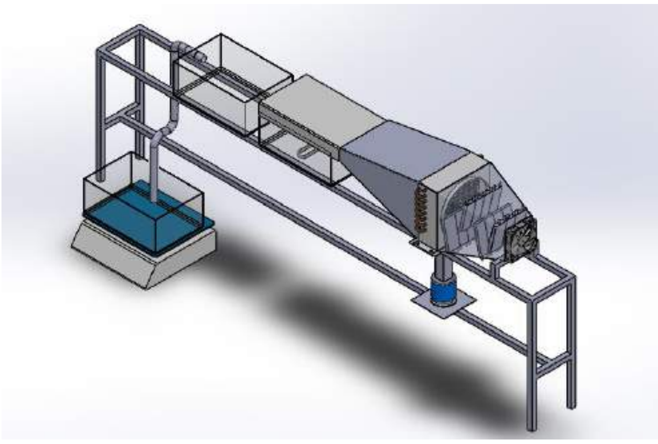

Fig. 1. Experimental rig

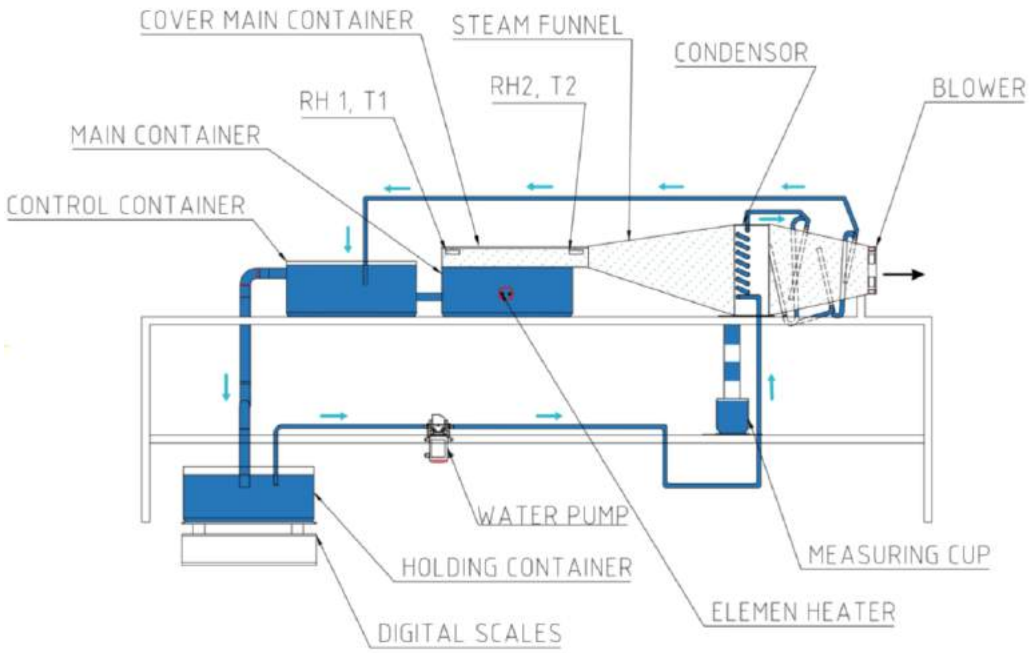

Fig. 2. Experimental setup

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

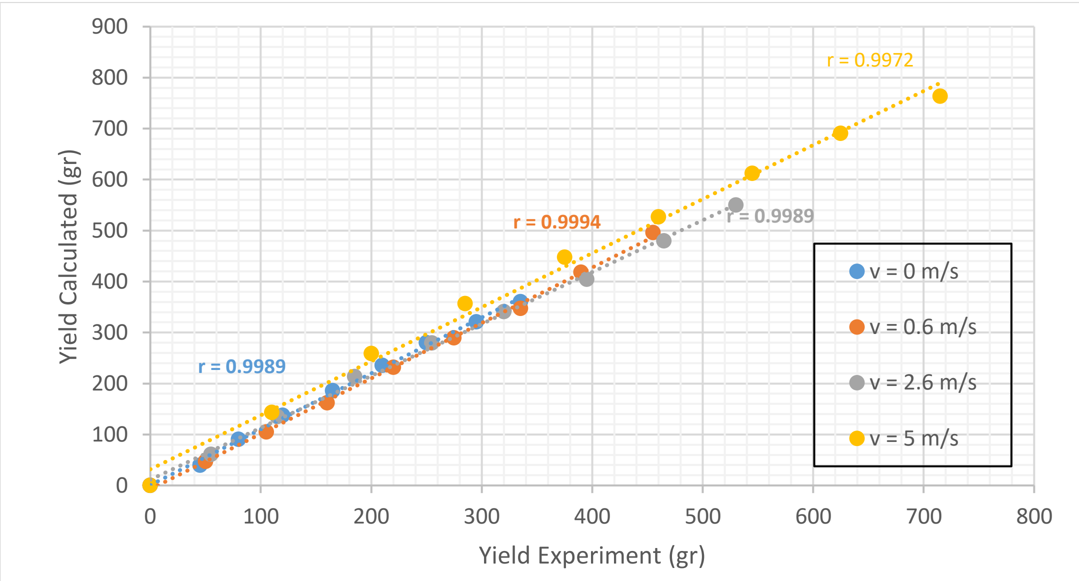

Fig. 4. Correlation of experimental and theoretical evaporation rates

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

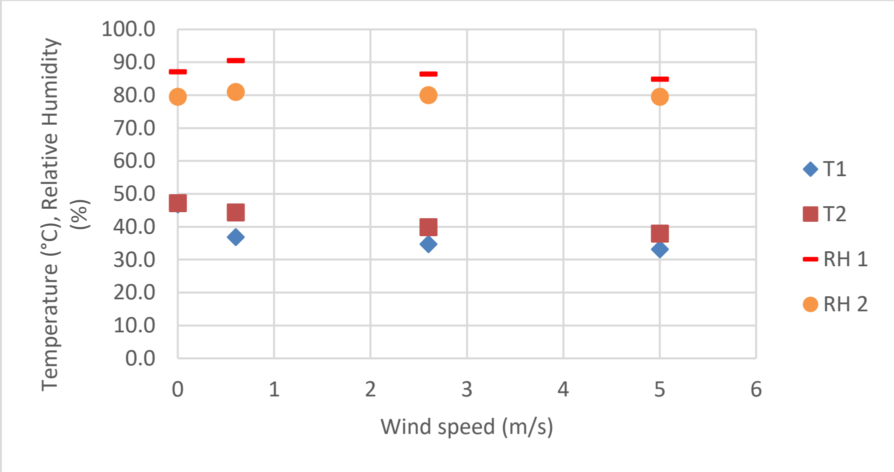

Fig. 5. Temperature (T1, T2) and relative humidity (RH1, RH2)

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].

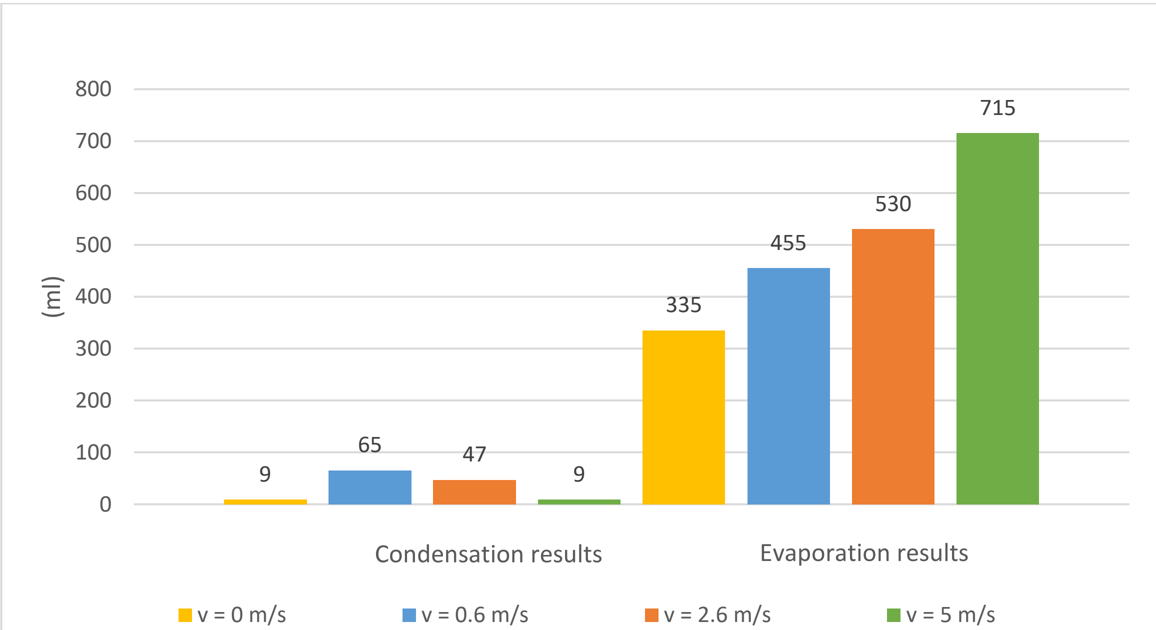

Fig. 6. Evaporation vs condensation over a two-hour period

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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References

[1] Habib, Somar Moaen, Ahmed Hamed, Ahmed Yahia Youssef, Mahmoud Kassem, and Abdalla Hanafi. "Dynamic Modeling and Simulation of the Forward Feed MED-TVC Desalination Plant." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 92, no. 1 (2022): 190-211. https://doi.org/10.37934/arfmts.92.1.190211

[2] Maizunati, Nur Afiyah, and Mohamad Zaenal Arifin. "Pengaruh Perubahan Jumlah Penduduk Terhadap Kualitas Air di Indonesia." *Jurnal Litbang Provinsi Jawa Tengah* 15, no. 2 (2017): 207-215. https://doi.org/10.36762/litbangjateng.v15i2.417

[3] Schewe, Jacob, Jens Heinke, Dieter Gerten, Ingjerd Haddeland, Nigel W. Arnell, Douglas B. Clark, Rutger Dankers et al. "Multimodel assessment of water scarcity under climate change." *Proceedings of the National Academy of Sciences* 111, no. 9 (2014): 3245-3250. https://doi.org/10.1073/pnas.1222460110

[4] Bakrie, M. “Krisis Air Bersih Melanda Pesisir Maros Sulsel.” *detikNews*, August 2, 2019. https://news.detik.com/berita/d-4649550/krisis-air-bersih-melanda-pesisir-maros-sulsel.

[5] Walangare, Kristian BA, Arie SM Lumenta, Janny O. Wuwung, and Brave A. Sugiarso. "Rancang bangun alat konversi air laut menjadi air minum dengan proses destilasi sederhana menggunakan pemanas elektrik." *Jurnal Teknik Elektro dan Komputer* 2, no. 2 (2013).

[6] Fithriatus, Shalihah. "Perlindungan Hukum Terhadap Kedaulatan Wilayah Negara Republik Indonesia Menurut Konsep Negara Kepulauan Dalam United Nation Convention On The Law Of The Sea (UNCLOS) 1982." (2016): 117.

[7] Lestari, Fera, Try Susanto, and Kastamto Kastamto. "Pemanenan Air Hujan Sebagai Penyediaan Air Bersih Pada Era New Normal Di Kelurahan Susunan Baru." *SELAPARANG: Jurnal Pengabdian Masyarakat Berkemajuan* 4, no. 2 (2021): 427-434. https://doi.org/10.31764/jpmb.v4i2.4447

[8] Ambari, M. "Indonesia Negeri Tropis, Tapi Krisis Air Bersih di Kawasan Pesisir Terjadi?." (2018).

[9] Belessiotis, Vassilis, Soteris Kalogirou, and Emmy Delyannis. *Thermal solar desalination: Methods and systems*. Elsevier, 2016.

[10] Mugisidi, Dan, Oktarina Heriyani, Zeinab S. Abdel-Rehim, and Hamdi Fathurohman. "The influence of container material conductivity to sea water evaporation." In *AIP Conference Proceedings*, vol. 1977, no. 1, p. 030023. AIP Publishing LLC, 2018. https://doi.org/10.1063/1.5042943

[11] Mugisidi, Dan, and Okatrina Heriyani. "Sea water characterization at ujung kulon coastal depth as raw water source for desalination and potential energy." In *E3S Web of Conferences*, vol. 31, p. 02005. EDP Sciences, 2018. https://doi.org/10.1051/e3sconf/20183102005

[12] Curto, Domenico, Vincenzo Franzitta, and Andrea Guercio. "A review of the water desalination technologies." *Applied Sciences* 11, no. 2 (2021): 670. https://doi.org/10.3390/app11020670

[13] Abd Wahid, Khairul Anuar, Ilham Fahmi, Zaid Puteh, Muhammad Nur Farhan Saniman, Kamal Rusulan, Khairul Azhar, and Wan Mansor Wan Muhammad. "Self-Desalination Seawater Jig Based on Solar Thermal Energy." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 91, no. 1 (2022): 92-101. https://doi.org/10.37934/arfmts.91.1.92101

[14] Youssef, P. G., R. K. Al-Dadah, and S. M. Mahmoud. "Comparative analysis of desalination technologies." *Energy Procedia* 61 (2014): 2604-2607. https://doi.org/10.1016/j.egypro.2014.12.258

[15] Amirfakhraei, Amirhossein, Taleb Zarei, and Jamshid Khorshidi. "Performance improvement of adsorption desalination system by applying mass and heat recovery processes." *Thermal Science and Engineering Progress* 18 (2020): 100516. https://doi.org/10.1016/j.tsep.2020.100516
[16] Sadasivuni, Kishor kumar, Hitesh Panchal, Anuradha Awasthi, Mohammad Israr, F. A. Essa, S. Shanmugan, M. Suresh, V. Priya, and Abderrahmane Khechekhouche. "Ground water treatment using solar radiation-vaporization & condensation-techniques by solar desalination system." *International Journal of Ambient Energy* 43, no. 1 (2022): 2868-2874. https://doi.org/10.1080/01430750.2020.1772872
[17] Pakombong, Stefany. "Efek Permukaan Berkain Pada Efisiensi Distilasi Air Energi Surya Jenis Bak."
[18] Mugisidi, Dan, Berkah Fajar, Syaiful Syaiful, Tony Utomo, Oktarina Heriyani, Delvis Agusman, and Regita Regita. "Iron Sand as a Heat Absorber to Enhance Performance of a Single-Basin Solar Still." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 70, no. 1 (2020): 125-135. https://doi.org/10.37934/arfmts.70.1.125135
[19] Liu, Kai, Zhi Wang, Can Jin, Fang Wang, and Xueyuan Lu. "An experimental study on thermal conductivity of iron ore sand cement mortar." *construction and Building Materials* 101 (2015): 932-941. https://doi.org/10.1016/j.conbuildmat.2015.10.108
[20] Mugisidi, D., R. S. Cahyani, O. Heriyani, and D. Agusman. "Effect of Iron Sand in Single Basin Solar Still: Experimental Study." In *IOP Conference Series: Earth and Environmental Science*, vol. 268, no. 1, p. 012158. IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/268/1/012158
[21] Kazemi, Mohammad Amin, David S. Nobes, and Janet AW Elliott. "Experimental and numerical study of the evaporation of water at low pressures." *Langmuir* 33, no. 18 (2017): 4578-4591. https://doi.org/10.1021/acs.langmuir.7b00616
[22] Szilagyi, Jozsef. "On the thermodynamic foundations of the complementary relationship of evaporation." *Journal of Hydrology* 593 (2021): 125916. https://doi.org/10.1016/j.jhydrol.2020.125916
[23] Jaafar, Zahraa Abdulkareem, Hassanain Ghani Hameed, and Ridha Hasan Hussein. "Experimental investigation of a single slope solar still performance-evaporation process enhancement." In *IOP Conference Series: Materials Science and Engineering*, vol. 928, no. 2, p. 022096. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/928/2/022096
[24] Aprizki, Eriz, Mamat Rokhmat, and Edy Wibowo. "Analisis Pengaruh Kemiringan Sudut Atap Kaca Dan Penambahan Cermin Pada Alas Basin Terhadap Laju Penguapan Air Garam Dalam Distilator Tenaga Surya." *eProceedings of Engineering* 5, no. 3 (2018).
[25] Ding, Tianpeng, Yi Zhou, Wei Li Ong, and Ghim Wei Ho. "Hybrid solar-driven interfacial evaporation systems: Beyond water production towards high solar energy utilization." *Materials Today* 42 (2021): 178-191. https://doi.org/10.1016/j.mattod.2020.10.022
[26] Chen, Chaoji, Yudi Kuang, and Liangbing Hu. "Challenges and opportunities for solar evaporation." *Joule* 3, no. 3 (2019): 683-718. https://doi.org/10.1016/j.joule.2018.12.023
[27] Mugisidi, Dan, Berkah Fajar, and Tony Utomo. "The effect of water surface level in sensible heat material on yield of Single Basin solar still: experimental study." In *Journal of Physics: Conference Series*, vol. 1373, no. 1, p. 012014. IOP Publishing, 2019. https://doi.org/10.1088/1742-6596/1373/1/012014
[28] Feilizadeh, Mehrzad, MR Karimi Estahbanati, Amimul Ahsan, Khosrow Jafarpur, and Amin Mersaghian. "Effects of water and basin depths in single basin solar stills: An experimental and theoretical study." *Energy conversion and management* 122 (2016): 174-181. https://doi.org/10.1016/j.enconman.2016.05.048
[29] Tarawneh, Muafag Suleiman K. "Effect of water depth on the performance evaluation of solar still." *JJMIE* 1, no. 1 (2007).
[30] Tiwari, Anil Kr, and G. N. Tiwari. "Effect of water depths on heat and mass transfer in a passive solar still: in summer climatic condition." *Desalination* 195, no. 1-3 (2006): 78-94. https://doi.org/10.1016/j.desal.2005.11.014
[31] Kabeel, A. E., Swellam W. Sharshir, Gamal B. Abdelaziz, M. A. Halim, and Ahmed Swidan. "Improving performance of tubular solar still by controlling the water depth and cover cooling." *Journal of cleaner production* 233 (2019): 848-856. https://doi.org/10.1016/j.jclepro.2019.06.104
[32] Geng, Junxia, Yan Luo, Haiying Fu, Qiang Dou, Hui He, Guoan Ye, and Qingnuan Li. "Temperature and pressure effect on evaporation behavior of chloride salts using low pressure distillation." *Progress in Nuclear Energy* 147 (2022): 104212. https://doi.org/10.1016/j.pnucene.2022.104212
[33] Speedy, Robin J., Pablo G. Debenedetti, R. Scott Smith, Chen Huang, and Bruce D. Kay. "The evaporation rate, free energy, and entropy of amorphous water at 150 K." *The Journal of chemical physics* 105, no. 1 (1996): 240-244. https://doi.org/10.1063/1.471869
[34] Fathinia, Farshid, Mehdi Khiadani, and Yasir M. Al-Abdeli. "Experimental and mathematical investigations of spray angle and droplet sizes of a flash evaporation desalination system." *Powder Technology* 355 (2019): 542-551. https://doi.org/10.1016/j.powtec.2019.07.081

[35] Farnham, Craig, Masaki Nakao, Minako NABESHIMA, and Takeo MIZUNO. "Effect of water temperature on evaporation of mist sprayed from a nozzle." *change* 1, no. 3 (2015): 5.
[36] Holman, J. P. "Heat transfer, 10th editi. ed." *Mc-GrawHill Higher education* (2010).
[37] Khan, Md Imran H., Chanaka Prabuddha Batuwatta-Gamage, M. A. Karim, and YuanTong Gu. "Fundamental Understanding of Heat and Mass Transfer Processes for Physics-Informed Machine Learning-Based Drying Modelling." *Energies* 15, no. 24 (2022): 9347. https://doi.org/10.3390/en15249347
[38] Mohamad, Barhm. "Lecture Notes in Mass Transfer. " (2022).
[39] Bravo, Jose L. "Principles and Modern Applications of Mass Transfer Operations By J. Benitez." (2011): 3243-3243. https://doi.org/10.1002/aic.12641
[40] Utami, Herti, and Azhar Azhar. "Buku Ajar Transfer Massa dan Panas." (2017).
[41] Rohmawati, Indah. "Simulasi Model Perpindahan Panas dan Massa pada Proses Pengeringan Butiran Kedelai." (2013).
[42] Murzin, Dmitry Yu. "Chapter 3: Chemical Processes and Unit Operations." Essay. In *Chemical Reaction Technology*, 67–102. Turku: De Gruyter, 2015. https://doi.org/10.1515/9783110336443-005
[43] Sorokova, Natalia, Vladimir Didur, and Miroslav Variny. "Mathematical Modeling of Heat and Mass Transfer during Moisture–Heat Treatment of Castor Beans to Improve the Quality of Vegetable Oil." *Agriculture* 12, no. 9 (2022): 1356. https://doi.org/10.3390/agriculture12091356
[44] Walelign, Tadesse, Eshetu Haile, Tesfaye Kebede, and Assaye Walelgn. "Analytical study of heat and mass transfer in MHD flow of chemically reactive and thermally radiative Casson nanofluid over an inclined stretching cylinder." *Journal of Physics Communications* 4, no. 12 (2020): 125003. https://doi.org/10.1088/2399-6528/abcdba
[45] Dan Mugisidi, Dan Mugisidi, Abdul Rahman Abdul Rahman, Oktarina Heriyani Oktarina Heriyani, and Pancatatva Hesti Gunawan Pancatatva Hesti Gunawan. "Determination of the convective heat transfer constant (c and n) in a solar still." *Jurnal Ilmiah Sains dan Teknologi* 11, no. 1 (2021): 1-12. https://doi.org/10.22146/teknosains.50908
[46] Kamel, Ammar Hatem, Haitham Abdulmohsin Afan, Mohsen Sherif, Ali Najah Ahmed, and Ahmed El-Shafie. "RBFNN versus GRNN modeling approach for sub-surface evaporation rate prediction in arid region." *Sustainable Computing: Informatics and Systems* 30 (2021): 100514. https://doi.org/10.1016/j.suscom.2021.100514
[47] Invernizzi, Marzio, Alessia Bellini, Riccardo Miola, Laura Capelli, Valentina Busini, and Selena Sironi. "Assessment of the chemical-physical variables affecting the evaporation of organic compounds from aqueous solutions in a sampling wind tunnel." *Chemosphere* 220 (2019): 353-361. https://doi.org/10.1016/j.chemosphere.2018.12.124
[48] Tanggu, Rini, Dian Pranata Putra Ambali, Rikardus Rantetasak, Nuri Tumba Saranga, Winriani Tandiabang, and Asri Palullungan. "Tingkat Evaporasi di Kampus II Universitas Kristen Indonesia Toraja." *Journal Dynamic Saint* 6, no. 2 (2021): 53-56.
[49] Uno, Paul J. "Plastic shrinkage cracking and evaporation formulas." *ACI Materials Journal* 95 (1998): 365-375. https://doi.org/10.14359/379
[50] Yuga, Ahmad Yudha, Tamrin Tamrin, Warji Warji, and Sapto Kuncoro. "Modifikasi Rancang Bangun Kondensasi Uap Air Laut untuk Mendapatkan Air Murni." *Jurnal Agricultural Biosystem Engineering* 1, no. 4 (2022): 446-454.
[51] Zhang, Ke, John S. Kimball, Ramakrishna R. Nemani, Steven W. Running, Yang Hong, Jonathan J. Gourley, and Zhongbo Yu. "Vegetation greening and climate change promote multidecadal rises of global land evapotranspiration." *Scientific reports* 5, no. 1 (2015): 1-9. https://doi.org/10.1038/srep15956
[52] Elango, C., N. Gunasekaran, and K. Sampathkumar. "Thermal models of solar still—A comprehensive review." *Renewable and Sustainable Energy Reviews* 47 (2015): 856-911. https://doi.org/10.1016/j.rser.2015.03.054
[53] Nurhayati, Nurhayati, and Jamrud Aminuddin. "Pengaruh kecepatan angin terhadap evapotranspirasi berdasarkan metode penman di kebun stroberi purbalingga." *Elkawnie: Journal of Islamic Science and Technology* 2, no. 1 (2016): 21-28.
[54] Mugisidi, Dan, Oktarina Heriyani, Pancatatva Hesti Gunawan, and Dwi Apriani. "Performance Improvement of a Forced Draught Cooling Tower Using a Vortex Generator." *CFD Letters* 13, no. 1 (2021): 45-57. https://doi.org/10.37934/cfdl.13.1.4557
[55] Dewi, Francisca Gayuh Utami. "Pengaruh Kecepatan Dan Arah Aliran Udara Terhadap Kondisi Udara Dalam Ruangan Pada Sistem Ventilasi Alamiah." *Jurnal Rekayasa Mesin* 3, no. 2 (2012): 299-304.
[56] Sulfemi, Wahyu Bagja. "Korelasi Kompetensi Pedagogik Guru dengan Prestasi Belajar Mata Pelajaran IPS Di SMP Muhammadiyah Pamijahan Kabupaten Bogor." (2019). https://doi.org/10.31227/osf.io/9qrbc
[57] Majhi, Babita, Diwakar Naidu, Ambika Prasad Mishra, and Suresh Chandra Satapathy. "Improved prediction of daily pan evaporation using Deep-LSTM model." *Neural Computing and Applications* 32 (2020): 7823-7838. https://doi.org/10.1007/s00521-019-04127-7
[58] Holman, Jack Philip. "Experimental Methods for Engineers Eighth Edition." (2021).

[59] Khamdila, Ali, Santhi Wilastari, and Agus Saleh. "Menjaga Kestabilan Suhu Ruang Evaporator Berdampak Pada Hasil Produksi Air Tawar Fresh Water Generator." *Jurnal Sains Dan Teknologi Maritim* 19, no. 2 (2019): 111-120. https://doi.org/10.33556/jstm.v19i2.200

[60] Mardatila, Ani. "Mengenal Siklus Air Beserta Pengertian, Tahapan Dan Urutannya." merdeka.com, August 28, 2020. https://www.merdeka.com/sumut/mengenal-siklus-air-beserta-pengertian-tahapan-dan-urutannya-kln.html.

[61] Ahmad, Latief, Raihana Habib Kanth, Sabah Parvaze, and Syed Sheraz Mahdi. *Experimental agrometeorology: a practical manual*. Vol. 159. Springer International Publishing, 2017. https://doi.org/10.1007/978-3-319-69185-5

[62] Davarzani, Hossein, Kathleen Smits, Ryan M. Tolene, and Tissa Illangasekare. "Study of the effect of wind speed on evaporation from soil through integrated modeling of the atmospheric boundary layer and shallow subsurface." *Water resources research* 50, no. 1 (2014): 661-680. https://doi.org/10.1002/2013WR013952

[63] As-syarif, Anwar Hidayat, Suwandi Suwandi, and Endang Rosdiana. "Pengaruh Penguapan Air Terhadap Suhu Dan Kelembaban Udara Di Suatu Ruangan." *eProceedings of Engineering* 8, no. 2 (2021).

[64] Young, Jim. "Factors Influencing the Likelihood of Surface Condensation on Mechanical Systems Insulation, Part 1" Insulation Outlook Magazine, July 1, 2012. https://insulation.org/io/articles/factors-influencing-the-likelihood-of-surface-condensation-on-mechanical-systems-insulation-part-one/

[65] Titahelu, Nicolas, and Samy J. Litiloly. "Analisis Laju Kondensasi Akibat Pengaruh Kecepatan Udara Terhadap Karakteristik Perpindahan Panas Pada Oven Pengering Pati Sagu Kapasitas." *ALE Proceeding* 1 (2018): 108-114. https://doi.org/10.30598/ale.1.2018.108-114

[66] Tamrin, Tamrin, Rivaldo Rivaldo, and Warji Warji. "Kinerja Alat Kondensasi Uap Air Laut Untuk Mendapatkan Air Murni." *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)* 10, no. 4 (2021): 425-431. https://doi.org/10.23960/jtep-l.v10i4.425-431