

STUDY ON THE USE OF COOLING WATER AS INPUT WATER TO IMPROVE DOUBLE SLOPE SOLAR STILL PERFORMANCE

Nova Risdiyanto Ismail✉
Department of Mechanical Engineering¹
nova@widyagama.ac.id

Purbo Suwandono
Department of Mechanical Engineering¹

Dadang Hermawan
Department of Mechanical Engineering¹

Frida Dwi Anggraeni
Department of Agricultural Product Technology¹

¹Universitas Widyagama Malang
35 Borobudur str., Malang-East Java, Indonesia, 65142

✉Corresponding author

Abstract

The problem for residents in island and coastal areas is the lack of fresh water, especially during the dry season. In the dry season, there is abundant potential for solar energy utilization. This potential can be utilized as an energy source for distilling seawater into fresh water using solar still technology. Solar still performance is influenced by the evaporation and condensation processes. Several researchers have made efforts to increase evaporation, such as enhancing the heat absorption of absorber plates and preheating seawater. This research aims to apply initial heating to seawater to enhance the evaporation process. The initial heating of seawater is obtained from heat absorption in the walls, which function as a cooling medium. Thus, this research aims to investigate the use of cooling water on the walls as input water to enhance the performance of double-slope solar stills. The research was carried out experimentally and theoretically. Research on the performance of a double-slope solar still utilizes wall cooling water as input water (SSDS.WCW.HC) compared to wall water cooling (SSDS.WCW). The research yielded an average daily condensate water productivity using SSDS.WCW.HC experimentally of 3.48 kg/10-hours and theoretically of 3.56 kg/10-hours, which is higher compared to SSDS.WCW experimentally of 3.16 kg/10-hours and theoretically of 3.27 kg/10-hours. The average daily energy efficiency using SSDS.WCW.HC experimentally is 53.77 % and theoretically 54.83 % higher compared to SSDS.WCW, which is 48.87 % experimentally and 49.81 % theoretically. The highest daily average exergy efficiency using SSDS.WCW.HC was 6.44 %, compared to 5.33 % for SSDS.WCW.

Keywords: solar still, double slope, water cooling, preheating, productivity, energy efficiency, exergy efficiency.

DOI: 10.21303/2461-4262.2024.003334

1. Introduction

Indonesia is a country with a tropical climate [1, 2], so the potential for solar energy is quite high [3]. This potential can be utilized for the distillation process of seawater into fresh water, using solar still technology [4, 5]. Solar still technology works by utilizing the evaporation and condensation method, resulting in fresh water [6, 7]. In this way, the application of solar still technology can help people who lack fresh water, especially during the dry season [8, 9].

Solar still technology has two types, namely active and passive [10]. In the passive type, several researchers have developed it by enhancing the performance of the absorber plate to increase the absorption of solar radiation heat [11, 12]. Increasing the absorption of solar radiation heat can be achieved by using a fin-shaped absorber plate. Fin-shaped absorber plates can enhance the reception of solar radiation intensity, thereby increasing evaporation [13, 14]. Increased evaporation can enhance the productivity of solar stills [15].

Some researchers are attempting to enhance the evaporation process by preheating the seawater before it is introduced into the solar still basin [16]. There are various ways to provide initial

heating to seawater before it enters the solar still basin, including using integrated solar collectors (such as concentrator and flat plate collector), other heating units (like evacuated tubes with heat pipe, parabolic concentrator), and hybrid solar stills (integrated with PV modules, powered by waste heat, integrated with solar pond) [17]. Other research utilizes solar water heaters to warm water prior to its entry into the solar still basin, which can enhance productivity [11]. Apart from enhancing the evaporation process, several researchers are also making efforts to improve the condensation process. Efforts to improve the condensation process involve increasing the condensation surface area. Increasing the condensation surface area can be achieved by utilizing various forms of covers, such as double-slope cover glass [18, 19], pyramid cover glass [20], octagonal-pyramid [21, 22], and four-fold slope [23]. Efforts to enhance the condensation process also involve reducing the temperature of the condensation surface. Reducing the temperature of the condensation surface can be achieved by flowing water over the cover glass [24, 25], spraying water on the cover glass [26, 27], and utilizing thermoelectric cooling on the cover glass [28, 29].

This research aims to enhance the evaporation and condensation process. Improved the condensation process by increasing the condensation surface area. Increased condensation surface area by utilizing walls as condensation surfaces. The condensation surface is cooled with seawater. Apart from enhancing the condensation process, this research also aims to improve the evaporation process. Improving the evaporation process can use fin absorber plates made of mortar material [30]. In addition to utilizing fin absorber plates, this research also involves preheating sea water before it enters the solar still basin. Sea water, as a cooling medium on the walls, can absorb heat from the solar still system, causing the sea water temperature to rise. The seawater is used as input water to facilitate the evaporation process.

Thus, this research aims to enhance the productivity and efficiency of double-slope solar stills. Double slope solar still with the addition of water cooling on the wall (SSDS.WCW) was compared to a double slope solar still with the addition of water cooling on the wall, where the cooling water is used as input water (SSDS.WCW.HC).

2. Materials and methods

2. 1. Experimental set up

The research was conducted at the Solar Energy and Alternative Energy Laboratory, Department of Mechanical Engineering, Widyagama University, in Malang, East Java, Indonesia. The geographical condition of the city of Malang is characterized by a latitude of -7.266667 and a longitude of 112.716667 , or with coordinates $7^{\circ}16'$ South Latitude and $112^{\circ}43'$ East Longitude.

The cover and walls of the double-slope solar still are made of 3 mm thick clear glass, while the bottom is made of 5 mm thick glass. To minimize heat and steam loss, all glass is sealed with silicone adhesive. Equipment setup can be seen in **Fig. 1**. This research is a continuation of previous research by utilizing heat from cooling water as input water [31].

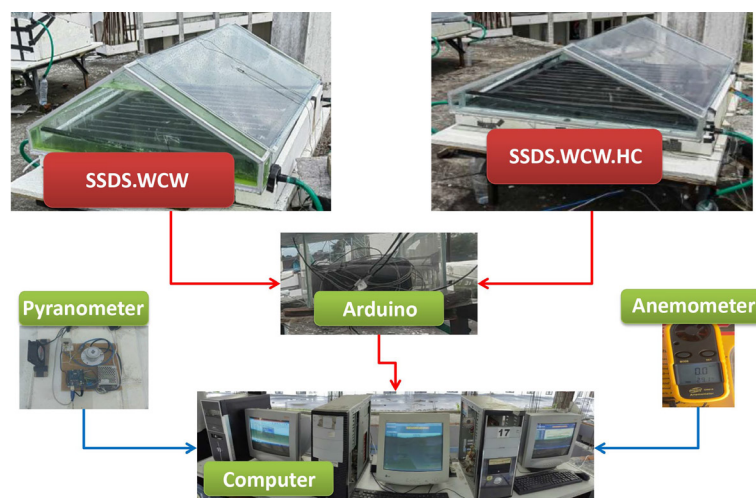


Fig. 1. Set up solar still equipment [31]

2. 2. Measuring equipment

Various instruments for measuring parameters used are thermocouples, pyranometers, anemometers, and measuring cups. The associated error percentage, accuracy, and range of instruments can be seen in **Table 1**.

Table 1
Measuring equipment

No.	Instrument	Accuracy	Range		% error
			Min	Max	
1	Thermocouple	$\pm 0.1\text{ }^{\circ}\text{C}$	$-100\text{ }^{\circ}\text{C}$	$200\text{ }^{\circ}\text{C}$	0.25 %
2	Pyranometer	$\pm 1.0\text{ W/m}^2$	0 W/m^2	1200 W/m^2	1 %
3	Anemometer	$\pm 0.1\text{ m/s}$	0 m/s	25 m/s	5 %
4	Measuring cup	$\pm 1.0\text{ mL}$	0 mL	200 mL	1 %

2. 3. Experimental procedure

Research was conducted both experimentally and theoretically. Double-slope solar still equipment with the cover glass tilted towards the east and west to maximize the receipt of solar radiation intensity. The water height at SSDS.WCW is 10 mm. At SSDS.WCW.HC, the water level was 5 mm, and cooling water was added with a flow capacity of 1.1×10^{-4} liters per second during the test. Data on temperature, solar radiation intensity, wind speed, and distillate output are measured every 60 minutes. Measurements of all necessary parameters are carried out from 7 a.m. to 5 p.m.

2. 4. Theoretical models of solar efficiency still

A mathematical model for heat balance in solar stills [32]. However, for solar still double slope absorbent mortar fins were developed based on previous research. To simplify the analysis, it can be assumed that the heat capacity of the cover glass, absorbing fins, and insulating materials are negligible. There is no vapor leakage in the solar still. Air and water vapor are considered as ideal gases. The temperature gradient does not change with the thickness of the glass cover. The physical properties of various materials are constant, and it is considered that there are no impurities on the cover glass.

Fig. 2 explains the heat transfer scheme in the double slope solar still by utilizing cooling water as feed/input water.

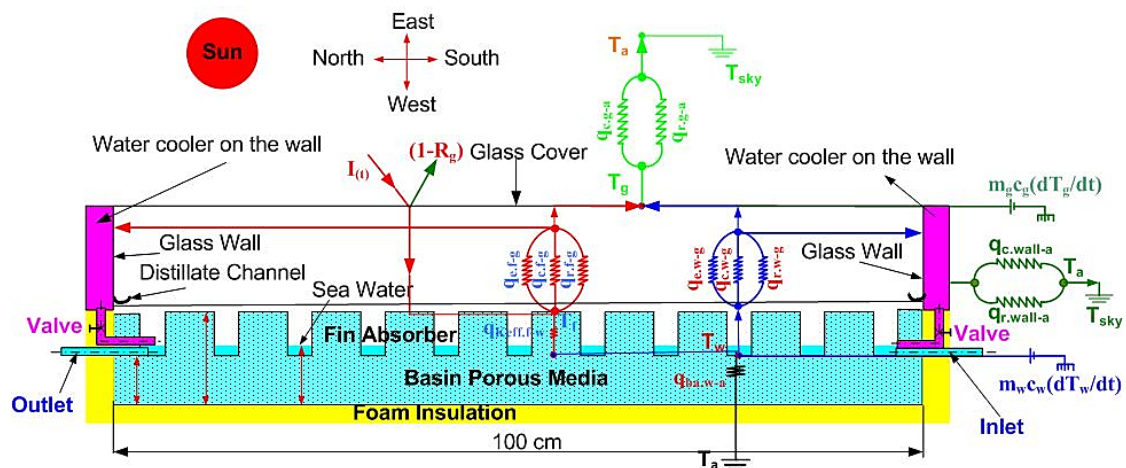


Fig. 2. Heat transfer scheme on solar still double slope by utilizing cooling water as feed water

Solar radiation received by the cover glass is partially absorbed, reflected and mostly transmitted to the absorber plate. The heat absorbed by the absorber plate is partly used to heat seawater on the porous fin body for the evaporation process, partly convected and reflected to

the condensation surface. In addition, the heat on the surface of the absorber plate will be transferred to the water basin by effective conduction. The heat received by the water basin will be stored, partially used for evaporation, convection and radiation to the condensing surface. On the condensation surface the heat will be discharged into the atmosphere and simultaneously the condensation process will occur. The condensation process will turn water vapor into fresh water.

2. 4. 1. Energy balance on glass cover

The heat balance on the cover glass is a development of [33, 34] and can be seen in equations (1)–(4). the equation is as follows:

$$\alpha_g (1 - R_g) I_{(t)} + q_{t,w-g} + q_{t,f-g} = q_{t,g-a}, \quad (1)$$

where α_g is the intensity of solar radiation absorbed by the cover glass, R_g is the intensity of solar radiation reflected by the cover glass, $I_{(t)}$ is the intensity of solar radiation at a certain time, $q_{t,w-g}$ is the total heat from the water basin to the glass, $q_{t,f-g}$ is the total heat from the water basin to the glass, and is the total heat from the glass to the atmosphere. To calculate $q_{t,w-g}$, $q_{t,f-g}$ and $q_{t,g-a}$ use the following equations:

$$q_{t,w-g} = (q_{c,w-g} + q_{c,w-gw}) + (q_{e,w-g} + q_{e,w-gw}) + (q_{r,w-g} + q_{r,w-gw}), \quad (2)$$

$$q_{t,f-g} = (q_{c,f-g} + q_{c,f-gw}) + (q_{e,f-g} + q_{e,f-gw}) + (q_{r,f-g} + q_{r,f-gw}), \quad (3)$$

$$q_{t,g-a} = (q_{c,gc-a} + q_{r,gc-a}) + (q_{c,gw-a} + q_{r,gw-a}), \quad (4)$$

where in equation (2) for $q_{c,w-g}$ is the heat of convection from water basin to glass, $q_{c,w-gw}$ is the heat of convection from water basin to glass wall, $q_{e,w-g}$ is the heat of evaporation from water basin to glass, $q_{e,w-gw}$ is the heat of evaporation from water basin to glass wall, $q_{r,w-g}$ is the heat of radiation from water basin to glass and $q_{r,w-gw}$ is the heat of radiation from water basin to glass wall. In equation (3) for $q_{c,f-g}$ is heat of convection from fins to glass, $q_{c,f-gw}$ is heat of convection from fins to glass wall, $q_{e,f-g}$ is heat of evaporation from fins to glass, $q_{e,f-gw}$ is heat of evaporation from fins to glass wall, $q_{r,f-g}$ is heat of radiation from fins to glass and $q_{r,f-gw}$ is heat of radiation from fins to glass wall. In equation (4) for $q_{c,gc-a}$ is the heat of convection from glass cover to atmosphere, $q_{r,gc-a}$ is the heat of radiation from glass cover to atmosphere, $q_{c,gw-a}$ is the heat of convection from glass wall to atmosphere and $q_{r,gw-a}$ is the heat of radiation from glass wall to atmosphere.

2. 4. 2. Heat balance in the fin absorber

The heat balance of the fin absorber plate is developed from [33, 35] into equation (5), as follows:

$$(1 - \alpha_g)(1 - R_g)(1 - R_f)\alpha_f I_{(t)} = q_{t,f-g} + q_{c,eff} + q_{sa}, \quad (5)$$

where R_f is the intensity of solar radiation reflected by the fins, α_f is the intensity of solar radiation absorbed by the fins, $q_{c,eff}$ is the effective conduction heat and q_{sa} is the heat loss to the side.

2. 4. 3. Effective conduction heat transfer

Heat transfer from the absorbent surface of the fins to the water basin [30], become:

$$q_{c,eff} = k_{eff} A_f \frac{dT}{dx}, \quad (6)$$

where to calculate the effective conduction coefficient [30, 36], as follows:

$$k_{eff} = ((1 - \epsilon) \cdot k_f) + (\epsilon - k_w). \quad (7)$$

2. 4. 4. Heat balance in basin water**2. 4. 4. 1. System SSDS.WCW**

The heat balance of the basin water in the SSD.WCW system is a development of [37] and is presented in equation (8), as follows:

$$q_{c.eff} = q_{t.w-g} + q_{ba} + m_w c_w \left(\frac{dT_w}{dt} \right), \quad (8)$$

where q_{ba} is the heat loss to the bottom of the system, m_a is the mass of the water basin, c_w is the specific heat water, dT_w is the water temperature difference and dt is the time difference.

2. 4. 4. 2. System SSDS.WCW.HC

The heat balance of the basin water in the SSD.WCW.HC system is a development of [38] and is presented in equation (9), as follows:

$$q_{c.eff} + q_{hc} = q_{t.w-g} + q_{ba} + m_w c_w \left(\frac{dT_w}{dt} \right), \quad (9)$$

where q_{hc} is the seawater preheating of the water cooler on the wall.

2. 4. 5. Distillation output productivity and efficiency

The evaporation process occurs in alkaline water and fin absorbers. The productivity of distilled water is measured every 60 minutes:

1. Productivity of distilled water in basin water.

From the theory written [39, 40], the equation becomes:

$$M_w = \frac{q_{e.w-g} \cdot 3600}{L_{ev}}. \quad (10)$$

Evaporation latent heat using equation [41]:

$$L_{ev} = (2501.67 - 2.389T_w) \cdot 10^3, \text{ (J/kg)}. \quad (11)$$

2. Productivity of condensate water on fin absorbers:

$$M_f = \frac{q_{e.f-g} \cdot 3600}{L_{ev}}. \quad (12)$$

3. Total distillation productivity.

Total productivity every 60 minutes, becomes:

$$M_{fw(t)} = M_f + M_w. \quad (13)$$

2. 4. 6. Efficiency energy solar still

Efficiency values every 60 minutes, [42] become:

$$\eta_{(t)} = \frac{M_{fw(t)} \cdot L_{ev}}{A_b \cdot \sum I_{(t)} \cdot \Delta t}. \quad (14)$$

2. 5. Mathematical model efficiency exergy

The exergy efficiency calculation is formulated by [43, 44]:

$$\eta_{ex} = \frac{\text{Exergy Output}}{\text{Exergy Input}}. \quad (15)$$

The exergy associated with solar distillation products is transferred from the fins and sea-water to the glass via evaporation, namely $Ex_{e,f-g}$ and Ex_{ew-g} . Therefore, the exergy efficiency equation of [45, 46], developed into:

$$\eta_{ex} = \frac{Ex_{e,w-g} + Ex_{e,f-g}}{Ex_{sun}}. \quad (16)$$

3. Result and Discussion

This research aims to enhance the efficiency of double-slope solar stills. The research compared a double-slope solar still with water cooling on the walls (SSDS.WCW) to a double-slope solar still with water cooling on the walls using the input water (SSDS.WCW.HC).

Fig. 3 displays the wind speed and solar radiation intensity. Solar radiation will be absorbed by the fin absorber plate through the cover glass. The solar radiation absorbed by the surface of the fin absorber plate is converted into heat. The heat received by the fin surface is transferred to the porous fin body, which contains water in the form of a thin layer. Additionally, the heat from the fin surface will also be transferred to the basin water. The heat received by the water in the fin body and the water basin is utilized for evaporation.

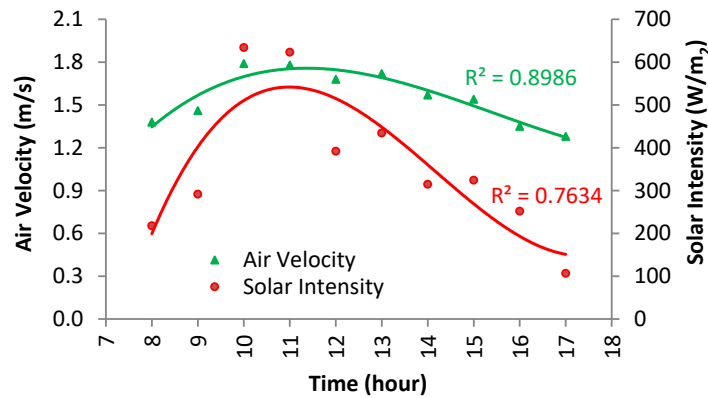


Fig. 3. Wind speed and solar intensity

The temperature data of the test results are presented in **Fig. 4, 5**. Average daily temperature of basin and fins water on SSDS.WCW.HC has increased compared to SSDS.WCW. An increase in the daily average temperature of the basin water of 2.40 °C and an increase in the average daily temperature of fins of 0.11 °C. This increase in temperature indicates that by utilizing cooling water as feed/input water and with a basin water level of 50 mm can increase the temperature of basin water and fins.

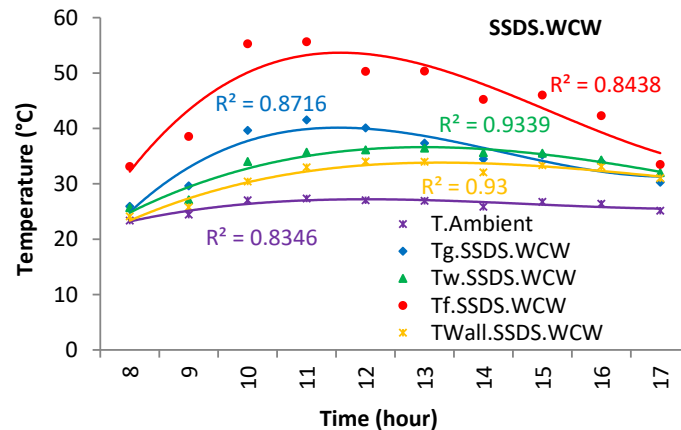


Fig. 4. Solar temperature still double slope water cooler (SSDS.WCW)

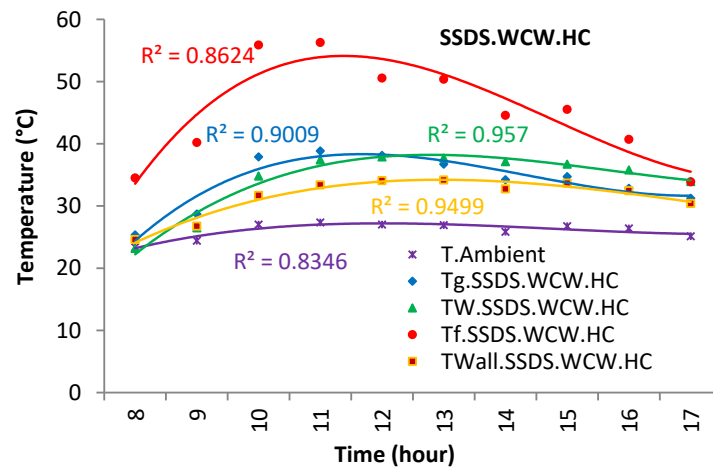


Fig. 5. Solar still double slope temperatures utilize water cooling as feed water (SSDS.WCW.HC)

The test was carried out for 6 days in obtaining data. The data obtained include temperature data for each solar still element. From these data obtained information about temperature differences between elements in solar stills. Daily average temperature difference on SSDS.WCW.HC has increased compared to SSDS.WCW. An increase in temperature difference occurs in the water basin to the glass cover and fins to the glass cover. Increased temperature differences can increase heat transfer to condensing surfaces (glass cover and glass wall). The average temperature difference increased during the 6-day experiment from basin water to glass cover by 2.07 °C and from basin water to glass wall by 2.21 °C. While the increase in heat transfer from fins to glass cover by 0.87 °C and from fins to glass wall by 1.01 °C. The increase in temperature difference indicates an increase in evaporation [47].

In Fig. 6, it is possible to see the accumulation of water productivity experimentally and theoretically using SSDS.WCW. HC is higher compared to SSDS.WCW. Using water cooling on the wall as feed water can increase the temperature of basin and fins water, thereby increasing the temperature difference between the evaporation surface and the condensing surface [48]. Increasing the temperature difference of the evaporating surface with the condensing surface can increase the value of evaporative heat [49]. Increasing the heat value of evaporation can increase freshwater productivity [50].

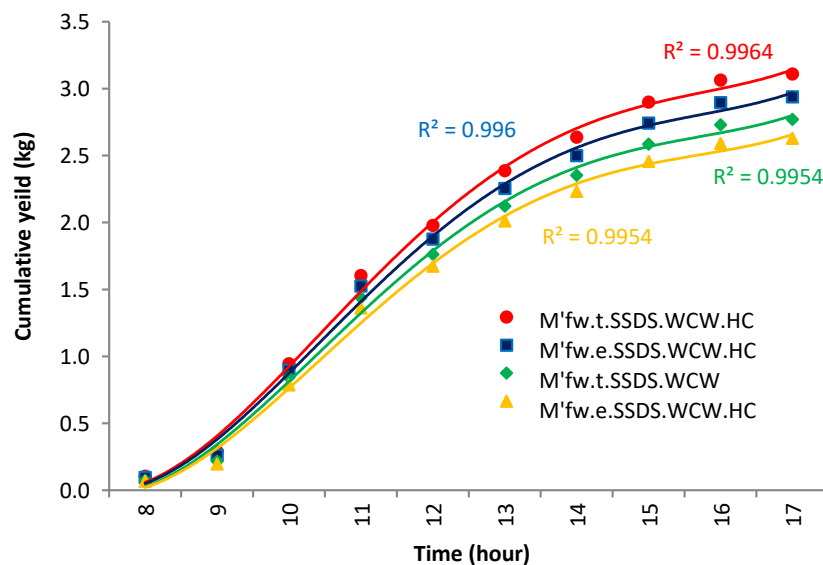


Fig. 6. Cumulative yield SSDS.WCW.HC and SSDS. Experimental and theoretical WCW

In Fig. 7, it is possible to see the highest freshwater productivity on the third day of testing using SSDS.WCW.HC theoretical is 3.56 kg/10-hours and experimental is 3.48 kg/10-hours, while the highest productivity is using SSDS.WCW is theoretically 3.27 kg/10-hours and experimentally 3.16 kg/10-hours at an average daily solar radiation intensity of 306.72 W/m².

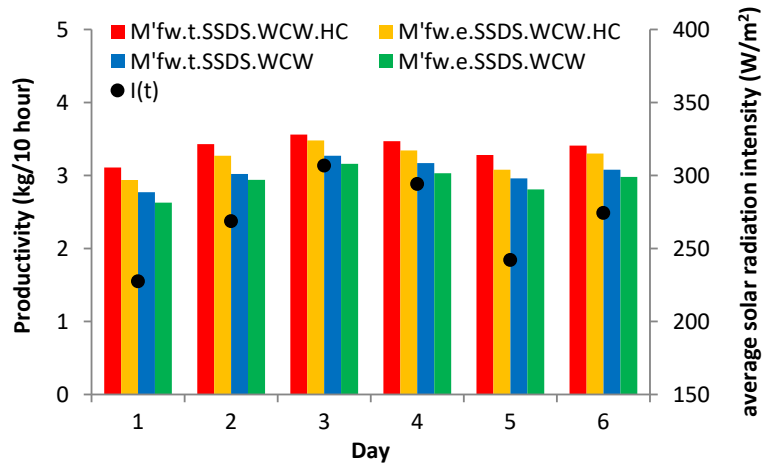


Fig. 7. Daily productivity SSDS.WCW.HC and SSDS. Experimental and theoretical WCW

Fig. 8 presents theoretical and experimental energy efficiency. The difference in theoretical and experimental energy efficiency values is not significant in both SSDS.WCW and SSDS.WCW.HC. Highest energy efficiency using SSDS.WCW.HC are compared to SSDS.WCW. This condition is caused by the difference in water temperature to the glass cover and the fins temperature to the glass cover. The difference in fins temperature to glass cover and water temperature to glass cover can increase the evaporation rate. High evaporation rates can increase the productivity of condensate water. High condensate water productivity can improve energy efficiency [51].

Fig. 8 shows the highest energy efficiency using SSDS.WCW.HC is theoretically 69.55 % and experimentally 67.53 % at solar radiation intensity of 623.15 W/m², while the highest energy efficiency uses SSDS.WCW theoretically amounted to 64.94 % and experimentally amounted to 62.66 % at solar radiation intensity of 634.04 W/m².

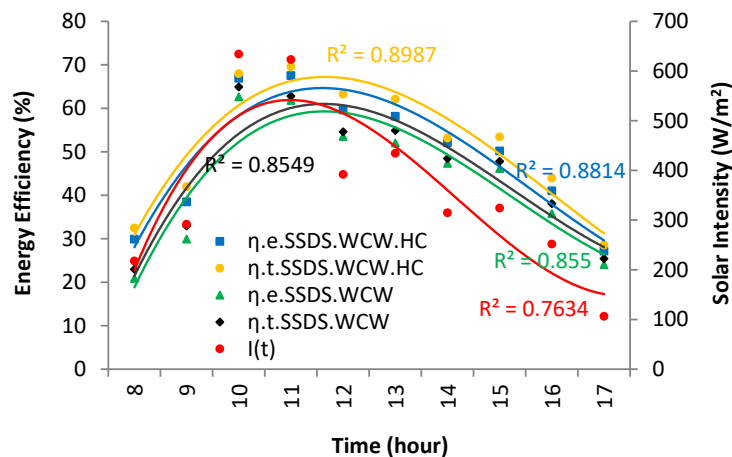


Fig. 8. Energy efficiency SSDS.WCW.HC and SSDS.WCW experimental and theoretical

In Fig. 9, it can be seen that the highest average daily energy efficiency using SSDS.WCW.HC is theoretically 54.83 % and experimentally 53.77 %, while the average daily energy efficiency uses SSDS.WCW is theoretically 49.81 % and experimentally 48.87 % at an average solar radiation intensity of 306.72 W/m².

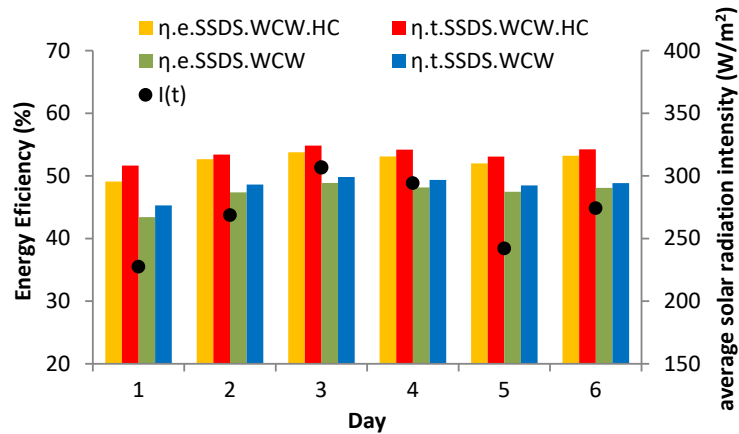


Fig. 9. Daily energy efficiency of SSDS.WCW.HC and SSDS. Experimental and theoretical WCW

In **Fig. 10**, exergy efficiency increases with increasing solar radiation intensity. Highest exergy efficiency using SSDS.WCW.HC by 8.86 % compared to SSDS.WCW at 8.31 %. In **Fig. 11**, the average daily exergy efficiency during testing using SSDS.WCW.HC at 6.44 % and using SSDS.WCW at 5.33 %. Exergy efficiency on SSDS.WCW.HC is higher than SSDS.WCW, this condition is caused by an increase in the temperature of basin water and fins. The increase in temperature causes an increase in temperature between the base water and the glass cover and between the fins and glass cover temperatures. An increase in temperature difference can increase evaporation exergy. Increased exergy evaporation can increase exergy efficiency and decrease exergy destruction [28, 52].

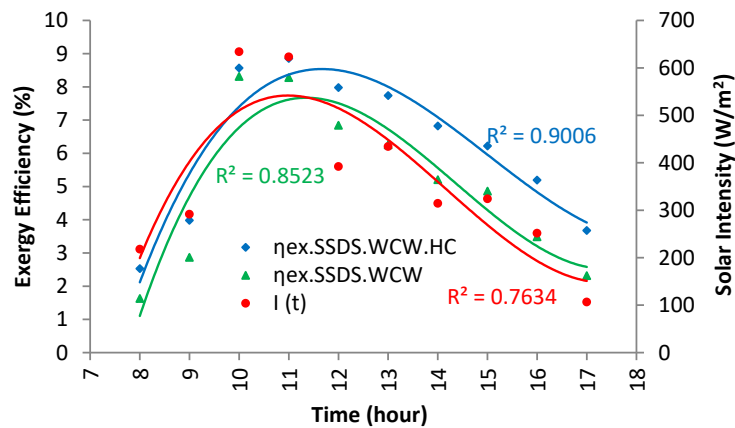


Fig. 10. Exergy efficiency SSDS.WCW.HC and SSDS.WCW

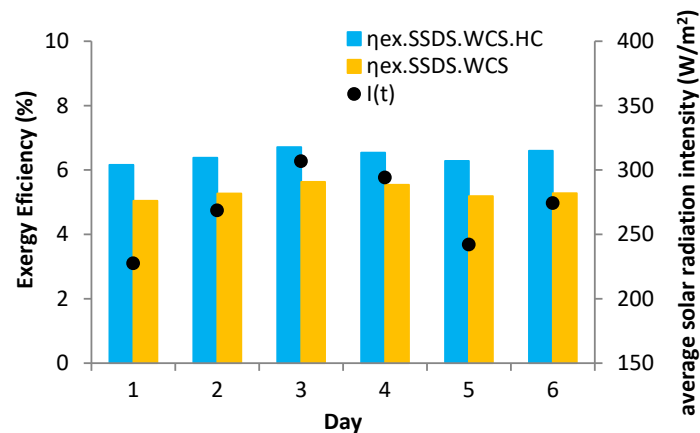


Fig. 11. Exergy daily efficiency SSDS.WCW.HC and SSDS.WCW

The solar stills efficiency improvement techniques proposed in this study are however limited by several factors such as weather circumstances, availability of materials and technological issues. Because of the nature of these areas that were covered in the research done in tropical regions where sunlight shone almost brightly and all the time, it is likely that findings obtained will be replicated there. For instance, when thinking about applying these results practically, one must think about environmental conditions structured locally, as well as whether appropriate or suitable materials exist for making them work appropriately or not and then lastly consider what level of expertise is needed to go through with such a project successfully within that region.

This research could be furthered by considering improved methods of heating, advanced computation models for design enhancement at various environmental situations, and suitable dimensions with possible applications in practice. Furthermore, it could involve environmental consequences assessment as well as user-centered design techniques while needed, agricultural applications would also be integrated into the technology. With these approaches more effective, versatile and universal solar stills can be reached to tackle water shortage problems.

4. Conclusions

This study compares SSDS.WCW with SSDS.WCW.HC resulting in condensate water productivity using SSDS.WCW.HC experimentally by 3.48 kg/10-hours and theoretically by 3.56 kg/10-hours higher than SSDS.WCW experimentally by 3.16 kg/10-hours and theoretically by 3.27 kg/10-hours. Daily average energy efficiency using SSDS.WCW.HC experimentally 53.77 % and theoretically 54.83 % higher than SSDS.WCW experimentally 48.87 % and theoretically 49.81 %. The highest daily average exergy efficiency using SSDS.WCW.HC is 6.44 % compared to SSDS.WCW of 5.33 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This research was initiated by BRIN – National Research and Innovation Agency (Indonesia) with contract Number: 53/IV/KS/06/2022 and Number: 009/Contract-KS/PTS.030.7/PN/VI/2022.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Acknowledgements

We as the Research Team would like to thank BRIN – National Research and Innovation Agency and LPDP – Education Fund Management Institution for financing research activities.

References

- [1] Yassi, A., Demmallino, E. B., Sultani, H. R. (2023). Tropical climate change and its impact on horticultural plants in Enrekang District, South Sulawesi, Indonesia. *Biodiversitas Journal of Biological Diversity*, 24 (6). <https://doi.org/10.13057/biodiv/d240601>
- [2] Natayu, A., Kamila, F., Dananjaya, I., Reflin, R., Fikri, M. (2021). Understanding the Climate Behavior Through Data Interpretation: Java-Bali-Nusa Tenggara Case. *Indonesian Journal of Computing, Engineering and Design (IJoCED)*, 3 (2), 130–145. <https://doi.org/10.35806/ijoced.v3i2.184>
- [3] Wibowo, A. I., Chang, K.-C. (2020). Solar energy-based water treatment system applicable to the remote areas: Case of Indonesia. *Journal of Water, Sanitation and Hygiene for Development*, 10 (2), 347–356. <https://doi.org/10.2166/washdev.2020.003>

- [4] Al-Mezeini, S. S. S., Siddiqui, M. A., Shariq, M., Althagafi, T. M., Ahmed, I. A., Asif, M. et al. (2023). Design and Experimental Studies on a Single Slope Solar Still for Water Desalination. *Water*, 15 (4), 704. <https://doi.org/10.3390/w15040704>
- [5] Issaq, S. Z., Talal, S. K., Azooz, A. A. (2023). Experimentation on enhancement of solar still performance. *International Journal of Renewable Energy Development*, 12 (4), 691–701. <https://doi.org/10.14710/ijred.2023.53239>
- [6] Fu, H., Dai, M., Song, H., Hou, X., Riaz, F., Li, S. et al. (2021). Updates on Evaporation and Condensation Methods for the Performance Improvement of Solar Stills. *Energies*, 14 (21), 7050. <https://doi.org/10.3390/en14217050>
- [7] Amir Khadim, M. A. A., Abd AL-Awahid, W. A., Hachim, D. M. (2020). Review on the types of solar stills. *IOP Conference Series: Materials Science and Engineering*, 928 (2), 022046. <https://doi.org/10.1088/1757-899x/928/2/022046>
- [8] Schwerdtner Máñez, K., Husain, S., Ferse, S. C. A., Máñez Costa, M. (2012). Water scarcity in the Spermonde Archipelago, Sulawesi, Indonesia: Past, present and future. *Environmental Science & Policy*, 23, 74–84. <https://doi.org/10.1016/j.envsci.2012.07.004>
- [9] Boretti, A., Rosa, L. (2019). Reassessing the projections of the World Water Development Report. *Npj Clean Water*, 2 (1). <https://doi.org/10.1038/s41545-019-0039-9>
- [10] Samuel, A., Brizuela, J., Chang, K.-C., Lin, C.-T. (2022). Design and Investigation of an Effective Solar Still Applicable to Remote Islands. *Water*, 14 (5), 703. <https://doi.org/10.3390/w14050703>
- [11] Amiri, H. (2022). Enhancing the stepped solar still performance using a built-in passive condenser. *Solar Energy*, 248, 88–102. <https://doi.org/10.1016/j.solener.2022.11.006>
- [12] Vembu, S., Attia, M. E. H., Thangamuthu, M., Thangamuthu, G. (2022). Energy, exergy, and economic analysis of solar still using coal cylinder fins: an experimental study. *Environmental Science and Pollution Research*, 30 (2), 2597–2606. <https://doi.org/10.1007/s11356-022-22325-0>
- [13] Ismail, N. R., Soeparman, S., Widhiyanuriyawan, D., Wijayanti, W. (2021). The Effect of Water Salinity and Radiation Intensity to the Temperature Distribution and Evaporation Rate inside Porous Media. *Tehnicki Vjesnik - Technical Gazette*, 28 (2). <https://doi.org/10.17559/tv-20191023092006>
- [14] Abdelgaied, M., Zakaria, Y., Kabeel, A. E., Essa, F. A. (2021). Improving the tubular solar still performance using square and circular hollow fins with phase change materials. *Journal of Energy Storage*, 38, 102564. <https://doi.org/10.1016/j.est.2021.102564>
- [15] Yuvaperiyasamy, M., Senthilkumar, N., Deepanraj, B. (2023). Experimental and theoretical analysis of solar still with solar pond for enhancing the performance of sea water desalination. *Water Reuse*, 13 (4), 620–633. <https://doi.org/10.2166/wrd.2023.102>
- [16] Sampathkumar, K., Arjunan, T. V., Pitchandi, P., Senthilkumar, P. (2010). Active solar distillation – A detailed review. *Renewable and Sustainable Energy Reviews*, 14 (6), 1503–1526. <https://doi.org/10.1016/j.rser.2010.01.023>
- [17] Manchanda, H., Kumar, M. (2015). A comprehensive decade review and analysis on designs and performance parameters of passive solar still. *Renewables: Wind, Water, and Solar*, 2 (1). <https://doi.org/10.1186/s40807-015-0019-8>
- [18] Caturwati, N. K., Yusuf, Y., Rosyadi, I., Almarwan, A. F. (2020). Comparison of the Effectiveness of 45° And 60° Cover Angle on the Production of Clean Water on Double Slope Solar Distillations. *Journal of Renewable Energy & Mechanics (REM)*, 03 (02), 59–69. Available at: https://eprints.untirta.ac.id/10780/1/paper_JREM_UIR%20NKC.pdf
- [19] Patel, S. K., Modi, K. V. (2020). Techniques to improve the performance of enhanced condensation area solar still: A critical review. *Journal of Cleaner Production*, 268, 122260. <https://doi.org/10.1016/j.jclepro.2020.122260>
- [20] Hammoodi, K. A., Dhahad, H. A., Alawee, W. H., Omara, Z. M. (2023). A detailed review of the factors impacting pyramid type solar still performance. *Alexandria Engineering Journal*, 66, 123–154. <https://doi.org/10.1016/j.aej.2022.12.006>
- [21] Singh, B. K., Ramji, C., Ganeshan, P., Mohanavel, V., Balasundaram, T., Kumar, V. V. et al. (2023). Performance Analysis of Solar Still by Using Octagonal-Pyramid Shape in the Solar Desalination Techniques. *International Journal of Photoenergy*, 2023, 1–9. <https://doi.org/10.1155/2023/4705193>
- [22] Sharshir, S. W., Rozza, M. A., Elsharkawy, M., Youns, M. M., Abou-Taleb, F., Kabeel, A. E. (2022). Performance evaluation of a modified pyramid solar still employing wick, reflectors, glass cooling and TiO₂ nanomaterial. *Desalination*, 539, 115939. <https://doi.org/10.1016/j.desal.2022.115939>
- [23] Sun, Z., Tu, W., Fang, S., Zhong, W. (2021). Comparison between double slope solar still and fourfold slope solar still: energy, exergy, exergoeconomic, and enviroeconomic evaluation. *Water Supply*, 22 (3), 2929–2945. <https://doi.org/10.2166/ws.2021.425>
- [24] Elmaadawy, K., Kandeal, A. W., Khalil, A., Elkadeem, M. R., Liu, B., Sharshir, S. W. (2021). Performance improvement of double slope solar still via combinations of low cost materials integrated with glass cooling. *Desalination*, 500, 114856. <https://doi.org/10.1016/j.desal.2020.114856>
- [25] Sibagariang, Y. P., Napitupulu, F. H., Kawai, H., Ambarita, H. (2022). Investigation of the effect of a solar collector, nozzle, and water cooling on solar still double slope. *Case Studies in Thermal Engineering*, 40, 102489. <https://doi.org/10.1016/j.csite.2022.102489>

- [26] Hameed, H. G. (2022). Experimentally evaluating the performance of single slope solar still with glass cover cooling and square cross-section hollow fins. *Case Studies in Thermal Engineering*, 40, 102547. <https://doi.org/10.1016/j.csite.2022.102547>
- [27] Shivamallaiyah, M. M., Kota Reddy, S. V., Shrikanth, V., Shetty, G., Rakesh, S. A., Mary John, J. et al. (2020). Experimental study of the influence of glass cover cooling using evaporative cooling process on the thermal performance of single basin solar still. *Journal of Mechanical Engineering and Sciences*, 14 (1), 6334–6343. <https://doi.org/10.15282/jmes.14.1.2020.11.0496>
- [28] Shatar, N. M., Sabri, M. F. M., Salleh, M. F. M., Ani, M. H. (2023). Energy, exergy, economic, environmental analysis for solar still using partially coated condensing cover with thermoelectric cover cooling. *Journal of Cleaner Production*, 387, 135833. <https://doi.org/10.1016/j.jclepro.2022.135833>
- [29] Shatar, N. M., Sabri, M. F. M., Salleh, M. F. M., Ani, M. H. (2023). Investigation on the performance of solar still with thermoelectric cooling system for various cover material. *Renewable Energy*, 202, 844–854. <https://doi.org/10.1016/j.renene.2022.11.105>
- [30] Ismail, N., Soeparman, S., Widhiyanuriyawan, D., Wijayanti, W. (2019). The influence of pores size and type of aggregate on capillary heat and mass transfer in porous. *Journal of Applied Engineering Science*, 17 (1), 8–17. <https://doi.org/10.5937/jaes17-18090>
- [31] Ismail, N. R., Suwandono, P., Hermawan, D., Anggraeni, F. D. (2024). Identifying enhancement of double slope solar still performance by adding water cooling to walls. *Energy-Saving Technologies and Equipment*, 3 (8 (129)), 33–44. <https://doi.org/10.15587/1729-4061.2024.302728>
- [32] Agrawal, A., Rana, R. S., Srivastava, P. K. (2017). Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison. *Resource-Efficient Technologies*, 3 (4), 466–482. <https://doi.org/10.1016/j.reffit.2017.05.003>
- [33] Agrawal, A., Rana, R. S. (2019). Theoretical and experimental performance evaluation of single-slope single-basin solar still with multiple V-shaped floating wicks. *Heliyon*, 5 (4), e01525. <https://doi.org/10.1016/j.heliyon.2019.e01525>
- [34] Kumar, S., Tiwari, G. N., Singh, H. N. (2000). Annual performance of an active solar distillation system. *Desalination*, 127 (1), 79–88. [https://doi.org/10.1016/s0011-9164\(99\)00194-0](https://doi.org/10.1016/s0011-9164(99)00194-0)
- [35] Al-Sulttani, A. O., Ahsan, A., Al-Bakri, B. A. R., Hason, M. M., Daud, N. N. N., Idrus, S. et al. (2022). Double-Slope Solar Still Productivity Based on the Number of Rubber Scraper Motions. *Energies*, 15 (21), 7881. <https://doi.org/10.3390/en15217881>
- [36] Kundu, B., Yook, S.-J. (2021). An accurate approach for thermal analysis of porous longitudinal, spine and radial fins with all nonlinearity effects – analytical and unified assessment. *Applied Mathematics and Computation*, 402, 126124. <https://doi.org/10.1016/j.amc.2021.126124>
- [37] Gaur, M. K., Tiwari, G. N. (2010). Optimization of number of collectors for integrated PV/T hybrid active solar still. *Applied Energy*, 87 (5), 1763–1772. <https://doi.org/10.1016/j.apenergy.2009.10.019>
- [38] Chávez, S., Terres, H., Lizardi, A., López, R., Lara, A., Vaca, M. (2021). Energetic, Exergetic and Entropy Evaluation in the Solar Distillation. *Journal of Physics: Conference Series*, 1723 (1), 012011. <https://doi.org/10.1088/1742-6596/1723/1/012011>
- [39] Dumka, P., Jain, A., Mishra, D. R. (2020). Energy, exergy, and economic analysis of single slope conventional solar still augmented with an ultrasonic fogger and a cotton cloth. *Journal of Energy Storage*, 30, 101541.
- [40] Shanmugan, S., Palani, S., Janarthanan, B. (2018). Productivity enhancement of solar still by PCM and Nanoparticles miscellaneous basin absorbing materials. *Desalination*, 433, 186–198. <https://doi.org/10.1016/j.desal.2017.11.045>
- [41] Fath, H. E. S., Hosny, H. M. (2002). Thermal performance of a single-sloped basin still with an inherent built-in additional condenser. *Desalination*, 142 (1), 19–27. [https://doi.org/10.1016/s0011-9164\(01\)00422-2](https://doi.org/10.1016/s0011-9164(01)00422-2)
- [42] Kabeel, A. E., Abdelgaied, M., Eisa, A. (2018). Enhancing the performance of single basin solar still using high thermal conductivity sensible storage materials. *Journal of Cleaner Production*, 183, 20–25. <https://doi.org/10.1016/j.jclepro.2018.02.144>
- [43] Layek, A. (2018). Exergetic analysis of basin type solar still. *Engineering Science and Technology, an International Journal*, 21 (1), 99–106. <https://doi.org/10.1016/j.jestch.2018.02.001>
- [44] Hassan, H., Yousef, M. S., Ahmed, M. S., Fathy, M. (2020). Energy, exergy, environmental, and economic analysis of natural and forced cooling of solar still with porous media. *Environmental Science and Pollution Research*, 27 (30), 38221–38240. <https://doi.org/10.1007/s11356-020-09995-4>
- [45] Sharon, H., Reddy, K. S., Gorjian, S. (2020). Parametric investigation and year round performance of a novel passive multi-chamber vertical solar diffusion still: Energy, exergy and enviro-economic aspects. *Solar Energy*, 211, 831–846. <https://doi.org/10.1016/j.solener.2020.10.016>
- [46] Abd Elbar, A. R., Hassan, H. (2020). Energy, exergy and environmental assessment of solar still with solar panel enhanced by porous material and saline water preheating. *Journal of Cleaner Production*, 277, 124175. <https://doi.org/10.1016/j.jclepro.2020.124175>
- [47] Shoeibi, S., Rahbar, N., Abedini Esfahlani, A., Kargarsharifabad, H. (2020). Application of simultaneous thermoelectric cooling and heating to improve the performance of a solar still: An experimental study and exergy analysis. *Applied Energy*, 263, 114581. <https://doi.org/10.1016/j.apenergy.2020.114581>

- [48] Shoeibi, S., Rahbar, N., Abedini Esfahlani, A., Kargarsharifabad, H. (2021). A review of techniques for simultaneous enhancement of evaporation and condensation rates in solar stills. *Solar Energy*, 225, 666–693. <https://doi.org/10.1016/j.solener.2021.07.028>
- [49] Seralathan, S., Chenna Reddy, G., Sathish, S., Muthuram, A., Dhanraj, J. A., Lakshmaiya, N. et al. (2023). RETRACTED: Performance and exergy analysis of an inclined solar still with baffle arrangements. *Heliyon*, 9 (4), e14807. <https://doi.org/10.1016/j.heliyon.2023.e14807>
- [50] Abu-Arabi, M., Al-harashsheh, M., Ahmad, M., Mousa, H. (2020). Theoretical modeling of a glass-cooled solar still incorporating PCM and coupled to flat plate solar collector. *Journal of Energy Storage*, 29, 101372. <https://doi.org/10.1016/j.est.2020.101372>
- [51] Yadav, V. K., Sarkar, J., Ghosh, P. (2023). Thermodynamic, economic and environmental analyses of novel concentrated solar-PV-thermal integrated combined power, cooling and desalination system. *Desalination*, 563, 116721. <https://doi.org/10.1016/j.desal.2023.116721>
- [52] Suraparaju, S. K., Natarajan, S. K., Mamilla, V. R., Pappala, S. M. T., Kurada, A., Lakamsani, M. S. V. P. (2023). Energy, exergy, economic and environmental (4E) analyses of solar still with paraffin wax as phase change energy storage material. *Materials Today: Proceedings*, 90, 1–5. <https://doi.org/10.1016/j.matpr.2023.03.345>

Received date 03.04.2024

Accepted date 29.08.2024

Published date 28.11.2024

© The Author(s) 2024

*This is an open access article
under the Creative Commons CC BY license*

How to cite: Ismail, N. R., Suwandono, P., Hermawan, D., Anggraeni, F. D. (2024). Study on the use of cooling water as input water to improve double slope solar still performance. *EUREKA: Physics and Engineering*, 6, 50–62. <https://doi.org/10.21303/2461-4262.2024.003334>