Enhanced performance of an active stepped-type solar still incorporating preheating and cooling systems

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Abstract: A modified stepped-type solar still was configured with identical dimensions and specifications to facilitate a performance comparison with the conventional solar still. This configuration was achieved by installing external booster reflectors at the upper and lower edges at optimal inclined angles, integrating a flat plate collector for preheating the incoming saline water, and augmenting the still receiver with air-cooling DC fans powered by a photovoltaic solar panel to improve evaporation and condensation rates. Consequently, both solar still systems were experimentally evaluated at salinity levels of 15000, 35000, and 45000 ppm under solar radiation insolation ranging from 490 to 998 W m^{-2}. A comparative theoretical analysis was performed to elucidate the thermo-physical properties and the efficiency of both stills. The theoretical analysis indicated that the output production of the modified still was higher than that of the conventional still with 62%. The cumulative daily distillate output of the modified still was 11.92, 11.38, 10.92, and 4.48 kg m^{-2}.day, reflecting overall increase of 121.5%, 133.0%, and 143.3%, comparing with the conventional still at salinity levels of 15000, 35000, and 45000 ppm, respectively. The daily performance efficiency of the modified still was 56.3, 64.7, and 62%. The annual costs of producing 1 kg of distilled water using the modified still was lower than that of the conventional still with 25%, 39.8%, and 42.5% at salinity levels of 15000, 35000, and 45000 ppm, respectively. So, it is recommended to apply the modified stepped solar still that achieved the higher performance and the lower costs.

Key words: Stepped-type solar still; Pre-heating; Flat plate collector; DC-fans; cooling; Thermo-physical; Costs

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1 Introduction

Freshwater is an essential resource for life on Earth, utilized by individuals primarily for drinking, cooking, agriculture, and various industrial applications. It is widely recognized that approximately 75% of the Earth's surface is covered by water; however, around 97% of this water is saline or brackish, rendering it unsuitable for direct human consumption (Sarhaddi, 2018; Singh et al., 2021). Only about 1% of the total water available is accessible for human use to satisfy their needs (Younes et al., 2021). In arid and rural areas, populations face challenges due to infrequent rainfall and a scarcity of surface water sources. Furthermore, transporting water to these regions is often deemed economically unfeasible and unreliable (Abd Allah and Tawfik, 2019). In such contexts, solar desalination presents a viable solution to address water shortages and supply freshwater for domestic

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use, as many of these areas benefit from adequate solar irradiance and possess abundant saline and unpalatable water resources. Consequently, there is an urgent requirement for an efficient, straightforward, eco-friendly, and cost-effective solar distillation system to fulfill the freshwater demands and provide safe drinking water for the inhabitants of these regions (Tawfik et al., 2022). Solar stills are regarded as one of the most promising technologies, offering a simple, safe, and environmentally friendly means of producing freshwater using free energy. As a result, researchers continually strive to enhance the productivity of solar stills, which currently have a limited output of only 2-4 liters per square meter per day, as noted (Velmurugan and Srithar, 2011). Kabeel and Abdelgaied (2020) had also shown that the productivity of traditional solar distillation systems is still limited, often ranging between 2-4 lit m^{-2} day^{-1}, which emphasizes the need for continuous technological improvements to enhance the effectiveness of these systems.

Solar stills are categorized into two types: passive solar stills and active solar stills. In the case of active solar stills, the sole source for raising the water temperature is direct sunlight. Consequently, the yield of pure water is relatively low, as these systems function at temperatures below 60°C. The active solar stills extra thermal energy (widely depends on integration of flat plate and concentrating collectors) is fed to the water in the basin to create a faster rate of evaporation. Thus, in a compassion, active solar stills provide higher productivity than passive solar stills (Gautam et al., 2019; Gnanaraj et al., 2016).

The most common designs of passive solar stills for direct solar desalination are basin (conventional design) and stepped (efficient design) solar stills. However, stepped-type solar still have higher efficiency of freshwater production than the basin solar still. This is due to the thickness of brackish/saline water layer is lesser thus the evaporation rate is much higher (Sadineni et al., 2008). Nayi and Modi (2018) showed that different types of improved designs, such as step-type solar stills, exhibit higher efficiency in freshwater production compared to conventional solar stills design, due to the lower thickness of the brackish or saltwater layer, which leads to increased evaporation rates and improved overall performance. Certainly, the forced water flow required in solar stills should need an electrical power pumping brackish/saline water. So, photovoltaic (PV) solar panel could supply the required power needed to pump in such isolated regions instead of unavailable electricity. Also, PV solar panel could operate cover fans for increasing condensing. Moreover, performance of the activated passive solar stills can provide potential improvements of freshwater production. In this context, Sarhaddi (2018) reported that attaching flat plate collector as a pre-heater for raising the temperature of the fed brackish/saline water has been focused in order to activate the passive solar stills system.

Focusing on review of literatures conducting on passive solar stills performance enhancement, the productivity increased by 55.6%-84.2% at salinity levels of 15000-45000 ppm more than conventional passive solar stills when only external booster mirror reflectors have been used as reported by (Abd Allah et al., 2020) meanwhile, about 125% increment was obtained during experimentation of solar stills with reflectors (Omara et al., 2014). El-Samadony et al. (2015) studied the performance of SSS with reflectors within about 92% increase in daily productivity more than basin solar still. Radhwan 2005) reported, that the daily production of freshwater and the efficiency of SSS built-in latent energy storage using a transient model was 4.6 l m^{-2} day^{-1} and 57%, respectively. Essa et al. (2021) stated that the system performance has been improved by using mirrors and coolers, leading to a significant increase in local fish production compared to conventional systems. El-Said and Tanaka (2018) discussed the improved productivity and efficiency of solar stills incorporating latent heat storage. Radhwan (2005) analyzed the enhanced performance of a modified stepped-type solar still system that incorporates preheating and cooling systems. The performance of this modified system is compared to that of a conventional solar still in terms of productivity, thermal efficiency, and the effects of various parameters such as the inlet and outlet water temperatures and different salinity concentrations. These enhancement led to an overall increase in system efficiency, particularly in the face of challenges such as high inlet water temperatures and increased salinity levels.

This study aimed to enhance the performance of the conventional solar still system. This enhancement is achieved by activating the solar still system and incorporating preheating and cooling systems.

2 Materials and methods

2.1 Experimental site and study date

This study was carried out at the Faculty of Agriculture, Zagazig University, Egypt, located at a latitude of 30.5° and a longitude of 31.5° during August and September 2021 at the period from 8:30 to 17:30, ensuring that the assessments were made under identical climate conditions.

2.2 Modified active stepped-type solar still

A modified active stepped-type solar still (M-SSS) was tested to assess their performance under identical climatic conditions, comparing with a conventional passive solar still (C-SSS). The modification involved the following incorporated enhancements:

1) Installation of external booster reflectors at both the upper and lower edges;

2) Integration of a flat plate collector to pre-heat the incoming saltwater;

3) Installing of air cooling fans to the still receiver, powered by a photovoltaic solar panel, to improve the rates of evaporation and condensation, temperature due to higher requirement of the heat energy to can be evaporated.

As illustrated in Figures 1 and 2. The top mirror was positioned at a 15° angle to the vertical plane, while the bottom mirror was set at a 50° to the horizontal plane. These angles were determined to be optimal for the external reflectors, as noted in the studies by Tanaka (2010, 2015). The two SSSs were primarily composed of a stepped basin featuring a step width of 4 cm and a depth of 2 cm, accompanied by a wooden box and a glass cover with a thickness of 3 mm. The stepped basin was constructed from aluminum that had been painted black. The wooden box was positioned at an angle of 30° relative to the horizontal plane. To reduce heat loss from the SSS to the surrounding environment, the basin was insulated with glass wool on the bottom and all sides. The M-SSS was integrated with flat plate collector with dimensions of (50×75 cm) augmented with internal copper coil (dia. ½ inch) and 15 cm of pitch. Four cooling DC-fans (0.25 ampere) were fixed on the glass receiver of the SSS and powered by an integrated 40 Watts PV panel. Table 1 showed the specifications of the implemented of conventional and modified stepped solar still systems. While, Table 2 showed the configuration of conventional and modified stepped solar still systems.

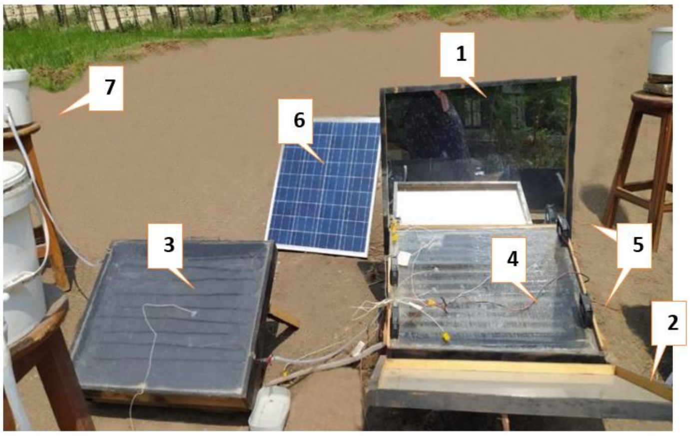
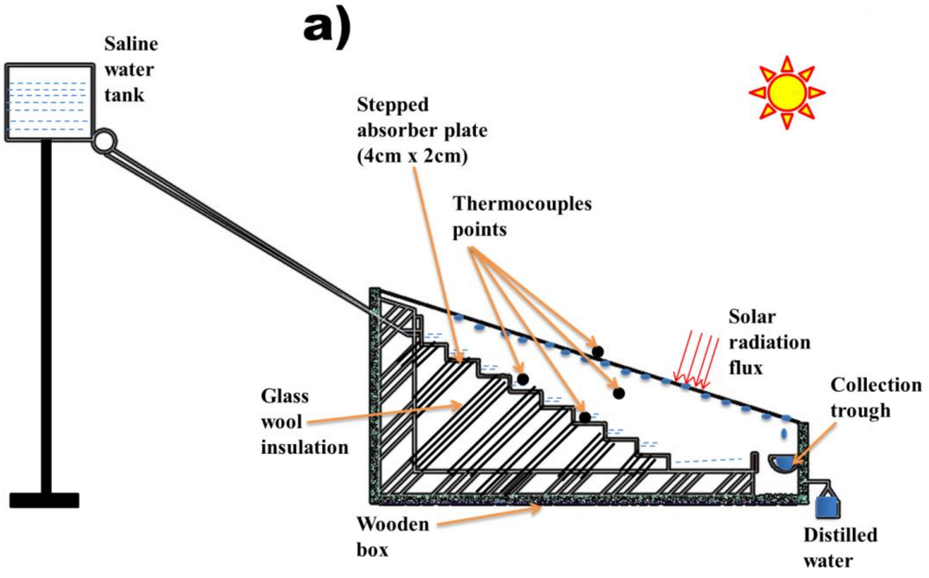
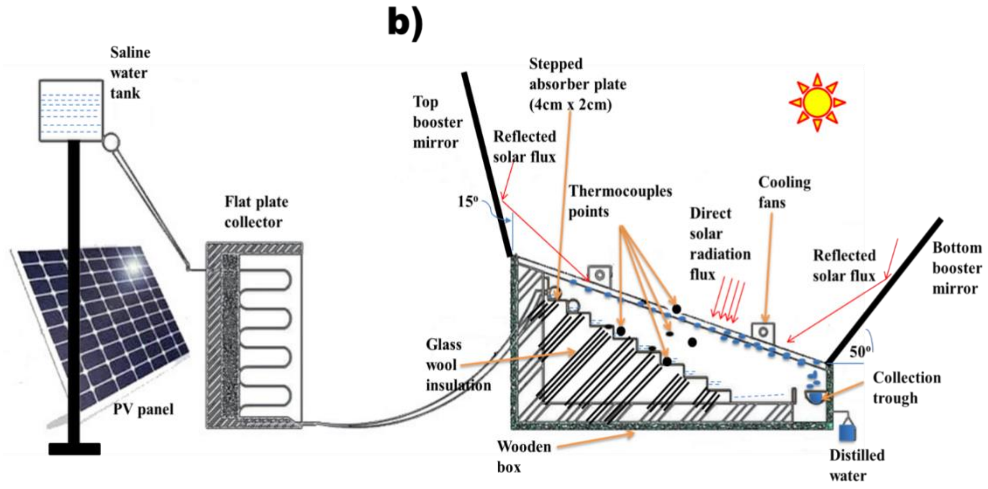


Figure 1 Configuration of modified stepped solar still system



(a) Conventional modified stepped solar still systems



(b) Modified stepped solar still systems

Figure 2 Schematic of conventional and modified stepped solar still systems

Table 1 Specifications of conventional and modified stepped solar still systems

Item	Specifications
Material of Stepped basin	Aluminum
Surface area of absorber, m^2	0.4606
Thickness of basin, mm	1.5
Wooden box dimensions, cm	75×55×2.5
Thickness of insulations, cm	2.5 (Glass wool)
Material of receiver surface	Glass (3 mm of thickness)

Table 2 Configuration of conventional and modified stepped solar still systems

Component	Conventional system	Modified system
Type of still	Simple stepped solar still	Modified stepped solar still
Energy source	Solar energy only	Solar energy + Flat plate collector
Thermal configuration	Natural system without preheating	Preheated water using a flat plate collector
Inlet water temperature	Dependent on solar radiation	Preheated water through the flat plate collector
Outlet water temperature	Varies with weather conditions	Higher due to preheating
Cooling system		Fans added to improve cooling and condensation, powered by a PV panel

2.3 Treatments and statistical design

During the study, the following treatments were tested:

1) Stepped solar still system: It included levels of modified and conventional systems.

2) Saline water: It included levels of 15,000,

35,000, and 45,000 ppm.

The preparation of saline water involved the addition of 15, 35 and 45 g of salt to one liter of purified water. This process was conducted under continuous agitation to achieve salinity levels of 15,000, 35,000, and 45,000 ppm, respectively. The experiment was designed statistically as a factorial experiment in complete randomized design with three replicates.

2.4 Measurements

Solar radiation flux: The solar radiation flux was recorded using a solar power meter (Model TES-132, TENMARS, Taiwan). This device has a measurement range of 0-2000 W m^{-2}, a resolution of 0.1 W m^{-2}, and an accuracy of ± 10 W m^{-2}.

Temperature: The temperature was measured using calibrated type-K thermocouples of a measuring range of -100°C to 1300°C and an accuracy of ±0.1% of the reading plus 0.7°C. The thermocouples were connected to a digital data logging thermometer (TENSMARS TM747-DU, Taiwan) to assess temperatures (°C) at various locations within the SSS. The recorded temperatures included ambient temperature (T_{am}), glass cover temperature (T_g), absorber temperature (T_{abs}), water temperature (T_w), and vapor temperature (T_v), with readings taken every 30 minutes.

All readings and measurements of solar radiation and temperatures were documented at 30 minutes intervals to describe the experiment's solar and ambient conditions.

Water thermo-physical properties: The water thermo-physical properties were determined using the measured temperatures (T_{am}, T_g, T_{abs} and T_w) for evaporative and condensate surfaces according to Arunkumar et al. (2010), Murase et al. (1983), Gnanadason et al. (2020) and Sarhaddi (2018) as follows:

Thermal conductivity (K) was determined as follows:

$$K = 0.0244 + (0.7673 \times 10^{-4})T_{av}\,,\quad \mathrm{W\,m^{-1}\,K^{-1}} \qquad (1)$$

Water dynamic viscosity (μ) was determined as follows:

$$\mu = (1.718 \times 10^{-5}) + (4.620 \times 10^{-8})T_{av}\,,\ Pa.s \qquad (2)$$

Water density (ρ) was determined as follows:

$$\rho = \frac{353.44}{(273.35+T_{av})}\,,\ kg\,m^{-3} \qquad (3)$$

Where, T_{av} is the arithmetic mean temperature of evaporative and condensate surfaces.

$$T_{av} = \frac{T_w + T_g}{2} \qquad (4)$$

Water latent heat (L) was determined as follows:

$$L = -0.00061432\,T_w^{\,3} + 0.0058927\,T_w^{\,2} - 2.36418\,T_w + 2500.79,\quad \mathrm{kJ\,kg^{-1}} \qquad (5)$$

Still productivity analysis:

Still theoretical hourly productivity: The still theoretical hourly was estimated using the following analysis:

The hourly distillate output per one square of area from SSS (Mew) is given by Arunkumar et al. (2010)

$$Mew = qew/L,\ \mathrm{kg\,m^{-2}\,h^{-1}} \qquad (6)$$

Where: *qew* is the rate of evaporative heat transfer from water to glass cover.

$$qew = hew(Tw-Tg),\ \mathrm{kJ\,m^{-2}\,h^{-1}} \qquad (7)$$

Where: *hew* is the evaporative loss heat coefficient.

$$hew = (16.273\times10^{-3})\times hcw\text{-}g\times(P_w-P_g)/(T_w-T_g),\ \mathrm{kJ\,m^{-2}\,K^{-1}\,h^{-1}} \qquad (8)$$

The convective heat transfer coefficient between water and glass (hcw-g) was calculated as follows:

$$hc.w-g = 0.884\left\{(Tw-Tg)+\frac{(Pw-Pg)(Tw+273.15)}{(268.9\times10^3)-Pw}\right\}^{0.33} \qquad (9)$$

Values of Pw, Pg are calculated as follows:

$$P\,(T) = exp\left\{25.317 - \frac{5144}{273+T}\right\} \qquad (10)$$

Still hourly productivity: The still hourly productivity (kg m^{-2} h^{-1}) was determined as cited by Abd Allah et al. (2020):

$$Hourly\ productivity\ (experimental) = \frac{hourly\ collected\ distillate\ water\ (ml)}{absorber\ area\ (m^2)*1000},\ kg\,m^{-2}\,h^{-1} \qquad (11)$$

Still accumulative productivity: The still accumulated productivity per one square meter (kg m^{-2} day^{-1}) was estimated by adding the obtained hourly productivity to the previous hour yield for the whole consecutive hours throughout day.

Still performance efficiency: The still hourly and daily performance efficiency was estimated as cited by Arunkumar et al. (2010)

$$hourly,\ \eta_{th}=\frac{(\dot{M}_{ew})act}{(\dot{M}_{ew})theo}\times 100,\quad daily,\ \eta_{th}=\frac{\sum_1^n(\dot{M}_{ew})act}{\sum_1^n(\dot{M}_{ew})theo}\times 100 \qquad (12)$$

Where, $(\sum\dot{M}_{ew})$ is the summation of the hourly productivity of distillate water, subtitled act referred to the actual experimented value, and referred to the predicted value of the theoretical analysis, (n) is the number of effective operating hours.

. Water distillation costs: The water distillation costs were calculated using the conventional method of estimating the fixed and variable costs. It was assumed that the still operated 340 days in the year, where the sun rise along the year in Egypt. The expected still life time was found to be 10 years. The total fixed costs of conventional and modified systems, encompassing fabrication and material expenses were 29 and 47 $, respectively. As cited by Kabeel (2009), the variable costs is estimated to be 30% of the total fixed costs annually.

2.5 Statistical analysis

A Two-Sample T-test (assuming unequal variances) was performed using Microsoft Excel 365 Software to test the hypothetical means of the productivity of conventional and modified stepped solar still systems.

3 Results and discussion

3.1 Hourly solar radiation flux and hourly ambient temperature

Figure 3 showed that the hourly intensity of solar radiation gradually increased from sunrise until reaching the maximum value at noon, and then it gradually decreased until reaching the minimum value prior to sunset. Consequently, the ambient temperature behaved the same trend of the solar radiation flux. The figure indicated that at the period of from hour 8:30 to 17:30 the maximum value of the hourly solar radiation flux was recorded as 998 W m^{-2}. While, at the same period, the recorded hourly values of ambient temperatures over the daylight hours during the experimentations ranged from 32°C to 36°C.

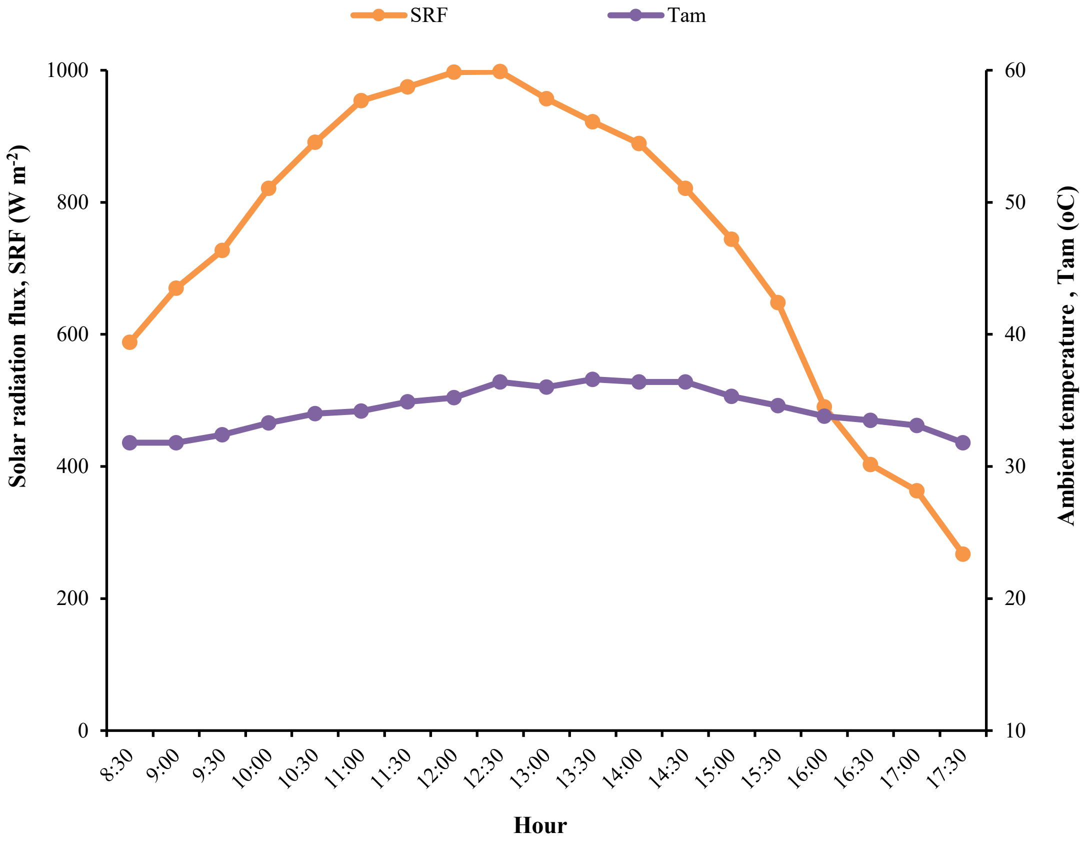


Figure 3 Fluctuation of hourly solar radiation flux and hourly ambient temperature

3.2 Hourly indicating temperatures

Figure 4 demonstrated the hourly indicated temperatures of the conventional and the modified stills i.e. glass temperature (T_g), water temperature (T_w), absorber temperature (T_{abs}), and vapor temperature (T_v). The modified still recorded higher values of the temperatures than that were recorded using the conventional still with 22%, 17%, 14.7%, and 20.4% for T_g, T_w, T_{abs}, and T_v, respectively. These results are higher than those reported by Abd Allah et al. (2020) who recorded an increase of 14.3%, 11.5%, 8.6%, and 2.5% for the previous hourly temperatures with the same respect.

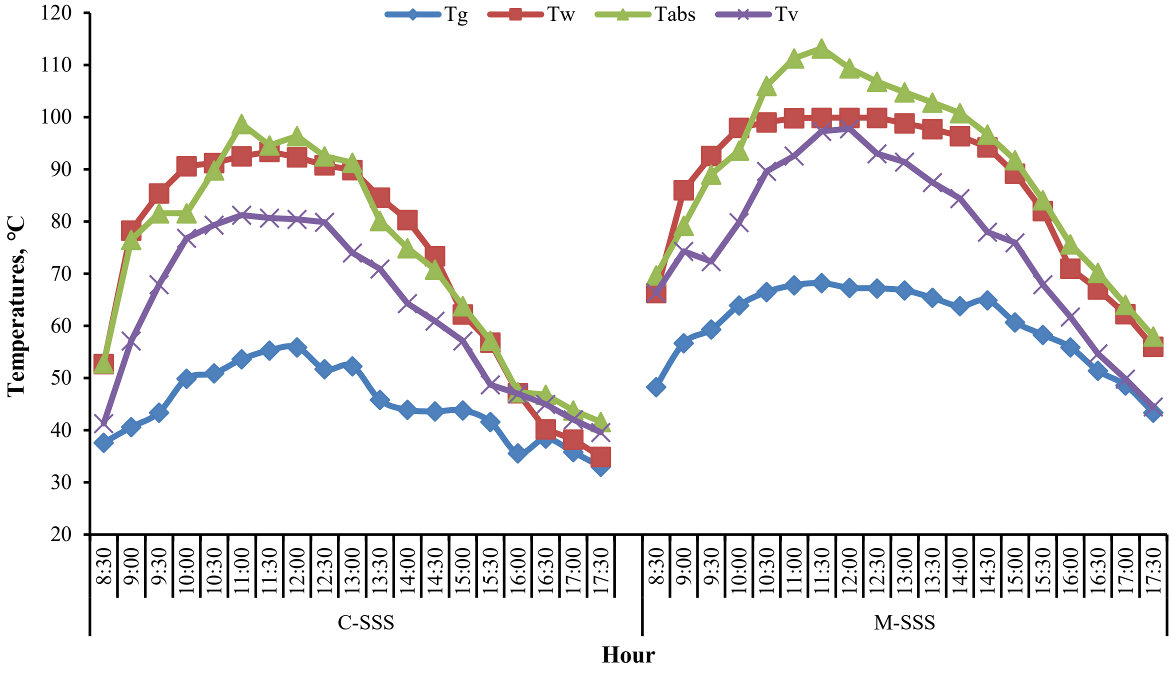


Figure 4 Fluctuation of hourly indicating temperatures

3.3 Water thermo-physical properties

Figure 5 showed that the water thermal conductivity and the water dynamic viscosity of the conventional and the modified stills reached the peak values at noon period as well as solar radiation flux distribution. This finding is due to the directly proportionality of solar radiation with the thermal conductivity and water dynamic viscosity. The modified still recorded higher values of thermal conductivity and water dynamic viscosity than that were recorded by the conventional still with 4.0% and 3.5%, respectively. The recoded results of thermal conductivity and dynamic viscosity were higher than that were obtained by Abd Allah et al. (2020) with 0.26% and 0.5%, respectively.

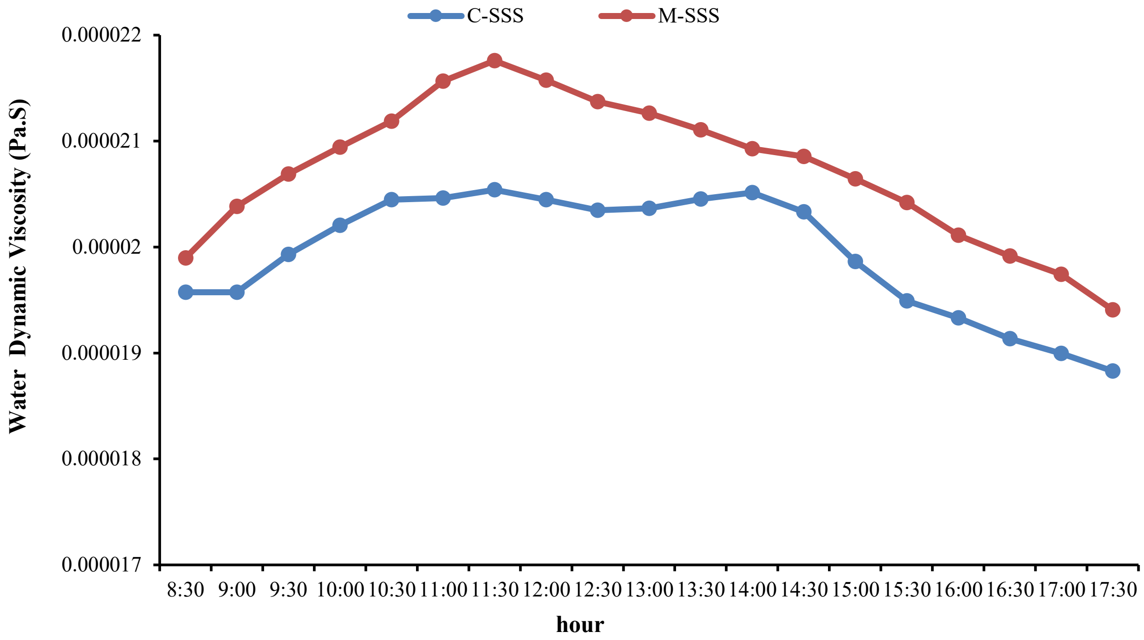
Meanwhile, the water density and the water latent heat of evaporation tends upside down solar radiation trends. This result is due to the inversely proportionality of solar radiation with water density and latent heat of evaporation. The modified still recorded lower values of water density and latent heat of evaporation than that were recorded by the conventional still with 4.4% and 8.5%, respectively. While, the obtained results of water density and latent heat of evaporation were lower than that were recorded by Abd Allah et al. (2020) with 0.28% and 0.537%, respectively.

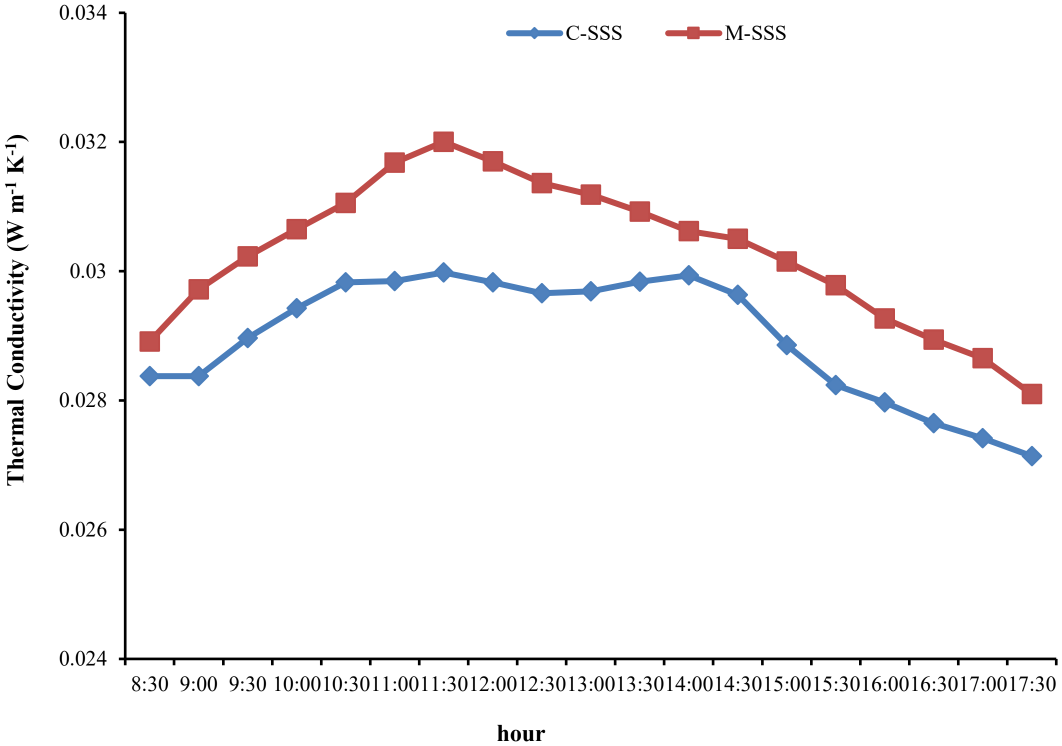
3.4 Still productivity analysis

3.4.1 Still theoretical productivity

Figure 6 presented that the hourly distillate water productivity of the stills attained its peak value at the noon period of 12:00 pm as the same behavior of the solar radiation intensity. Also, the accumulative productivity of the modified still was higher than that of the conventional still. It is due to the increased evaporation rate of water of the modified still that remained higher in the afternoon period, as a result of cooling of the still cover by air-fans and reflecting the solar radiation by the booster-mirrors.

The cooling process was crucial for optimizing the performance of the modified still. The incorporation of air fans and booster mirrors not only facilitates the retention of elevated temperatures over extended periods but also guarantees the system's efficiency throughout the day. This cooling strategy effectively lowers the temperature of the still cover, thereby supporting elevated evaporation rates and enhancing condensation efficiency. As a result, there is a significant increase in both hourly and accumulative distillate output. Therefore, during the entire day, the total condensate theoretically-analyzed output of the modified still was higher with 62%, comparing with the conventional still. Also, the theoretically accumulative productivity increases up to 17.6 kg m^{-2} day^{-1} for M-SSS compared to 10.8 kg m^{-2} day^{-1} for C-SSS.





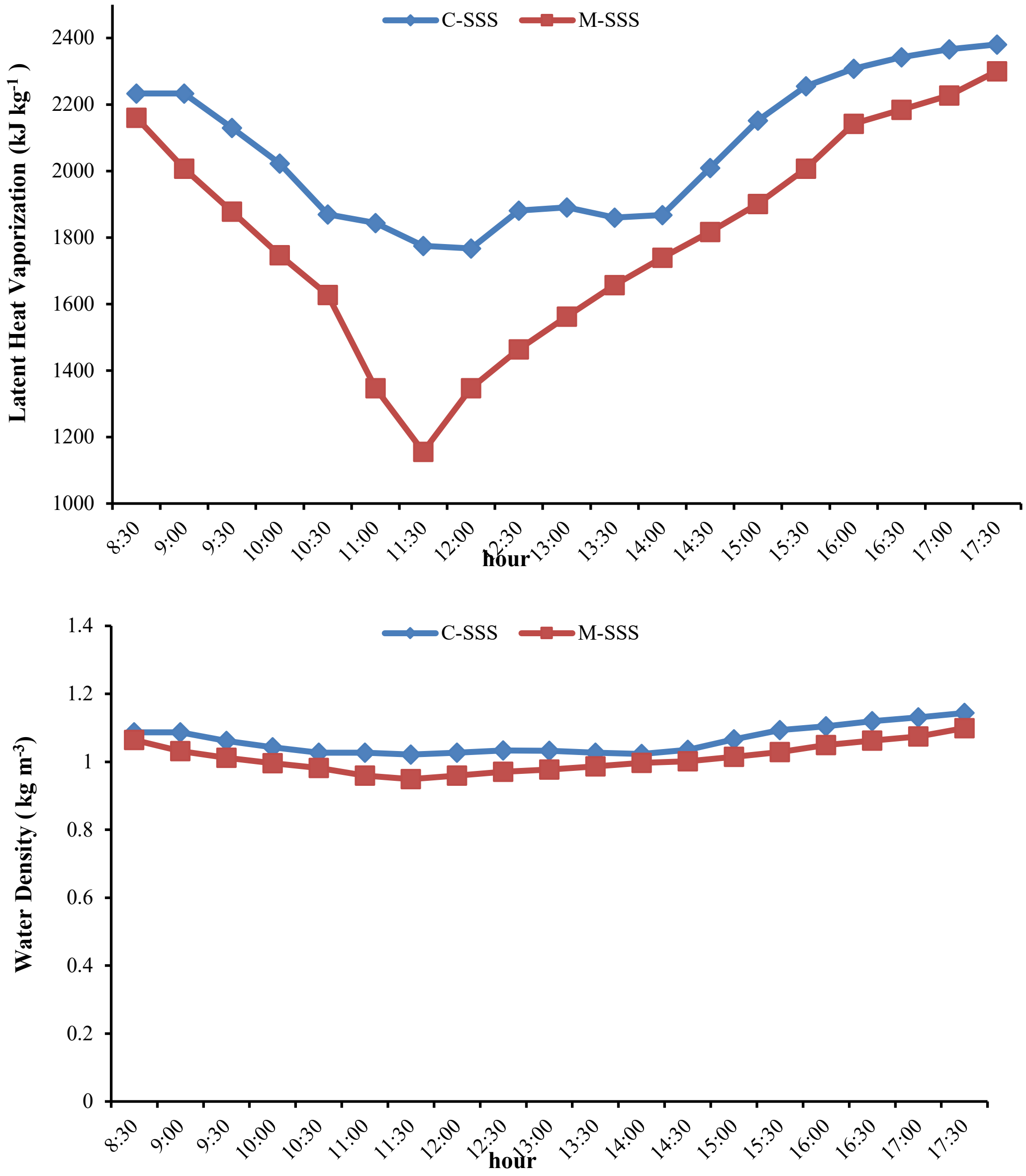


Figure 5 Fluctuation of water hourly thermo-physical properties

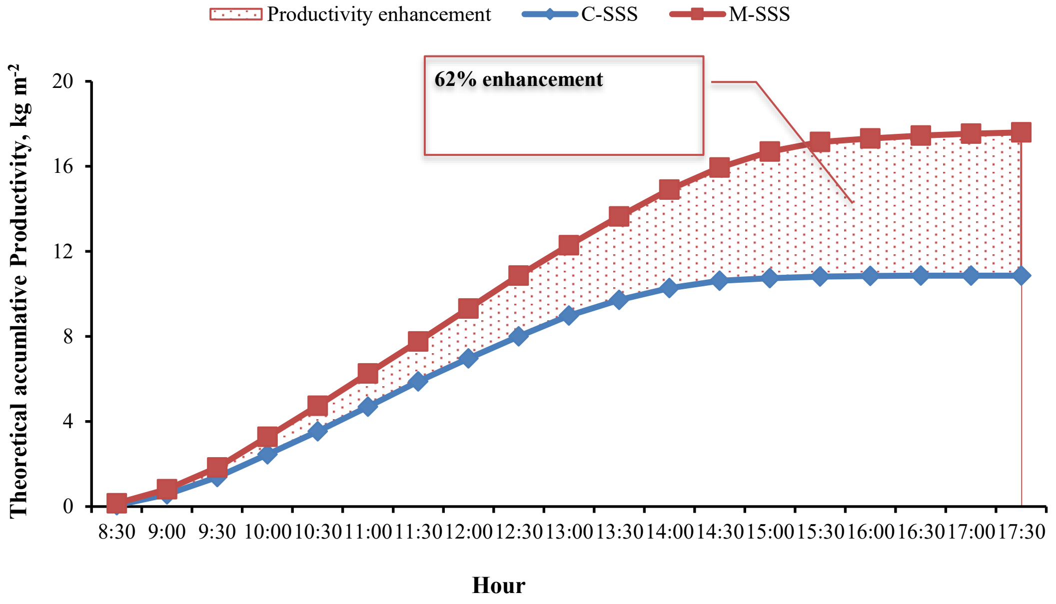


Figure 6 Still theoretical productivity

3.4.2 Still hourly productivity

Figure 7 showed that the modified still recorded the hourly productivity values of 1.269, 1.21 and 1.155 kg m^{-2} h^{-1} at water salinity levels of 15000, 35000 and 45000 ppm, respectively. While, the corresponding values of the hourly productivity that were recorded by the conventional still were 0.65024, 0.62858 and 0.62446 kg m^{-2} h^{-1} at the previous salinity levels with the same respect. The modified still recorded higher hourly productivity values than the conventional still with 95.2%, 92.4 and 84.9% at the previous water salinity levels with the same respect.

3.4.3 Still accumulative productivity

As indicated in Figure 7 the modified still achieved the accumulative productivity values of 11.92, 11.38 and 10.92 kg m^{-2} day^{-1} at water salinity levels of 15000, 35000 and 45000 ppm, respectively. Whilst, the corresponding values of the accumulative productivity of the conventional still were 5.38, 4.89 and 4.48 kg m^{-2} day^{-1} at the previous water salinity levels with the same respect. The modified still recorded higher values of the accumulative productivity than the conventional still with 121.5%, 133.0%, and 143.3% at the previous water salinity levels with the same respect.

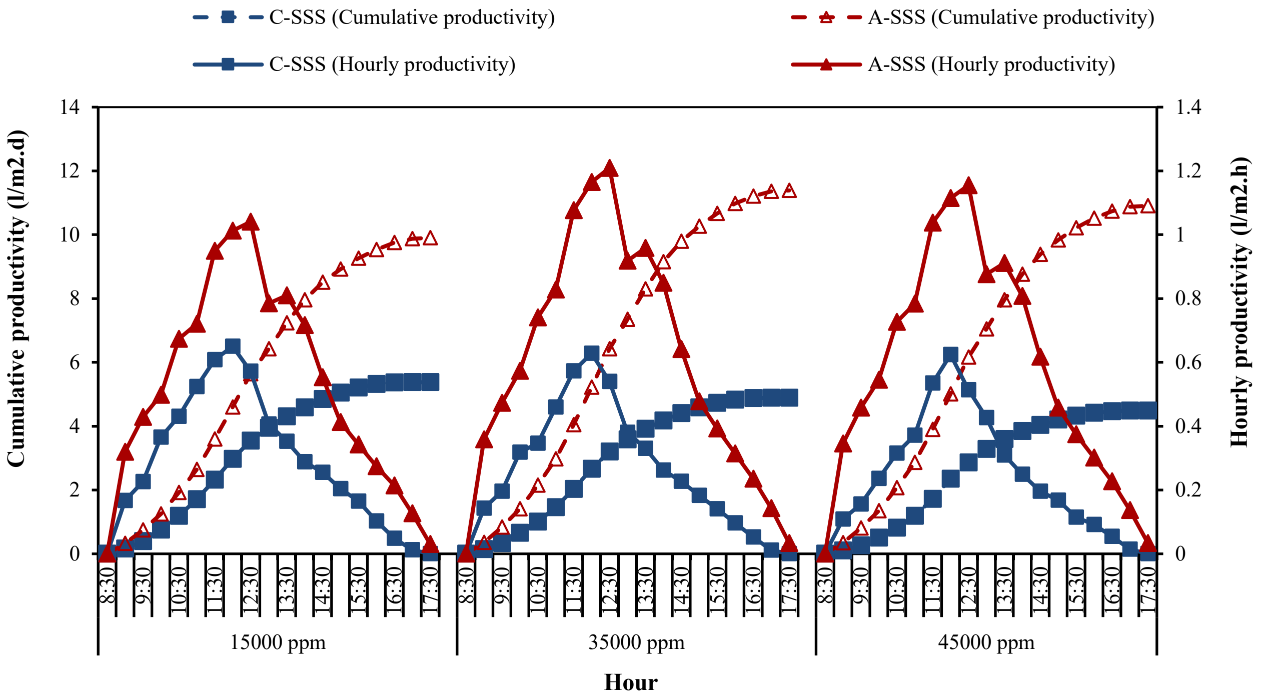


Figure 7 Still hourly and accumulative productivity

As illustrated in Table 3, the obtained results indicated a statistically significant difference in the hypothetical means of the still accumulative productivity between the modified and the conventional stills, with *p*-values for all comparisons being less than 0.05. Therefore, the modified utilized in this study is endorsed.

Table 3 Still accumulative productivity *p*-values and t-stat

Water salinity, ppm	t-stat	*p*(T<=t) two-tail
15000	-3.365266	0.0023056
35000	-3.532826	0.001501
45000	-3.647034	0.001117

3.4.4 Still performance efficiency

Figure 8 indicated the proportion of the still performance efficiency with the water salinity. Also, the figure showed that the modified still achieved higher performance efficiency than the conventional solar still system at all levels of water salinity. The modified still recorde performance efficiency values of 56.3%, 64.7% and 62% at the salinity levels of 15000, 35000 and 45000 ppm, respectively. While, the performance efficiency values of the conventional still were 49.5%, 45% and 41.3%, at the previous salinity levels with the same respect. This finding is attributed to the adverse impact of the water salinity on the still output production, which is hindered by the inadequate evaporative energy that generated by the conventional still to counteract the molecular energy presented in saline water. In contrast, further energy to compensate the limited evaporative energy in conventional still that was obtained by increasing the solar fluxes and preheating the water in case of the modified still. Thus, the productivity per unit area as well as the performance increased.

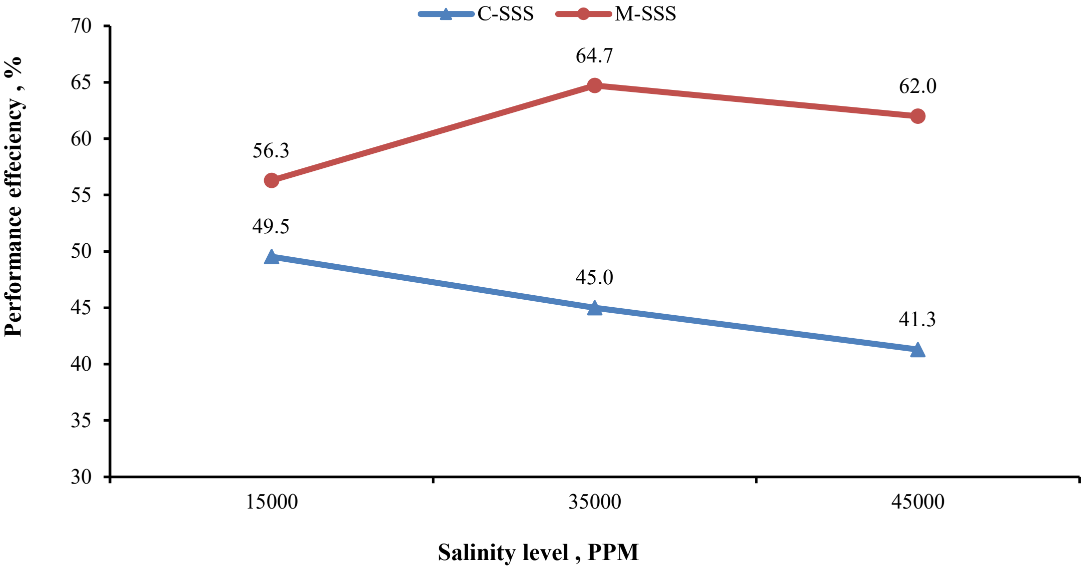


Figure 8 Still performance efficiency

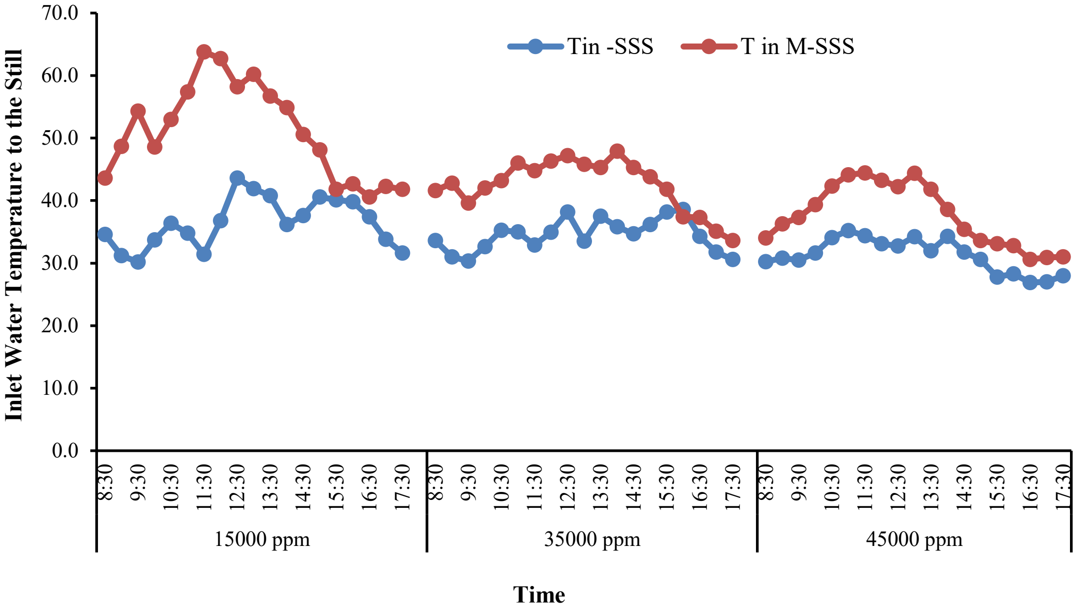


Figure 9 Still inlet water temperature

The cooling process was crucial for optimizing the performance of the modified still. The incorporation of air fans and booster mirrors not only facilitates the retention of elevated temperatures over extended periods but also guarantees the system's efficiency throughout the day. This cooling strategy effectively lowers the temperature of the still cover, thereby supporting elevated evaporation rates and enhancing condensation efficiency. As a result, there is a significant increase in both hourly and accumulative distillate output. Therefore, during the entire day, the total condensate theoretically-analyzed output of the modified still was higher with 62%, comparing with the conventional still. Also, the theoretically accumulative productivity increases up to 17.6 kg m^{-2} day^{-1} for M-SSS compared to 10.8 kg m^{-2} day^{-1} for C-SSS.

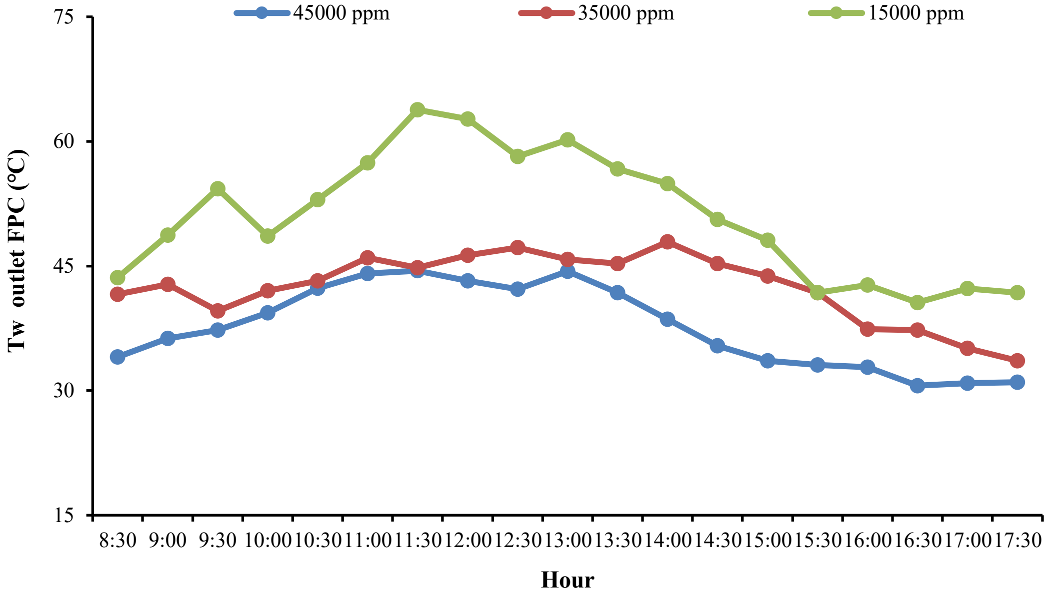


Figure 10 Hourly still outlet water temperature

The results of the still productivity could be discussed as follows:

1) Effect of water preheating on condensation: The inlet water temperature affected directly the amount of the generated vapor inside the still. This contributed to the higher evaporation rate, thus increasing the need for an effective condensation process. In this context, the fans play a crucial role in enhancing the condensation process by improving heat exchange between the vapor and the condenser. When water enters at a high temperature, the system requires enhanced condensation efficiency to avoid thermal energy loss. The fans help accelerate heat transfer from the vapor to the condenser, leading to faster vapor condensation and conversion into distilled water. This means that higher inlet water temperatures make the fans more effective in promoting the condensation process.

2) Effect of water salinity on condensation: Salinity has a direct impact on the efficiency of evaporation and condensation. There is a proportion of the salt concentration in the water with the boiling point of the water. This means that the still requires more energy to increase the water temperature to the evaporation level. However, the presence of fans helps improve the condensation process even with increased salinity. When the salt concentration increases, the water viscosity increases, slowing down evaporation. However, the fans offset this effect by improving the condensation process. This reduces the negative impact of salinity on the overall still efficiency.

3) Effect of fans on condensation and cooling: The fans increase the airflow rate over the condenser surface, enhancing heat transfer from the vapor to the external air. This improves the cooling efficiency within the system, meaning the condensed vapor turns into water faster. When high-temperature water is used, the fans further enhance cooling, effectively converting thermal energy into mechanical energy during the cooling process. With increased salinity, the role of the fans becomes even more crucial in maintaining system efficiency by reducing the negative effects of salinity on the condensation process.

3.5 Water distillation costs

Figure 11 showed that the estimated annual costs of distillation one kg water using the conventional still were 0.04, 0.044 and 0.048 $ at levels of salinity of 15000, 35000 and 45000 ppm, respectively. While, the corresponding values of the annual costs using the modified still were 0.03, 0.0265 and 0.0276 $ at the previous levels of salinity with the same respect. Thus, the annual costs of the modified still was lower than that of the conventional still with 25%, 39.8% and 42.5% at the previous salinity levels with the same respect.

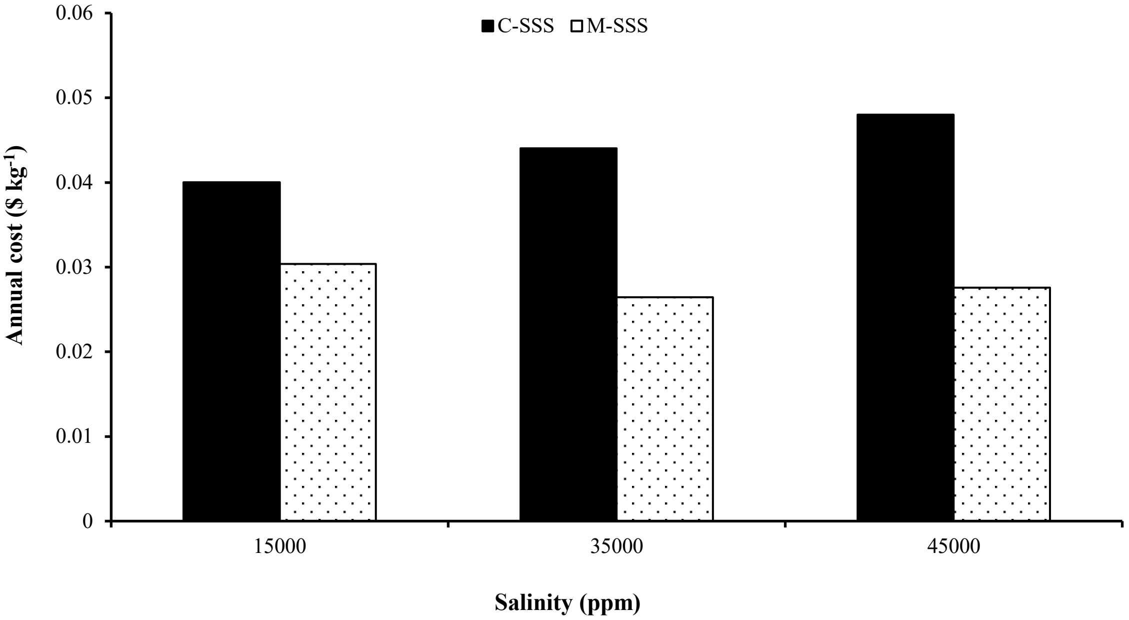


Figure 11 Water distillation costs

4 Conclusion

The most important results could be concluded as follows:

1) The theoretical analysis prove that be 62% of output production for the modified still higher than the conventional still.

2) The modified still achieved maximum vapor temperature of water higher than the conventional still with 20.4%.

3) The modified still lowered the latent heat than the conventional still with 8.5%.

4) The modified still accumulative productivity values were higher than the conventional still with 121.5%, 133.0% and 143.3% at salinity levels of 15000, 30000 and 45000 ppm, respectively.

5) The modified still performance efficiency values were 56.3%, 64.7% and 62%, while, the conventional still performance efficiency values were 49.5%, 45% and 41.3% at the previous salinity levels with the same respect.

6) The modified stille lowered the annual costs of water distillation with 25%, 39.8% and 42.5% than the conventional still at the previous salinity levels with the same respect.

Thus, these obtained results prove low cost and more improvements of still's performance and thermo-physical properties for the modified still. So, it could be recommended.

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