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Convective Coefficient and Evaporative in Forced Flow Solar Still

Koefisien Konveksi dan Evaporasi pada *Solar Still* Aliran Paksa

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Abstract

The water crisis is a significant global problem, with more than 2 billion people lacking water and 1.1 billion having no access to clean water. Desalination, a method of converting seawater into fresh water by removing salt, is a potential solution to help coastal populations. This study aims to determine the convection and evaporation heat transfer coefficients and the effect of condenser cooling water temperature on the evaporation process and the increase in freshwater condensate. The research methodology involved the analysis of heat and mass transfer in a solar desalination system. A desalination device was designed to test the evaporation process with seawater temperature heated using halogen lamp light. Results show that increasing seawater temperature from 27°C to 42°C results in condensation when the temperature reaches about 30°C, affecting the water surface pressure and evaporation rate. Evaporation and condensation efficiencies are affected by convection and evaporation heat transfer, resulting in a convection heat transfer (0.84296 W/m^2.°C) and evaporation heat transfer coefficient (23.81353 W/m^2.°C). This research demonstrates the potential of solar desalination technology in producing clean water.

Keywords: desalination, heat transfer, conduction.

***SDGs*:**

6 CLEAN WATER AND SANITATION

Abstrak

Krisis air bersih merupakan masalah global yang signifikan, dengan lebih dari 2 miliar orang kekurangan air dan 1,1 miliar tidak memiliki akses pada air bersih. Desalinasi, metode mengubah air laut menjadi air tawar dengan menghilangkan garam, merupakan solusi potensial untuk membantuk penduduk sekitar pesisir pantai. Penelitian ini bertujuan untuk menentukan koefisien perpindahan panas konveksi dan evaporation, pengaruh suhu air pendingin kondensor terhadap proses penguapan dan peningkatan kondensat air tawar. Metodologi penelitian melibatkan analisis perpindahan panas dan massa dalam sistem desalinasi tenaga surya. Alat desalinasi didesain untuk menguji proses penguapan dengan suhu air laut yang dipanaskan menggunakan sinar lampu halogen. Hasil menunjukkan bahwa suhu air laut yang meningkat dari 27°C hingga 42°C menghasilkan kondensasi saat suhu mencapai sekitar 30°C, mempengaruhi tekanan permukaan air dan laju penguapan. Efisiensi penguapan dan kondensasi dipengaruhi oleh perpindahan panas konveksi dan evaporasi, yang menghasilkan perpindahan panas konveksi (0.84296 W/m^2.°C) dan koefisien perpindahan panas evaporasi (23.81353 W/m^2.°C). Penelitian ini menunjukkan potensi teknologi desalinasi tenaga surya dalam menghasilkan air bersih.

Kata Kunci: desalinasi, perpindahan panas, konveksi.

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1. INTRODUCTION

In recent times we see that in every region many have difficulty in finding clean water, the problem of clean water needs in everyday life is a challenge in the problem. Based on data from WHO 2000. In several countries around the world, more than 2 billion people lack water. 1.1 billion people do not have access to adequate water, and 2.4 billion people do not have access to proper sanitation (Dewantara, Suyitno and Lesmana, 2018). As Indonesia is surrounded by sea water, many coastal areas are affected by the shortage of clean water and salt, many coastal communities buy water to maintain clean wate (Mulyanef, Burmawi and K., 2014). Forecasts of economic growth with increased efficiency suggest that water demand could exceed 40 per cent by 2030 (Ahmadi *et al.*, 2020). The generation rate of stored heat energy can determine the evaporation efficiency (Chen, Kuang and Hu, 2019). The high demand for clean water in Indonesia has resulted in a water crisis in some areas of the country (Maizunati and Arifin, 2017). Desalination is a method used to convert seawater into fresh water by removing the salt content, in this process, evaporation and condensation are two important stages. Under conditions in which temperature regulation can be defined in terms of air cooling (Aprizki, Rokhmat and Wibowo, 2018; Wiratmaja, Dantes and Artha, 2021). BMKG observed an increase in air temperature in Indonesia in recent years (Salma, 2022). Solar technology has been around for thousands of years and is used to distill water (Tiwari and Tiwari, 2006). In distillation or desalination requires a condenser device (Dika, 2020). The main function of a condenser in a steam power installation is to condense a rate of steam generated in the evaporation process generated in the condenser (Mahmud, 2015).

In distillation or desalination there are many processes regarding the use of technology (Curto, Franzitta and Guercio, 2021). An evaporation that is carried out slowly makes the remaining vapour so that it becomes pure water. In distillation or desalination using solar energy can facilitate the production of clean water with sunlight (Mugisidi *et al.*, 2018). Process in seawater desalination to separate the salts to a special place and other minerals in water (Amirfakhraei, Zarei and Khorshidi, 2020). From distillation or desalination can the effect of evaporation to get a physical better for use (Khamdila, Wilastari and Saleh, 2019; Szilagyi, 2021). The conversion of seawater to freshwater through desalination not only provides important benefits in meeting clean water needs, but also provides value-added opportunities as by-products. While the potential economic value generated is high, it should be noted that the efficiency of modern desalination equipment is still a challenge (Mugisidi *et al.*, 2020). However, research is needed on the temperature of the condenser cooling water in increasing freshwater condensate in salt fields. The purpose of this study is to determine how much the coefficient results in conducting convection and evaporation heat transfer to the evaporation process in increasing fresh water condensate.

2. METHODOLOGY

In Figure 1 the process flow carried out in the research process is as follows:

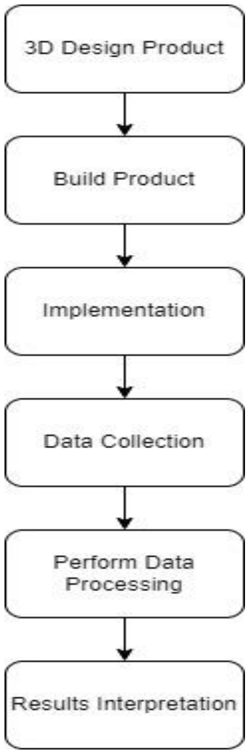


Figure 1. Research methodology.

Based on Figure 1, the first step undertaken is to design the product in 3D using Solidworks software. Subsequently, once the 3D product design is completed, researchers begin implementing the design into a functional tool. Following this, the formed tool is implemented for use as a condenser to investigate the effect of condenser water temperature on the increase of fresh water condensate. From the conducted implementation, researchers collect necessary data which are then processed and interpreted in accordance with existing theory.

2.1. Heat Transfer

Heat transfer is the main pillar to maintain thermal balance in a room (Pandu and Purwanto, 2021). Mass transfer can also be interpreted as heat transfer from one substance to another. Mass transfer mechanisms can occur by involving three ways conduction, convection, and radiation (Mahmuddin, 2016). This process also involves the transfer of water vapour from the material to be dried to the water (Amin, Jamaluddin and Rais, 2018). Many physical and chemical processes include mass transfer, desalination, and evaporation. The use of mass transfer describes the physics involved in the molecular diffusion and convective movement of chemical species in a system. Previous research tells us that mass transfer rates can vary depending on the physical and chemical parameters of the system, such as temperature, pressure, and flow rate (Sorokova, Didur and Variny, 2022).

Evaporation is the physical process by which a liquid, such as water, changes into a gaseous state through the addition of heat energy. During evaporation, the liquid molecules gain enough energy to overcome the intermolecular forces of attraction and leave the liquid phase, switching to the gas phase (Helwig *et al.*, 2016). ome physical parameters that affect evaporation include air humidity, air temperature, and wind speed (Poernomo, 2015).

Mathematically, the solar distillation efficiency (η) is determined by multiplying the condensation yield by the latent heat of vapourisation and dividing it by the solar radiation and can be calculated:

$$(\eta) = \frac{\sum md\ x hfg}{\sum 1(t)_s x\ A_s\ x\ t} \quad (1)$$

where:

$\sum_{md}$: Evaporation Result (kg)
H_{fg} : Latent Heat Of Exhalation(J/kg)
$\sum 1(t)_s$: Light Intensity (W/m^2)
A_s : Containment Basin Area (m^3)
T : Time (s)

In determining the evaporation yield per hour (M_w) calculated with the following equation (Zhang *et al.*, 2015; Mugisidi *et al.*, 2022):

$$m_w = \frac{h_{ew-gi}(T_w - T_{gi})}{h_{fg}}\ x3600 \quad (2)$$

where:

M_w : Evaporation per hour (g)
$H_{ew\text{-}gi}$: Evaporation Heat Transfer (W/m^2.°C)
T_w : Water Temperature (°C)
T_{gi} : Temperature on Glass (°C)
H_{fg} : Latent Heat Of Exhalation (J/kg)

The convection heat transfer coefficient h_{cw-gi} can be calculated using the equation (Haddad, Al-Nimr and Maqableh, 2000):

$$h_{cw-gi} = 0.884\ x\ (T_w - T_{gi}) \left[\frac{(P_w - P_{gi}).(T_w + 273{,}15)}{268900 - P_w}\right]^{\frac{1}{2}} \quad (3)$$

where:

$H_{cw\text{-}Gi}$: convection heat transfer (W/m^2.°C)
T_w : Water Temperature (°C)
T_{gi} : Temperature On Glass (°C)
P_w : Water pressure (N/m^2)
$P_{g\text{-}I}$: Inner glass cover pressure (N/m^2)

To calculate the evaporative heat transfer coefficient, H_{ew-gi} calculated by the equation:

$$h_{ew-gi} = 16{,}273\ x\ 10^{-3}\ .\ h_{ew-gi}\ .\frac{p_w - p_{gi}}{T_w - T_{gi}} \quad (4)$$

where:

$H_{ew\text{-}gi}$: Evaporation Heat Transfer (W/m^2.°C)
P_w : Water pressure (N/m^2)
$P_{g\text{-}I}$: Inner glass cover pressure (N/m^2)
$T_{g\text{-}I}$: Temperature on glass (°C)

In Dunkle's theoretical mass calculation model, this calculation refers to the constants C and N, which vary depending on the geometry of the solar cell. The constants C and N are also used to derive the Nusselt number, which is ultimately used to determine the value of the convection heat transfer coefficient (Elango and Murugavel, 2015).

To determine the heat transfer coefficient, it is necessary to know the Nusselt number (Nu) of the solar still (Mugisidi *et al.*, 2022):

$$N_u = \frac{h_{cw-gi} \cdot d_f}{k_f} \quad (5)$$

where:

h_{cw-gi} : Convection Heat Transfer (W/m^2.°C)
k_f : Thermal Conductivity of Objects (W/m.°C)
d_f : Material Density (kg/m^3)

Meanwhile, to determine the heat transfer coefficient:

$$h_{cw-gi} = \frac{k_f}{d_f} C(G_r P_r)^n \quad (6)$$

where:

h_{cw-gi} : Convection heat transfer (W/m^2.°C)
d_f : Material Density (kg/m^3)
k_f : Thermal Conductivity Of Objects (W/m.°C)
P_r : Prandtl
G_r : Grashof

2.2. Pressure

Pressure is the distribution of force per unit area. If a force is applied to a small area, the pressure will be high; conversely, if the force acting on the surface is large, the pressure will be low (Sukarno, Bono and Prasetiyo, 2016). It is important to recognise that the pressure in the condenser is not a single parameter to be considered, but rather a part of the entire cooling system (Tanusekar and Sutanhaji, 2014). Pressure in the condenser fluctuates throughout the refrigeration cycle depending on operating conditions and system design (Nurhayati and Aminuddin, 2016).

The equation used to calculate water pressure is as follows:

$$P_w = exp\left[25.317 - \left(\frac{5144}{T_w+273}\right)\right] \quad (7)$$

where:

P_w : Water pressure (N/m^2)
T_w : Water Temperature (°C)

Evaporation is the process that occurs when water is converted into gas or vapour. It is caused by the pressure difference between the water surface and the air above it, which performs the functions of internal convection, radiation, and evaporation depending on the water vapour (Febrianto, Kabib and Nugraha, 2018):

$$q_{ew-gi} = h_{ew-gi}\,(T_w - T_{gi}) \quad (8)$$

where:

H_{ew-gi} : Evaporation Heat Transfer (W/m^2.°C)
T_w : Water Temperature (°C)
T_{gi} : Temperature On Glass (°C)

Evaporation is the process that occurs when water is converted into gas or vapour. It is caused by the pressure difference between the water surface and the air above it, which performs the functions of internal convection, radiation, and evaporation depending on the water vapour (Febrianto, Kabib and Nugraha, 2018):

$$q_{ew-gi} = h_{ew-gi}\,(T_w - T_{gi}) \quad (9)$$

where:

h_{ew-gi} : Evaporation Heat Transfer (W/m^2.°C)
T_w : Water Temperature (°C)
T_{gi} : Temperature On Glass (°C)

2.3. Tools and Materials

This desalination test is to determine how much cooling water temperature in the condenser occurs in increasing the fresh water condensate produced in the salt field. In the condenser used to evaporate seawater in the salt field. The condenser uses 2 mm aluminium plate material in the shape of a trunk, in its conical condensate which is given a baffle to provide more evaporation paths. The materials used in this tool are presented in Table 1, for the tools used are presented in Table 2.

In Figure 2a, the design of this research tool was carried out in the mechanical engineering laboratory of Prof. Dr HAMKA's Muhammadiyah University from December 2023 to March 2024. A schematic of the desalination plant used in this study is shown in Figure 2b. The seawater in this container is heated by the reflection of lamp light through the glass on the main container at a lamp

Table 1. Materials.

No	Materials		
	Materials	Function	Specifications
1.	Wood	To create a seawater main sectional basin	Teak block 2cm 144 x 101 mm
2.	Plywood	For the base on the slope of the tub Plywood phenolic film 5mm 95 x 139 mm	For the base on the slope of the tub Plywood phenolic film 5mm 95 x 139 mm
3.	Alumunium	To make a condenser	Aluminium plate 2mm
4.	Aquaproof	For lining the inside and outside of the main tub cross section	Aquaproof 1kg grey colour
5.	Philips Halogen Lamp	To reflect light heat into seawater	1000 Wat Plusline

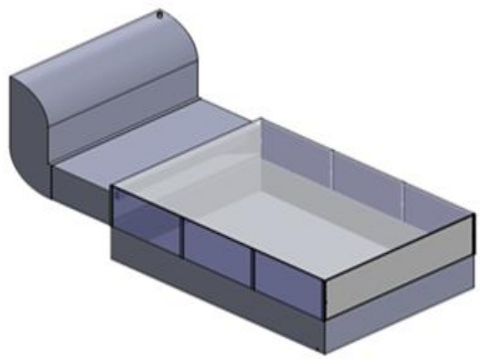
Table 2. Tools.

No	Tools		
	Materials	Function	Specifications
1.	Thermostat XH-W3001	Temperature	-50°C - 110°C, Temperature Accuracy 0.1°C.
2.	Digital thermometer Water temperature	Digital thermometer Water temperature	-50°C - 110°C, resolution 0.1°C, Accuracy ±0.1°C
3.	Digital hygrometerHumidity	Digital hygrometer Humidity	10% - 99%, resolution 1%, Accuracy ±1%
4.	Solar Power	To measure the heat light of the lamp	0,1 W/m²
5.	5kg digital scales	To determine how much evaporation results	0 - 5 kg, 1 g

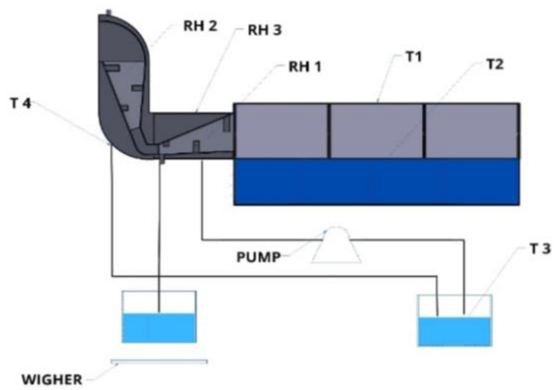
heat temperature of 1,200 W/m² When evaporating water, water vapour goes to the steam funnel and then enters the condenser with lamp light radiation during the test.

The evaporated seawater from the reservoir goes to the condenser, which then flows into the control reservoir that exits through the condenser channel. To ensure that the water level in the condenser remains at a certain level, the condenser vessel has a depth of storage where water is continuously circulated through a pump to cool it. Therefore, the water level of the inner condenser remains the same, while the seawater level in the sump reservoir decreases due to evaporation.

Furthermore, the evaporation results were measured through a digital scale to determine how much evaporation was produced every 15 minutes. The scheme of data collection in this study is presented in Figure 2b. Where T2 the temperature of seawater in the reservoir, T1 the temperature of the fixed glass heat that reflects to the seawater in the cross section of the tub, T3 the temperature of the cooling water entering the condenser which continues to circulate. RH1 is the humidity of the evaporation rate entering through the condenser, RH2 is the humidity at the condenser trunk, RH3 is the humidity at ambient temperature.



(a) Research design front view.



(b) Research scheme side view.

Figure 2. Experimental rig.

3. RESULTS AND DISCUSSION

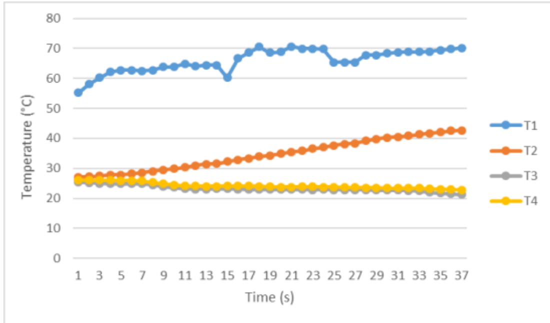
In the large-scale desalination device in Figure 3 shows that the process of taking evaporation data in a salt field, seawater in the main tub container is heated through a halogen lamp which then sends some of the heat flowing into the seawater above it. An increase in water temperature increases the pressure on the water surface, causing evaporation. This data was collected when the temperature of the water in the main basin container was about 27 °C which produced vapour. This data was collected every 15 minutes for 9 hours over the 3-day test period.

Figure 3. Desalination equipment.

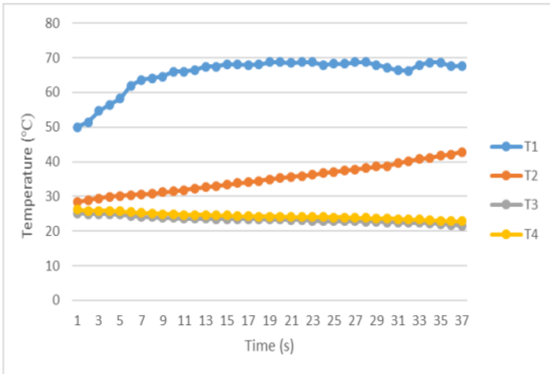
3.1. Temperature

Temperature in this study to measure the level of heat and cold in the desalination device (Pramana, 2018). When testing the temperature results have different levels of heat during the test. In this study the authors collected data on glass temperature (T1), seawater temperature (T2), cooling water temperature in (T3) and cooling water temperature out (T4). Temperature data is obtained in testing for 3 days of data collection. The following is a table of temperature data in the desalination device.

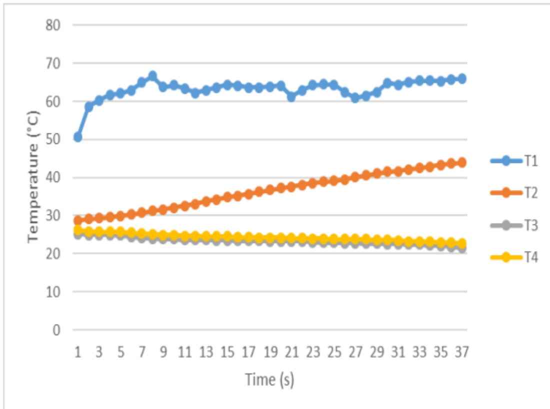
In Figure 4 the occurrence of condensation is due to the heat of the seawater temperature which continues to increase, because the heat is transmitted through the base plate of the cross-sectional container (Sayuti *et al.*, 2023). Based on the data above, the average T2 seawater temperature starts from 27°C - 28°C to the highest temperature of 40°C - 42°C. Of all the temperatures tested, not all evaporation processes occur, only starting from 09.30 at a temperature of 30 ° C seawater which produces condensation. The heat contained in the water vapour is released through the condenser siding.



(a) Day 1



(b) Day 2



(c) Day 3

Figure 4. Experimental results of the effect of time on temperature.

When condensation occurs, cooling water is needed. Cooling water is used to transfer heat that occurs when seawater evaporates. Cooling water in the graph above with a decreasing temperature, starting at a temperature of 25.3°C to a cold temperature of 21.3 ° C at the temperature in the condenser. The graph above has the same increase in seawater temperature as the increase in cooling water in and cooling water out, in the test for 3 days. This affects the increase in the evaporation process that occurs during the testing process.

3.2. Evaporation

The result in knowing the amount of fresh water produced in desalination is determined in the process of evaporation of seawater. The process of evaporation of seawater will be better if the temperature of seawater in the sectional container always increases in temperature. We can see that this temperature increases because it accumulates, this increase in temperature causes increased evaporation. The temperature of the water temperature encourages the evaporation of water and eventually condenses on the inside of the glass which results in evaporation. The condensation process that occurs on the inside of the glass is directly affected by the difference in water temperature pressure using equation (7) (Nababan and Ambarita, 2017). The temperature in Figure 4 which continues to increase at T2 shows that the evaporation process. In Figure 5, the evaporation results have increased in the 3 days of testing, due to the temperature in seawater increasing significantly resulting in increased evaporation.

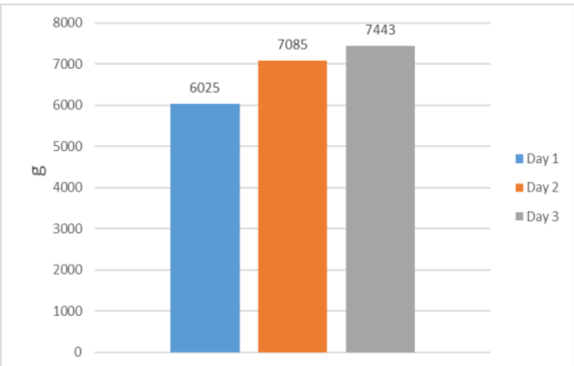


Figure 5. Evaporation result.

In the context of desalination mw is water that successfully passes through the membrane in the separation process and becomes clean water produced by the desalination system. The results of the experiment to determine the results of the evaporation rate which shows an evaporation per hour (mw) with this calculation model in an evaporation process calculated by equation (2) (Rahmani, Boutriaa and Hadef, 2015). To determine the efficiency of the condensate yield in the productivity of diesel stiil can be known by equation (1). Evaporation results obtained from actual and theoretical calculations that increase during each test (Catrawedarma, 2008). Actual Mw calculation of the mechanical work done by the system considering factors such as efficiency and to determine the performance or evaporation yield.

The dimensionless nusselt, rayleigh, prandtl, and grashoff numbers represent convection and evaporation heat transfer in water-to-air systems. Therefore, they are integrated into the energy balance of a solar distillery (Syukri *et al.*, 2023). Furthermore, the Nusselt number is a number used in heat transfer to measure the relationship between convection and conduction heat transfer (Hinojosa *et al.*, 2005). Then to produce the convection heat transfer coefficient (h_(cw-gi)) using the system obtained by the equation (3) which obtained results from 3 days of experiments 0.84296 $W/m^2.°C$.

Evaporative heat transfer coefficient (Hew – gi) is obtained by using equation (4) which obtained results from 3 days of experiments 23.81353 $W/m^2.°C$. Meanwhile, the total heat transfer was found to be 3824.44 Watts. However, the line equation obtained using power regression can be compared with equation (6). The constant coefficients c and n are found to be equal to 0.9876, 0.8177, and 0.9063, respectively. The heat transfer coefficient is calculated with constants c and n with the dunkle model, this heat transfer is used to calculate the resulting water bath. The calculation results have a degree of difference between the convection coefficient and the evaporation heat transfer coefficient. We can see that the experimental hc calculation result is lower than the experimental he calculation, so the evaporation heat transfer coefficient gets high results experimentally. It can be compared with the results of similar journal experiments, this experiment is higher in convection and evaporation heat transfer (Mugisidi *et al.*, 2021).

4. CONCLUSION

In the context of heat transfer, research shows that it is important to quantify the convection and evaporation heat transfer relationships. The convection heat transfer coefficients were calculated using the Dunkle model and the results of these calculations are in accordance with the results of existing journals, which show the coefficients of the convection and evaporation heat transfer processes. With the results of convection heat transfer 0.84296 $W/m^2.^\circ C$, evaporation heat transfer 23.81353 $W/m^2.^\circ C$, and the total heat transfer amount is obtained as follows 3824.44 Watts. This study aims to determine how much the coefficient results in convection and evaporation heat transfer. The results of this study make an important contribution to understanding and optimising the desalination process using solar technology and show great potential in overcoming the problem of clean water shortages in coastal areas of Indonesia.

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