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Optimization of an inverted multi-stage double slope solar still: An environmentally friendly system for seawater purification

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ABSTRACT

Many people who live in remote coastal areas face a critical shortage of fresh water because they have a limited access to natural water resources. However, various proven technologies are available today that could solve this problem. Among them, the solar still can be preferred for providing potable water because it is simple and has no negative effect on the environment. In this study, the productivity of the double slope multi-stage basin solar still was optimized to enhance its efficiency. Materials were selected based on fresh water productivity factors for the double slope multi-stage solar still and fabricated according to a specified design. Results indicated that the inverted multi-stage double slope solar still system was identified as the ideal design. The most important parameters considered were seawater depth, mirror inversion vs. non-inversion, TDS, EC, and pH. Atmospheric temperature was found to influence water productivity. The maximum productivity was 1.80 L m^{-2} d^{-1} with a 2-cm depth of seawater using an inverted mirror.

Keywords: Distillation; Seawater; Solar still; Mirror inversion; Water productivity

1. Introduction

Knowledge of the water cycle in nature can be traced to the classic Greek philosopher Aristotle, who described the water cycle as early as 350 BCE [1]. In the past, Phoenician sailors made use of solar radiation to get fresh drinking water, and Arab alchemists used vessels and concave mirrors heated with solar radiation to get fresh water from seawater. According to Delyannis [1], Della Porta explained in his book many techniques to obtain freshwater from solar distillation in 1589. The first passive solar desalination installation designed by engineer Charles Wilson was published in 1872, near Las Salinas, in northern Chile and produced about 22.7 m^3 of fresh water per day. Today several types of solar stills, which convert seawater to fresh water, exist including single-basin slope solar stills, double-effect basin solar stills, multi-effect basin type solar stills, vertical solar stills, tubular-type solar stills, steeped type solar stills, and finned and corrugated basin solar stills [2]. Over the years, different studies have been undertaken to improve the productivity of solar stills. These studies have mainly resulted in improving the solar still distillation process as described below.

1.1. Type of absorbent material

Velmurugan et al. [3] focused on studying the performance of stepped solar stills. Their independent vari-

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ables were depths of seawater, wind velocity, and types of absorbent materials. The materials included fin; pebble and fin; sponge, fin, and pebble; and sponge and fin. Their solar still was designed using 50 trays with two different seawater depths, with the first 25 trays filled to a 10-mm depth and the remaining 25 trays filled to 5 mm. The results showed that the productivity of a stepped solar still without any modification was approximately 0.45 L m^{-2} and was obtained with a wind velocity of 0.6 m/s. The maximum amount of fresh water collected was 0.90 L m^{-2}, which was obtained using fin, pebble and sponge and with a 0.6 m s^{-1} wind velocity. The results indicated an increase in productivity of 98% compared to that of the basin condition. In general, the results showed an inverse relationship between productivity and wind velocity.

Ouar et al. [4] focused on improving single slope solar still productivity by using bitumen, charcoal, and Chinese black ink as absorbent materials. They first conducted the experiment by coating the entire surface of the absorber with 0.5 cm of bitumen. Then they changed the absorbent material by adding 100 g of charcoal. Finally, they added nine drops of black ink to the water's surface. The experiment ran from 09:00 am to 05:00 pm, but they conducted a second phase to study the solar still's productivity during the nocturnal period. The maximum diurnal productivity was 5.05 kg m^{-2} d^{-1} and was obtained using a 0.5-cm thickness of bitumen, which increased the productivity of the single slope solar still by 25.35% as compared to the baseline. The yields for bitumen, charcoal, black ink and the control unit were 5.05, 4.77, 4.30, and 4.03 kg m^{-2} d^{-1}, respectively. The results indicated that bitumen, charcoal, and black ink improved the productivity of the solar still by 25.35%, 18.42%, and 6.87%, respectively, when compared to the baseline.

Sellami et al. [5] focused on improving the performance of the solar still by adding an absorber in the form of blackened layers of sponge in a single slope solar. The independent variable studied in their experiment was the sponge thickness. The results of the nine–hour experiment reported that the productivity witness still was 3.05 kg m^{-2} while sponge thicknesses of 1.5, 1.0 and 0.5 cm had respective yields of 2.14, 3.75, and 4.81 kg m^{-2}. The results also indicated that the maximum amount of collected water was 4.81 kg m^{-2} d^{-1} which was obtained using a 0.5-cm thick sponge. Fresh water productivity increased by 57.77% compared to the base still productivity of 3.05 kg m^{-2} d^{-1}.

Pal et al. [6] analyzed the performance of a modified basin double slope multi–wick solar still by investigating independent variables of water depth and absorbent material. The experiments were carried out from August 2015 until July 2016. The observations were registered for a 23-h period, from 07:00 am to 06:00 am the next day. The total yield obtained in the modified solar still with black cotton and jute wicks were 7.74 and 7.04 L d^{-1}, respectively. The results indicated that the highest amount of collected water was 9.01 L d^{-1} with a 2-cm water depth and was obtained with black cotton.

1.2. Depth of water and temperature

Sangeeta et al. [7] observed that the independent variables that affect solar still productivity were the depth of seawater and temperature of the inlet water. The productivity of an inverted absorber double basin solar still (DBSS) increased by about 10% when the temperature of the water entering the basin increased from 22°C to 35°C. Suneja and Tiwari [8] pointed out that the distilled water produced from an inverted absorber solar still (IASS) doubled the productivity of a conventional still. They reported that increasing the water depth for an inverted absorber in the lower basin led to an increase in the daily yield.

Abdul-Wahab and Al-Hatmi [9] indicated that integrating a refrigeration cycle with an inverted design increased fresh water productivity. In addition, they found that when water depth increased, so too did productivity. The experiment lasted 24 h, starting at 7:00 am. The independent variables studied were temperature and depth of water. The results showed that the highest productivity (1.5 L) was seen at 2:00 pm with temperatures of 30°C and 8 cm of water. A subsequent study focused on evaluating the performance of an inverted solar still when integrated with a refrigeration cycle. The independent variables were temperature and water depth. All their experiments lasted for 24 h. The results showed that the maximum amount of water collected by the IASS was 3.76 L d^{-1} and was obtained with 4 cm of sea water at 35°C. Using the same depth and temperature of the seawater in the refrigeration inverted solar still (RIASS), 6.40 L d^{-1} of water were collected. These results indicated an increase in solar still productivity of approximately 70.21%. The results showed that the highest amount in RIASS was 10.08 L d^{-1} and obtained with seawater depth of 6 cm at 35°C [9].

1.3. Design of solar still parts structure

The performance of an evacuated multi-stage solar still was analyzed by Reddy et al. [10]. The authors studied many parameters that affect the productivity of multi-stage solar stills such as the number of stages, the temperature difference between the stages, the gap between the stages, the seawater's salinity, the mass flow rate and the wind velocity. The results showed that, until the fourth stage, as the number of stages increased, the productivity increased. Increasing the number of stages beyond four was found to have no effect on further improving productivity. In terms of the temperature differences between stages, it was found that the higher the temperature difference between stages, the higher evaporation and condensation were obtained, which caused higher productivity of the solar still. Reddy et al. [10] also studied the effect of the gap in solar still productivity. They mentioned that when the gap between stages decreased the productivity increased. Also, they studied the effect of salinity and recognized that when the salinity increased the evaporation rate decreased as well as the productivity. The effect of mass flow rate also was analyzed, and the result showed that the productivity increased as the mass flow rate decreased until the flow rate reached a critical point, at which productivity decreased. They also studied the effect of wind velocity on heat loss from the solar still. They found that the increase in velocity resulted in an increase in heat lost from the solar still, which caused a decrease in productivity.

1.4. Additional surface cover

El-Sebaii and El-Bialy [2] focused on improving solar still productivity by covering the additional surface area so the rate of condensation would increase. Adding extra surface area led to an increase in the heat capacity of the evaporation area, and the elevated basin water was heated by the thermal energy released from condensation. The outer surface cover was maintained at an ambient temperature by integrating a number of fans. The authors indicated that the daily productivity of a DBSS with extra surface area was 10.7 L m^{-2} d^{-1}. The tube type solar still was designed for use in desert plantations. According to El-Sebaii and El-Bialy [2], the water produced from tube type solar stills was supplied immediately to the ground by penetration because the water condensed in the tube, eliminating the need for a tank. They observed that the latent heat of wax affected distillation productivity and contributed to about 15% of the water productivity. Also, they founded that the distillate productivity was about 0.29 L m^{-2} when the irradiative intensity went from 200 W m^{-2} to 600 W m^{-2} and back to 200 W m^{-2} during a cyclic stepwise change.

Kabeel et al. [11] compared the productivity of a normal conventional solar still with that of a modified solar still with heat injection and phase change materials (PCMs). Their experiments, carried out in Egypt for six months between 6:00 am and 10:00 pm, found that the average productivity of a normal conventional solar still was 4.5 L m^{-2} d^{-1} whereas that of the modified still was 9.36 L m^{-2} d^{-1}, with a 108% increase in productivity. Therefore, it was concluded that the productivity of a conventional still was lower than that of a modified still.

1.5. Material used for insulation

Shukla et al. [12] studied the effect of PCMs in solar still productivity. PCMs result in latent heat storage that was able to store energy during heat transfer and phase change. The authors found that the productivity of a solar still was better when using PCMs. In their study, paraffin wax was the most common PCM used due to its low price and high availability.

Mousa et al. [13] designed a mathematical model to predict the productivity of a solar still involving PCMs. They studied many independent parameters that affect solar still productivity such as the maximum irradiation intensity, the feed flow rate, the PCM melting point and the amount of PCM. The results indicated that as solar intensity intensified, productivity increased. In addition, it was found that the decrease of feed water flow improved productivity. The productivity was found to be affected negatively by the amount of PCMs present and positively with an increase in PCMs' melting point. The conclusion was that the productivity of a solar still with PCMs at a specific solar irradiation intensity can be increased by reducing the flow rate of feed water and using PCMs with higher melting points.

Based on the foregoing facts, the overall goal of the current study was to design and construct a solar still with optimized productivity. Specific objectives were (1) to develop solar stills with more advanced concepts in design, configuration, type, and operational parameters; (2) to determine the operating performance of the fabricated solar still under identical operational and weather conditions in Oman; (3) to investigate experimentally the effect of various variables on solar still performance to identify the principal variables that control the productivity of solar stills; and (4) to investigate the economic and efficiency of the solar still.

2. Methodology

2.1. Description of study region

The experimental set up was installed at the College of Engineering, Sultan Qaboos University, Oman. The location was at latitude of 23º37′ N and longitude of 58º35′ E. The solar still was allocated south facing to receive the maximum solar radiation. The climate of Muscat features a hot, arid climate with long and very hot summers and warm winters. Annual rainfall in Muscat is about 100 mm (4 in), falling mostly from December to April. In general, precipitation is scarce in Muscat with several months, on average, seeing only a trace of rainfall. The climate is very hot, with temperatures reaching as high as 49°C (120°F) in the summer.

Considering the above-mentioned facts, Oman lies in high solar insolation band and the huge solar energy potential can be used to convert saline water to fresh water. This produced fresh water can be used by small communities that live in remote areas of Oman, which are suffering from a scarcity of fresh water. The most easy and economical way to convert the available saline water into potable water is by using solar stills.

2.2. Designing improved technology

Through rigorous concept generation and analysis, an improved design was developed (Fig. 1). The design was a multi-stage double slope basin still with fins at the base and integrated with an inverted mirror. The still depended on solar radiation to heat water in the basin. The inverted mirror was used to reflect the solar radiation; therefore, the water would evaporate faster, producing more fresh water. Adding fins at the bottom of the basin increased the area exposed to solar radiation thereby heating the basin water faster.

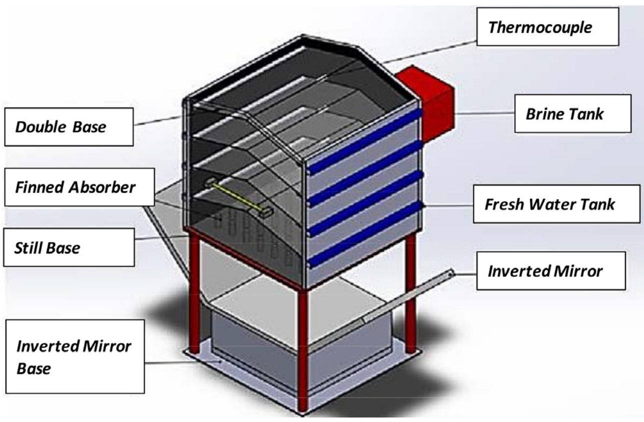

Fig. 1. Schematic diagram of the developed solar still.

2.3. Experimental set-up

Experiments with the multi-stage solar still were conducted from 24 April to 3 May 2018 at Sultan Qaboos University (SQU) in Muscat, Oman, under atmospheric weather conditions (Table 1). All experiments started at 07:30 am and finished at 09:00 pm. The yield of distillate water from the solar still was recorded every day. The experiments were conducted to measure different parameters, including water depth inside the stages (i.e. 1 and 2 cm) with/without inversion, total dissolved salt (TDS) (i.e. 38 and 19 g L^{-1}), electrical conductivity (EC) and pH.

The temperature was recorded using thermocouples connected to a data logger and adjusted in such a way that one of them was used to measure the outside temperature, with one thermocouple devoted to each stage. The inverted mirror was fixed under the solar still. The solar still door was closed, and the gap was filled with insulation to make sure that no air leaked from the still (Figs. 1 and 2). The fresh water containers were closed after connecting the pipes. The quantity of water produced was measured, and a sample of water was taken for analysis. Before and after the experiment, water samples were taken to the laboratory to measure pH, electric conductivity, and TDS.

3. Results and discussions

3.1. Productivity

Productivity varied from day to day mainly due to changes in the experimental parameters and atmospheric weather conditions. The maximum productivity was found in the Experiment #7 (1.80 L m^{-2} d^{-1}) (Fig. 3) and minimum productivity was in the Experiment #2 (0.90 L m^{-2} d^{-1}). Freshwater productivity was compared with that recorded in previous experiments conducted in Muscat, Oman (Table 2). Abdul-Wahab and Al-Hatmi [9] recorded the highest productivity (10.80 L m^{-2} d^{-1}) with inverted absorber solar still integrated with a refrigeration cycle (RIASS). This productivity occurred under almost identical climactic conditions with seawater in Muscat.

Table 1
Description of experimental conditions

Experiment number	Experimental set-up		
	Depth (cm)	TDS (g L^{-1})	Inverted
1	1	38	Yes
2	1	38	No
3	1	19	Yes
4	1	19	No
5	2	38	Yes
6	2	38	No
7	2	19	Yes
8	2	19	No
9	1	Seawater	Yes
10	2	Seawater	Yes

Fig. 2. Solar still setup and experiment using seawater in Muscat, Oman.

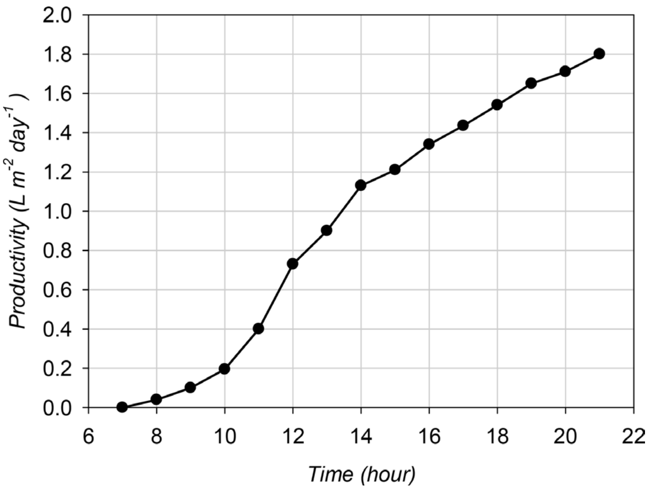

Fig. 3. Cumulative productivity recorded using the modified solar still with seawater in Muscat, Oman.

3.2. Quality of water produced

Total dissolved solids (TDS), pH and electrical conductivity (EC) were investigated as water quality parameters using a Seven Compact™ S220 pH/ion meter and S230 conductivity meter (Mettler-Toledo AG, Schwerzenbach, Switzerland). Both EC and TDS were highly reduced in the

Table 2
Comparison of solar still experiments conducted at different periods under Muscat (Oman) weather condition

Authors	Type of still	Design specification	Productivity (L m^{-2} d^{-1})
Current study	Multi-stages double slope basin still	It is constructed from galvanized steel with an inverted multi-stage double slope basin still and fins at the base (1 m^2) and integrated with inverted mirror.	1.8
Al-Hinai et al. [14]	Single effect solar still	It consists of a basin that accommodates the brackish water and is covered by two sloping glass cover symmetrical at the center.	4.15
Al-Hinai et al. [14]	Double effect solar still	It consists of 2-story basin type-solar still with glass cover for both basins. The first basin glass cover is used as the base for the second basin.	6.10
Abdul-Wahab et al. [15]	Conventional solar still	It is made using galvanized iron sheet of 2 mm thickness with an absorbing square basin area (1 m^2) its bottom painted black to maximize solar radiation absorption. The condensing cover is a single glass with 6 mm thickness.	0.80
Abdul-Wahab et al. [15]	Double glass solar still	It is fabricated similar with the conventional solar still as described above but has double-glass cover with 10 mm spacing and water flowing between the double-glass cover as cooling means.	1.18
Abdul-Wahab et al. [16]	Inverted absorber solar still	It is a combination of a conventional solar still and a curved reflector under the basin. The basin (1 m^2) fabricated using 1.5 mm thickness galvanized iron sheet. The reflector is made up of galvanized iron sheet of 1.5 mm thickness with aluminum foil on its inner surface to increase reflectance.	3.50
Dev et al. [17]	Inverted absorber solar still	It is fabricated from galvanized iron sheet with 1.5 mm thickness having a basin area of 1 m2 and a curved reflector under the basin.	6.30
Dev et al. [17]	Single slope solar still	It is fabricated from galvanized iron sheet with 1.5 mm thickness having a basin area of 1 m2 and insulated from bottom side with 3 mm Styrofoam to protect heat loss.	2.15
Dev et al. [17]	Inverted absorber solar still (IASS)	It is made from galvanized iron sheet of 5/16 inch thickness with a dimension of 40 cm long and 20 cm wide. The enclosure made up of glass 5/16-inch thickness and its sides insulated with 5 cm thick Styrofoam. The basin was colored black and filled with 4 cm water depth.	3.41
Abdul-Wahab and Al-Hatmi [18]	Inverted absorber solar still integrated with a refrigeration cycle (RIASS)	It consists of two main parts: an inverted absorber solar still (IASS) as described above and a refrigeration cycle with inlet and outlet lines. The basin was colored black and filled with 6 cm water depth.	10.80

fresh water produced, mainly due to the salts, which did not evaporate when the water evaporated and condensed. Also, the pH value was reduced after desalination. However, errors with pH values occurred during initial trials, mainly due to corrosion in several parts of the solar still's fresh water collection areas. The error in pH was eliminated by solving the corrosion problem (Table 3).

The quality of the produced water has been highly improved since the solar still system practically converts the sea water (salty water) to fresh water through evaporation and condensation process. For the present case, the quality of the produced fresh water dominantly fulfills the WHO standard level for drinking water (Table 3). Total dissolved solids (TDS) level of less than about 600 mg/L is generally considered to be good.

3.3. Factors affecting productivity

3.3.1. Water depth

It is clear from the results that the water productivity in the Experiment #9 (1.74 L m^{-2} d^{-1}) was higher than the water productivity in the Experiment #10 (1.25 L m^{-2} d^{-1}). Thus, as water depth increased, water productivity decreased (Fig. 4).

3.3.2. Inverted mirror enhancement

The effect of the inverted mirror on water productivity was revealed in the differences found between Experiments #1 and #2 as the only variable that differed between the two

Table 3
Quality of produced fresh water with respect to the seawater source

Solar still	Depth (cm)	Water feed (morning)			Collected produced fresh water (evening)			Productivity (L m^{-2} day^{-1})
		pH (± 0.002 pH)	EC (µs/cm) (± %0.5 of measured value)	TDS (mg/L) (± %0.5 of measured value	pH	EC (µs/cm)	TDS (mg/L)	
Inverted	1	6.07	4.56E + 04	33.250	6.9	211	130	1.00
		6.13	2.84E + 04	21.750	7.41	2010	1210	1.13
		7.88	Seawater (3.93E + 04)	32.250	6.32	196	100	1.74
	2	7.65	5.51E + 04	41.750	5.44	36.2	10	1.12
		6.36	8.86E + 04	71.500	5.64	18.53	10	1.80
		8.26	Seawater (4.07E + 04)	29.500	6.15	51	20	1.25
Non-inverted	1	7.66	5.32E + 04	27.750	4.8	170.3	50	0.90
		6.27	4.40E + 04	34.000	7.04	256	150	1.05
	2	5.39	3.83E + 04	42.000	5.2	70.2	110	0.91
		7.45	2.61E + 04	18.500	5.89	11.93	10	1.59

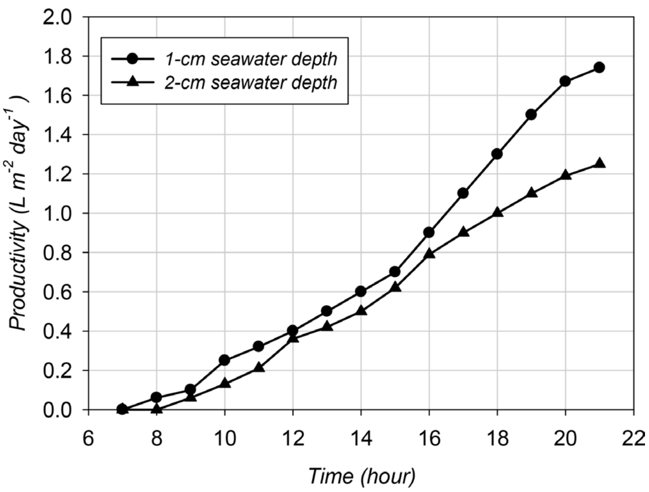

Fig. 4. Cumulative productivity of the solar still with a 1-cm vs. 2-cm seawater depth.

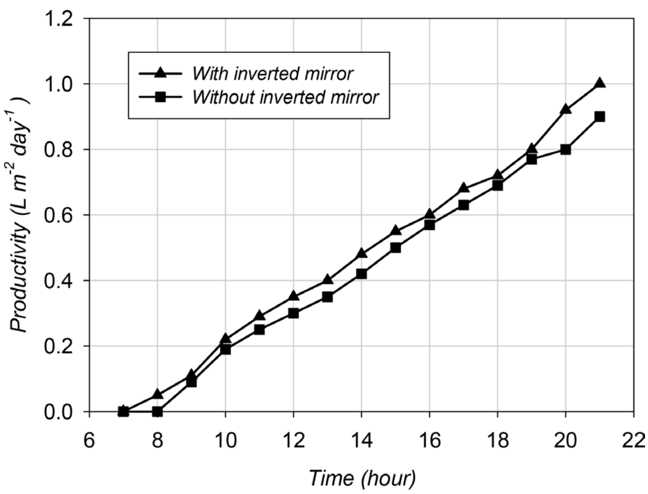

Fig. 5. Cumulative productivity of stills with and without inverted mirror.

was the use of an inverted mirror in the Experiment #1. The Experiment #1 had water productivity of 1.00 L m^{-2} d^{-1} vs. water productivity of 0.90 L m^{-2} d^{-1} in the Experiment #2. Thus, the inverted mirror influenced water productivity positively (Fig. 5).

3.3.3. Ambient temperature

The outside temperature mainly dictates the temperature inside the solar still and in turn influences the evaporation of water inside the solar still as well as its productivity. Thus, as outside temperature increased so did productivity. Fig. 6 shows the temperature of water in the solar still, which is essentially the ambient temperature of the water when enclosed in steel. The ambient temperature was mainly influenced by solar radiation, which ranged between 909–1010 mW m^{-2} between 12:00 and 13:00 h on

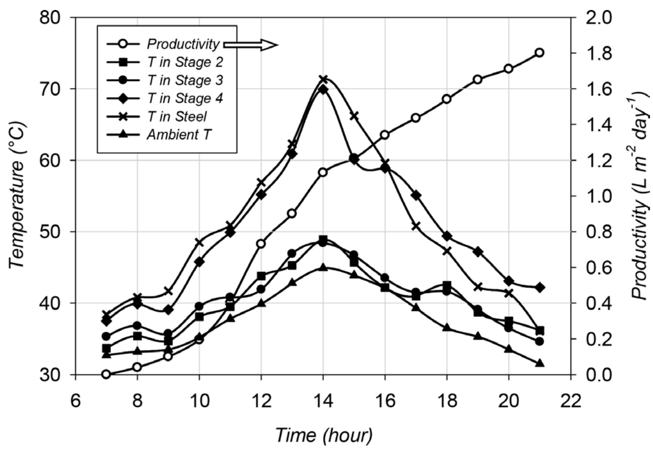

Fig. 6. Productivity with respect to temperature of the solar still in the Experiment #7.

the experiment days. The solar radiation pattern was similar for all experimental days except Day-5 when the solar radiation was reduced during the morning (Fig. 7).

3.4. Economic and efficiency analysis

The economic analysis for the multi-stages double slope basin still undertaken in Table 4 using the Dev and Abdul-Wahab [17] approach considering the initial cost of the system 235.8 OMR (Omani Rial) or 613.1 USD (United States Dollar) with conversion rate 1 OMR equals 2.60 USD in year 2018 (Supplementary Material 1). The analysis shows the minimum cost of distilled water should be 0.12 USD L^{-1} in order to cover the annual cost of the system. Comparatively, the cost for desalination water source in Oman ranges between 0.065 and 1.2 USD m^{-3} [19,20], which makes the multi-stages double slope basin still not economically competitive.

The maximum efficiency of the multi-stages double slop basin still estimated to be 3.6% considering the maximum productivity 1.80 L m^{-2} d^{-1} with a total application of 50 L of seawater per day maintaining 2-cm depth within the basin. The efficiency of the system is low and further research works are needed to enhance the efficiency and economic viability of the system.

4. Conclusions

The best design for optimizing solar still productivity was created taking into consideration the customers' requirements and was selected through the weight matrix evaluation method. The experiments were conducted under normal Muscat weather conditions. The results of this study indicate that water productivity from solar stills was affected by the experimental parameters and weather conditions. Based on the experimental findings, the main conclusions were drawn as follows:

- The inverted multi-stage double slope solar still was identified as the ideal design.
- The most important parameters considered were seawater depth, mirror inversion vs. non-inversion, TDS, EC, and pH.

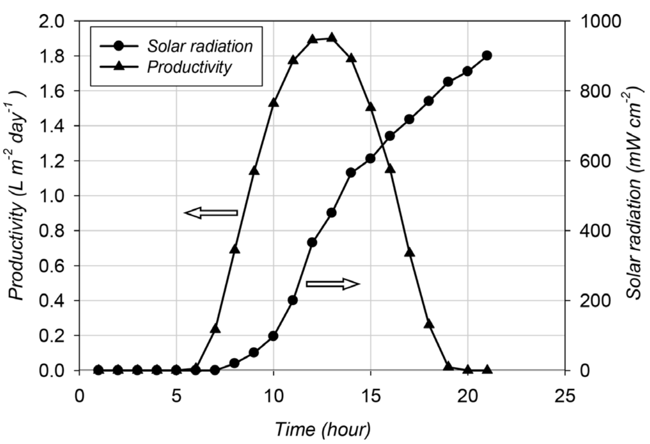

Fig. 7. Productivity with respect to solar radiation recorded during the experiment days in Muscat, Oman.

Table 4
Economic and efficiency analysis of the multi-stages double slope basin still

Parameters	Unit	Values
I) Economic analysis		
Principle cost (P)	USD	613.1
Salvage value (s) (10% of principle value)	USD	61.3
Life of the solar still (n)	Year	15
Interest rate (i)	%	10%
Capital recovery factor (CRF = [(i(1+i))]^n/((1+i)^n–1))		0.13
Sink fund factor (SFF = 1/((1+i)^n–1))		0.31
Annual first cost (CRF × P)	USD	80.60
Annual maintenance cost (15% of annual first cost)	USD	8.1
Annual cost/m^2 (Annual first cost + annual maintenance cost – annual salvage value)	USD/m^2	27.36
Annual yield of the solar still (average daily yield × 365) (assuming average daily yield = 1.8 L at water depth 0.02 m)	L	657
Annual useful energy (annual yield × latent heat of vaporization) Latent heat of vaporization = 0.65 kWh/kg	kWh	427.1
Annual cost of distilled water per L		
(annual first cost/annual yield)	USD/L	0.12
Annual cost of distilled water per kWh		
(annual first cost/annual useful energy)	L/kWh	0.19
II) Efficiency analysis		
Total amount of sea water applied to basin per day	L	50
Maximum daily purified water yield per day	L	1.8
Efficiency	%	3.6

- The maximum productivity was 1.80 L m^{-2} d^{-1} at a 2-cm seawater depth with an inverted mirror.
- As the water depth inside the stages increased, the water productivity decreased, while the inverted mirror increased the quantity of water produced.
- TDS, EC, and pH values were decreased after the water was desalinated. Atmospheric temperature also was found to influence water productivity. When temperature increased, productivity also increased.

Conflict of interest statement

There is no conflict of interest declared by the authors.

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Table S1
Initial cost for the multi-stages double slope basin still

Items	Unit	Number of units	Unit cost (OMR)*	Total cost (OMR)	Total cost (USD)
1) Equipment					
1.1 Mirrors for collecting solar radiation	Count	3	4.0	12.0	31.2
1.2 Glass plate for collecting solar energy and condensing the collected produced water	Count	2	10.0	20.0	52.0
1.3 Insulation to prevent heat leak	Count	1	3.0	3.0	7.8
1.4 Tank to contain the sea water	Count	1	19.0	19.0	49.4
1.5 Pipes for water flow in the system	Count	2	0.8	1.6	4.2
1.6 Tank for collecting the fresh water	Count	8	2.0	16.0	41.6
1.7 Frame to fix the parts	Count	1	25.0	25.0	65.0
1.8 Steel stand as a support system	Count	1	20.0	20.0	52.0
1.9 Door for closing the system	Count	1	10.0	10.0	26.0
1.10 Back plate	Count	1	10.0	10.0	26.0
1.11 Silicon for fixing parts and insulate air leaking	Count	8	0.5	4.0	10.4
Subtotal equipment cost				140.6	365.6
2) Man-power					
2.1 Structure assembly	Man-day	1	30.0	30.0	78.0
2.2 Stages assembly for collecting feed water	Man-day	3	8.4	25.2	65.5
2.3 Stages assembly top and bottom glasses	Man-day	2	7.5	15.0	39.0
2.4 Back plate assembly on the frame	Man-day	1	10.0	10.0	26.0
2.5 Assembly door on the frame	Man-day	1	15.0	15.0	39.0
Subtotal manpower cost				95.2	247.5
Grand total Cost				235.8	613.1

* Exchange rate 1 OMR = 2.6 USD in year October 2018