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Research Article

The effect of the covers number on the production rate for the single-slope solar still

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Abstract:

In this study, an attempt was made to compare the thermal performance of two identical single-slope solar stills using a different number of covers (single cover and double cover). These experiments were carried out at the Tractors and Agricultural Machinery Research and Testing Station - Agricultural Engineering Research Institute - Alexandria at 31.2 °N latitude, 29.92 °E longitude and 15 meters above sea level. The experiments were conducted from the 1th of May to the end of June 2022. Various climatic factors and measurements of solar stills were monitored, measured and recorded. The average solar energy available per hour within solar wind speed and ambient air temperature during daytime, 432.82 W, 3.89 m/s, and 26.18 C° . The thermal efficiency for the single-slope solar still of double cover was higher than that of the other single-slope solar still (single cover) about 5.6%. The distillation efficiency for the single-slope solar still of single cover was higher than that of the other single-slope solar still (double cover) by 8.8 %.

1. Introduction

There is a severe lack of fresh water in the world today. Along with the deterioration of existing water supplies, the growing world population leads to the assumption that two thirds of the population will lack sufficient fresh water by the year 2025 (UNEPb 2003 and Aybar et al. 2005). The areas with the severest water shortages are the warm, arid countries in the northern, Africa and southern Asia within the latitudes 15-35ºN (Hussain, 2003). In the light of this fact, the desalination process seems to be the only realistic option as a new and reliable route to obtain the fresh water. The regions in most need of additional fresh water are also the regions with the most intense solar radiation. For this reason thermal solar energy in desalination processes should be the most promising application of renewable energies to seawater desalination (Garzia, 2002a). The situation today is, however, somewhat different, since only 0.02% of the global desalination capacity is represented by renewable energy systems (Garzia 2002 b). According to the rapid increase of the population over the globe, desalination is increasingly considered to be necessary and feasible method to provide people by the adequate amounts of fresh water. By 2025, about 70% of the world's population will face water shortage problems (Li et al 2013 and Weldekidan et al., 2018). Egypt in the world of scarcity is not an exception. Now, the present per capita availability of water annually is approximately 985 m3, while the per capita availability of cultivated land is as low as 0.05 hecktare. The main and almost exclusive source of water for Egypt is the Nile River, which represents 97% of the country's fresh water resources. The river supplies water to a population of about 65 million inhabitants where the country's growing population is expected to reach 120 million in the year 2025, which will increase the demands for the already scarce water and arable land. Almost 85% of this amout of water is allocated for agriculture with overall irrigation efficiency lies between 65-75%, whereas water allocated for domestic and industrial usages is less than 15%. Based on the measures towards water resources management, Egypt is facing serious challenges such as deterioration of water quality and the growing demand-supply gap (Arar, 1998. As is known, distillation industry is a large energy intensive sector, since it needs huge amount of energy which is not available in most remote and desert areas (Perakis et al., 2017). So the main two challenges facing the Government to develop agriculture activities are to supply those areas with the necessary energy and water. Implementing agriculture activities in those areas need special kind of management between the three issues; energy, water and agriculture. A sustainable solution for one almost always has an impact at the others. The solution for this interact problem is not practical by building more conventional power plants or water delivery with the required normal treatment or to use the ordinary ways to grow crops. It should implement new thinking for producing energy, water and food. It must be solved simultaneously in sustainable smart ways that would not only handle with their scarcity, but also must concern about cost effective technologies for best use of energy and water to grow food. Energy management is by using sustainable renewable energy sources and making full use of all the produced energy by cogeneration and heat recovery of one type of fuel energy. Solar which is sustainable abundant energy in those places can play this role in different agriculture applications. Water management by using clean energy, storage water, advanced techniques in desalination, irrigation and cultivation. Solar energy or both can be used simultaneously with the desalination process in those places have ground water in a reasonable depth. Land management will be through small area controlled agriculture as green houses, protected hydroponic cultivation and most suitable type of irrigation all year round. Another scenario is by cultivating part of the year and then used the GH as agricultural products dryer (Khattab et al., 2016). The method of direct solar desalination is mainly suited for small production systems, such as solar stills, in regions where the freshwater demand is less than 200 m^3/day. This low production rate is explained by the low operating temperature and pressure of the steam. The original solar still can be described as a basin with a transparent cover of (e.g. glass). The interior of the still contains seawater and air. When the seawater is heated by solar radiation, it starts to evaporate and the formed vapour is mixed with the air above the water surface. On meeting the inside of the glass ceiling of the still the humid air is re-cooled and some of the vapour condenses on the glass. If the glass cover is tilted, the formed condensation drops will start running down the cover by gravitational forces, and may then be collected at the side of the still (Fath, 1998). There are various methods of desalinating sea and brackish water. These include flash distillation, multi-effect distillation, membrane distillation, reverse osmosis, forward osmosis, ion exchange, capacitive deionization, and electro dialysis and seawater greenhouse technology. The energy for desalination can be obtained from fossil fuel or alternate energy sources such as biomass, wind, solar, geothermal energy, or industrial waste heat. Among the various methods of solar desalination, solar stills have several advantages including simplicity, low cost, ease of maintenance, and low environmental impact. However, they also have disadvantages, such as low performance, that hinder their commercial uptake (El Nokaschy 2008, and TREC 2007). While the purification of salty water is usually a costly process predicated on the water source's chemical and physical properties, evaporating water and condensing the vapor is considered a good choice. Several desalination technologies have emerged over the past few decades and solar desalination is recognized as one of the potential distillation methodologies due to its low energy consumption and less system complexity. A solar still is the most commonly developed device for solar desalination. The solar still designs are different based on the application and required study. In particular, single-slope solar stills (SSSS) are one of the most popular kinds of solar stills due to their ease of fabrication and simplicity. This technology, however, is still in the research and development stage due to its limited production rate. Hence, further enhancements are required to improve the daily output of the SSSS system (Srithar., 2018). The present study aims to test and examine the possibility of using solar energy to distill salty well water and the resulting supply of fresh water using two identical single-slope solar stills with different numbers of glass covers for the stills (single glass cover (SCSS) and double glass cover (DCSS).

2. Materials and Methods

2.1. Experiment's setup

2.1.1. Equipment used (single-slope solar still)

Single-slope solar distillater is one of the simplest devices that use solar energy, and it works and is used to desalinate underground brackish water and. Two identical single-slope solar stills were manufactured in the workshop of the Tractors and Agricultural Machinery Research and Testing Station - Alexandria, and tested during this pilot study for the desalination of brine (the salinity of well water is 15,000 ppm) . The four monoclinic of slope solar stills were directed east-west stationary with no sun tracking. Each single-slope solar module still contains many essential components; Basin and sides, reflector, cover glass (single glass and double glass), salt water inlet, desalinated water outlet, and fresh water collection water bowl as shown in Figure (1), and Figure (2) .The bottom and sides of the solar slope still form the water of the basin. The basin for water consists of an aluminum plate with a thickness of 2.0 mm and overall dimensions of 90.0 cm in length and 50.0 cm in width and 5.0 cm in height and a net size of 2.25 × 104 cm^3.

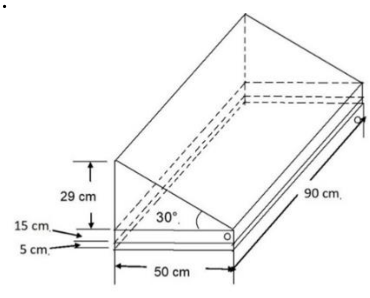


Figure (1) Schematic diagram of single-slope solar still

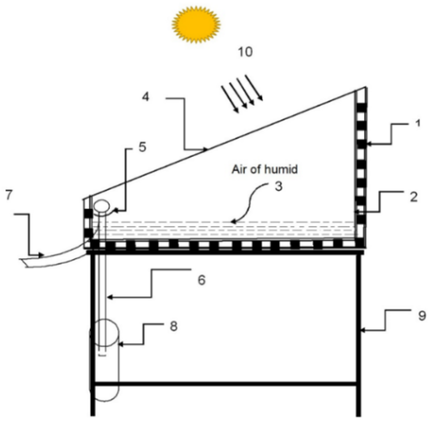


Figure (2) Different technical and effective components of solar distill.

No	Component
1	Insulation material
2	Trough
3	Saline water
4	Glass cover
5	Fresh water gutter
6	Outlet fresh water
7	Saltwater inlet
8	Tank of fresh water
9	Distiller holder

It defines the solar collector's absorbing plate when it acts as a solar absorbent panel. In order to increase the effective absorption of the solar radiation flux on the bottom of the basin water, the upper surface of the basin was painted with black matte paint. Under the aquarium there is a metal frame for fixing it, made of angle iron (2.5 × 2.5 cm). To prevent corrosion of the metal frame, it is coated with an excellent anti-corrosion paint. To provide and maintain brine feeding into the basin water, there is a 12.5 mm diameter PVC inlet tube that is positioned on the lateral side of the aquarium. To bring the portable condensed water (desalinated water) from the inner surface of the cover glass there is a galvanized semi-cylindrical gutter, 60 mm in diameter located just below the inclined inner cover, covered on one side open from the other side. Another 12.5 mm diameter PVC pipe was connected to the open side of the galvanized sheet metal gutter to collect the condensed desalinated water. One of the single-slope solar still with single cover glass, and one of the double cover glass. The angle of inclination of the glass cover was determined by calculating the average optimal angle of inclination for the year ($\beta_{o,ave}$), by calculating the average optimal angle for each month using the average day of the month (β_o), using the following equation, (ASHRAE, 2010):-

$$o, ave. = \frac{(\sum_1^{12} \beta o)}{12}, \quad \text{degree} \qquad (1)$$

$$\beta o = cos^{-1}[cos(\emptyset).cos(\delta).cos(\omega) + sin(\emptyset).sin(\delta)], \text{ degree} \qquad (2)$$

Where:- Φ = Latitude angle in Alexandria = 31.2°, δ = Solar declination angle

$$\delta = 23.45 \sin[0.9863(284 + n)], \quad \text{degree} \qquad (3)$$

n = Number of the average day of the month calculated for the year 365 day,

$$\omega = \text{Solar hour angle}, = (LAT - 12)15, \text{ degree} \qquad (4)$$

$$LAT = LST + (ET/60) + (LSM - LON)/15 \qquad (5)$$

Where: LAT = Local apparent solar time, decimal hours, LST = local solar time, decimal hours, ET = equation of time, decimal minutes, LSM = local standard time meridian, decimal degree of arc, and LON = local longitude, decimal degree of arc. The recommended Average day for May and June Months (15 and 11) respectively. And Values of (n = 135 and 162) by May and June Months and equation of time, decimal minutes (ET = 1.1 and 3.3) respectively, (ASHRAE, 2010).

2.1.2. Measuring and data recording unit

Data logger:- Arduino microprocessor unit (mega2560) and displayed on the liquid crystal display (LCD) were used for collecting, recording, and reading from the thermos-cable sensors (type K). Arduino Humidity and Temperature Sensor (DHT 22) with an accuracy of ± (1°C) at room temperature and 0 to 120°C temperature range) and with humidity range from 0 - 99 % with an accuracy of ± (1%).

Solar meter :- The most commonly used commercial radiometer in different countries is probably the Kipp and Zohne solar meter which is used in weather stations and field experiments for the measurement of radiation in the wavelength range of 0.3 to 3.0 µ. A typical instrument has an output of approximately 0.5 mV per 100 W/m^2.

Electrical conductivity (EC) meter :- To determine the electrical conductivity of saline water before distillation and water after distillation (fresh water), reference measurement are provide with device WTW-720 which is electronic device for laboratory measurement, is standard device for conductivity and temperature measurement in a laboratory conditions with a large multifunction display.

Acidity (pH) meter:- To determine the acidity of saline water before distillation and water after distillation (fresh water), a model Metter Toledo , Plus FP20 pH/mV Meters Compact, benchtop meter provides high quality pH/mV measurements with simple click of a button. Range (pH)0.00 to 16.00, resolution (pH) 0.01 and accuracy (pH) ±0.01.

The technical specification of the passive single-slope solar still and the factors that used in the computation are summarized and listed in Table (1). The heat energy transfer (q_{ec}) by evaporation-condensation can be calculated from the following equation. (Velmurugan et al., 2009; Kalidasa et. al., 2010; Duffie and Beckman, 2013; Kabeel et. al., 2017 and Abdellatif.,et al., 2020):-

$$q_{ec} = m_D A_b h_{fg}, \quad \text{Watt} \qquad (6)$$

$$m_D = 9.15 \times 10^{-7} h_{c,w-g} (P_{wb} - P_{wg}), \text{ kg/m}^2\text{s} \qquad (7)$$

Where: m_D= transfer rate of mass, kg/m^2 s, h_{fg} = Latent heat of evaporation of salt water, kJ/kg,

Table 1. Some technical specifications of single-slope solar still.

Category	Property	Value
trough	Absorptivity (α), decimal	0.90
	Surface area (A_b), m^2	0.45
	Specific heat (C_{pb}), J/kg ºC	900
	Density (ρb), kg/m^3	2698
	Thermal conductivity of insulation (k_i), W/m	0.04
	ºC	0.05
	Thickness of insulation (X_i), m	1.616
	Overall heat transfer coefficient (U_o), W/m^2 ºC	0.14
glass	Surface area of sides (Asides), m^2	3.0
	Thickness of glass cover, mm	30.0
	Tilt angle of cover surface, degree	0.05
	Absorptivity of glass (αg), decimal	0.95
	Effective transmittance of glass (τg),	0.90
	Emissivity of glass (εg), decimal	0.54
Saline	Surface area of glass cover (Ag) , m^2	0.05
water	Absorptivity of saline-water (α_w),	0.95
	Effective transmittance of water (τ_w),	0.96
	Emissivity of saline-water (ε_w),	0.40
	Surface area of saline-water (A_w) , m^2	4190
	Specific heat of saline-water (C_{pw}), J/kg ºC	1025
	Density of saline-water (ρ_w), kg/m^3	

The average latent heat (h_{fg}) in kJ/kg at an average trough water temperature (T_w) was calculated using the following equation (Kabeel and Abdelgaied, 2016 and Abdellatif, S. M.et al., 2020).

$$h_{fg} = 2501.9 - 2.40706\ T_w + 1.192217 \times 10^{-3}\ T_w^2 - 1.5863 \times 10^{-5}\ T_W^3,\ \text{kJ/kg} \quad (8)$$

Where: T_W = Temperature of salt water at interval time. °C, and $h_{c,w\text{-}}g$ = Convection heat transfer for a single-slope solar energy can be estimated as using equation:-

$$\eta_{th} = \frac{q_{ec}}{3.6RA_b\,(\tau\alpha)} \times 100, \% \quad (9)$$

Because of some distillated freshwater may be lost and back again into the basin by dripping from the cover surface or leakage from the collecting trough, therefore, the distillation efficiency can be calculated as follows:-

$$\eta_{th} = \frac{mh_{fg}}{3.6RA_b\,(\tau\alpha)} \times 100, \% \quad (10)$$

Where: m = the hourly distillated water (kg).

Throughout the duration of the experimental work (12 hour/m^2/day), the data were measured and stored in computer files in order to compute and analyze all previous equations statistically.

3. Results

Nowadays, the demand for drinking water production has developed greatly due to population increase and industrial growth. Therefore, desalination technologies are growing rapidly in order to meet these fresh water requirements. Although solar stills are simpler in design and require little maintenance and low operating experience, their freshwater throughput is limited. Among single-slope passive solar stills, their main processes of heating, evaporation and condensation occur naturally. There are two main parameters that affect the thermal performance and productivity of the single-slope solar still; the Design parameters (tilt angle of glazing cover, salt water depth), and environmental parameters (intensity of solar radiation , ambient air temperature, and wind speed). These parameters and their impact on the thermal performance and the yield of distilled water of the single-slope solar stills were studied by many researchers and discussed in the review of literature. However, there is no readily available information about these parameters and their impact on the thermal performance of monoclinic solar for long-term operation under different climatic conditions. The two identical solar stills under different design and satisfactorily operated under the environmental standards (the Preservation of the environment) without any failure during the long-term of experimental work.

3.1 Parameters Affecting Thermal Performance of Solar still

There are three different factors that affect the thermal performance and fresh water yield of a passive solar still. These general parameters are understood; Climatic conditions, which include the intensity of solar radiation, ambient air temperature, wind speed, depth of salt water in the solar still, and temperature of salt water. The rate of freshwater productivity will be directly proportional to the intensity of solar radiation and wind speed, and inversely proportional to the ambient air temperature.

3.1.1 Intensity of solar radiation

The flux of solar radiation incident on the solar stills is only the source of thermal energy needed to heat the salt water or any internal bodies of the solar still. Solar radiation incident inside the solar still mainly affects the tank material (black aluminum) and salt water temperatures, resulting in the thermal performance of the solar still including; Thermal efficiency and evaporation process efficiency. In this study, the brine desalination process was achieved using four identical single-slope solar stills during the period from 1st May to 30th June. During the brine desalination process, there were 660 hours of bright sunlight, of which 610 hours (92.42%) were measured and recorded and used in the distillation process during the experimental work. Table (2) and Figures (3) summarizes the hourly average solar radiation intensity which were measured and monitored on the horizontal and inclined surfaces outside and inside the solar stills throughout the four consecutive months.

The intensity solar radiation incident on a horizontal surface outside the solar stills in clear sky days gradually increased from the early morning hours until it reached the maximum values at around the noon, and thereafter decreased until reached its minimum values just prior to sunset. The hourly average intensity of solar radiation on horizontal and inclined surfaces and work were, respectively, 194.16 W (on May) and 225.54 W (on June) respectively.

Table (2): Hourly average solar radiation W/m^2 (SR_H), maximum, ion flux incident on horizontal surface outside (SR_{ho}) and inclined surf SR_i), reflected from back wall (SR_{ir}), and total (SR_{it}) inside the solar stil

Month		SR_H W/m^2	Solar Rad							
			SR_{ho}	SR_{io}	SR_i	SR_{ir}	SR_{Total}	$SR_{d,i}$	$SR_{d,ir}$	$SR_{d,Total}$
May	**Maximum**	740.96	333.43	378.82	359.88	412.98	772.86	341.89	392.33	734.22
	Minimum	69.624	31.33	35.34	33.57	14.27	47.84	31.89	13.55	45.44
	Mean	431.46	194.16	220.10	209.10	193.95	403.04	198.64	184.25	382.89
	SD	±238.39	±107.28	±121.97	±115.87	±144.79	±259.13	±110.08	±137.55	±246.18
June	**Maximum**	827.14	372.21	422.76	401.62	449.38	851.01	381.54	426.91	808.45
	Minimum	106.25	47.81	53.82	51.13	12.24	63.37	48.58	11.62	60.20
	Mean	501.21	225.54	255.66	242.88	223.79	466.67	230.74	212.60	443.34
	SD	±258.36	±116.26	±132.23	±125.62	±161.25	±285.19	±259.77	±262.04	±270.93
Average	**Mean**	432.82	194.77	220.62	209.59	178.99	388.58	199.11	170.05	369.15
	SD	±74.49	±33.52	±38.09	±36.19	±42.81	±78.59	±34.38	±40.67	±75.05

The hourly average solar radiation incident on the horizontal plane. The inclined surfaces outside the solar stills, inside the solar stills, reflected from the back wall, and the total available solar radiation inside the solar stills with different covers (single and double) during the two consecutive months were. 403.04 (±259.13), 382.89 (±246.18), 468.13 (±278.69), and 444.71 (±246.18), W, respectively. Thus, the aluminum back wall increased the available total solar radiation inside the solar stills on an average by 41.67%. While, using the tilt angle 30˚ resulting in increasing the solar radiation flux incident on the inclined surface with different covers (single and double) by 50.12% and 52.76 as compared with that incident on the horizontal surface respectively. The hourly average intensity of solar radiation varied from hour to hour, day to day, and month to month according to the climatic conditions, the solar altitude angle, and the solar incident angle as indicated in Table (2) and Figure (4). It was changed from 431.46 (±238.39) W, in May to 501.21 (±258.36) W in June.

Thereafter, it decreases its minimum values just prior to sunset. The hourly average intensity of solar radiation on horizontal and inclined surfaces varies from month to month as a result of changes in altitude and solar incidence angles, as shown in Table (2) and Figure (3). So, the lowest and highest hourly averages solar radiation flux incident on the horizontal surface outside the solar stills during the period of experimental work

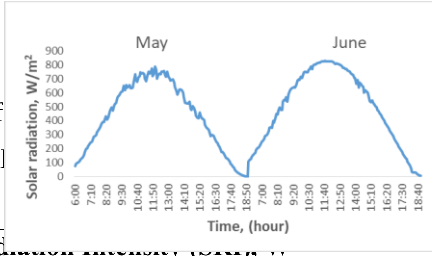


Figure (3): Direct incident solar energy on a horizontal surface outside the solar still (W/m^2)

3.2 First Experiment: The effect of the number of cover on the efficiency of the Single-slope solar still

The transfer of thermal energy via evaporation and condensation, thermal performance, distillation efficiency, and freshwater throughput rate in relation to the duration of the distillation process will generally be affected by the number of cover in the water basin. Two different covers of the solar still, a single cover and a double cover. The experiment was conducted from 1st May to 30th June, on two solar stills, the first a single cover and the second double cover with water salinities of 15023 ppm and pH 7. 6. During the experimental study, a depth of 2 cm (AbdelLatif. et al., 2020) of salt water was used for the sample (9 liters).

Table (3): Hourly maximum, minimum and average wind speed (V, m/s), ambient air temperature (Tao), solar altitude angle (Ψ), and solar energy available inside the solar stills (SRt, W) during this experimental work.

Month		**V, m/s**	**Tao, °C**	**Ψ, degree**	**S_{Rt}, W**	
					Single cover	**Double cover**
May	Maximum	4.65	27.10	78.52	772.86	734.22
	Minimum	3.87	18.46	9.08	47.84	45.44
	Mean	4.20	24.33	44.08	403.04	382.89
	SD	±0.25	±2.36	±22.97	±259.13	±246.18
June	Maximum	4.71	30.90	82.02	851.01	808.45
	Minimum	1.33	22.01	10.78	63.37	60.20
	Mean	3.58	28.03	45.83	466.67	443.34
	SD	±0.83	±2.54	±23.37	±285.19	±270.93
Average	Mean	3.89	26.18	44.96	434.86	413.12
	SD	±0.64	±2.45	±23.17	±272.47	±258.85

The intensity of available solar radiation outside and inside the solar still, air temperature, and wind speed blowing over the solar stills varied from day to day, cover temperature of solar still, brine temperature, and distilled water rate. The hourly average wind speed, ambient air temperature, and solar energy available of months from May to June are Summarized and included in Table (3).

The hourly average total solar radiation available inside each of the solar still (single cover and double covers) was 403.034, 382.89, 466.67 and 443.33 W, respectively, with an average of 392.96, and 455 W, respectively. These variations occurred due to increasing the solar altitude angles from May (44.08 ±22.97) to June (45.83 ±23.37). Solar radiation varied from hour to hour, day to day, and month to another during the experimental period as clearly revealed in Figure (4). Because of the intensity of solar radiation is only the main source of heat energy utilized in heating and evaporation of saline water, the temperatures of black basin plate and saline water were increased and decreased as well as the intensity of solar radiation.

The hourly average temperatures of black basin, saline water, cover surface, and the latent heat of evaporation of saline water, thermal performance efficiency, distillation efficiency, and daily average productivity of freshwater for the two different covers, and two different water salinity during this experimental work (from 1st May to 30th June) are depicted in Table (4).

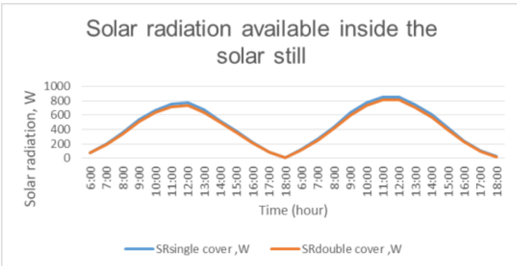


Figure (4): Solar radiation available inside the solar still during the first experiment

As the thermal energy absorbed by the saline water in the basin increased, this led to an increase in the water temperature depending on the intensity of solar radiation available inside the solar stills. The black basin temperatures of the two different covers and the different water salinities of the salt water during this experiment were gradually increased from 6:00 a.m. until reaching the maximum values at 1:00 p.m, thereafter, these temperatures decreased slowly. Therefore, the hourly average salt water temperatures for the two different stills (single cover, and double cover) of saline water were augmented from 21.56 to 68.86˚C, and 22.97 to 73.96 ˚C at those times, respectively. Accordingly, the black plate temperature was increased by 47.3, and 50.99 ˚C during the daylight time for the two different Single-slope solar stills, respectively. Consequently, the black plate temperature underneath of double cover of saline water was highly increased by 7.70 %, as compared with the other still (single cover).

The hourly average black basin temperatures for the two different solar stills of saline water, respectively, were augmented from 44.95 ˚C (±13.79) to 48.46 ˚C (±13.43), and 48.10 ˚C (±14.84) to 51.85 ˚C (±13.43) during May and June, respectively, as shown in Table (4). Accordingly, the differences in salt water temperatures between the beginning and end of the experiment increased by 3.51, and 3.75˚C for the two different solar stills, respectively. These variations occurred due to the increase in intensity of solar radiation. The hourly average black basin temperatures during this experiment for the two different solar stills of saline water were 46.70 ˚C (±13.61), and 49.98 ˚C (±14.14), respectively. Although each one of solar stills received the same intensity of solar radiation, there were differences in black panel temperatures during this experiment due to the difference in the number of covers between the two solar stills. As the number of covers increased the plate's ability to retain heat energy increased, and its temperature then increased.

The thermal energy absorbed by the black plate under the salt water was transferred by natural convection to the water, causing its temperature to rise. During this experiment, the temperature of the salt water for the two different cover numbers and the salinity of the brine were gradually increased from 6:00 a.m. until the maximum values a1 were reached at 1:00 p.m., thereafter, these values tend to decrease slowly. Accordingly, the average hourly brine temperatures of the two different solar stills, SCSS and DCSS, were increased from Salty water from 19.86 ˚C to 64.86 ˚C, and 21.40 ˚C to 69.89 ˚C at those times respectively. Therefore, the salt water temperatures were increased by 45.00, and 48.49 ˚C during those times for the two different solar stills, respectively. Consequently, the salt water temperature with single still (double cover) was highly increased by 7.02 % as compared to SCSS.

These differences between the two solar stills were occurred due to the differences in heat loss from inside to outside the solar still, which can be attributed to the difference in the number of covers. The temperature of the brine in the two solar stills was rose rapidly after sunrise until it reached its maximum value at the afternoon period, then gradually decreased and remained higher than the ambient air temperature by about 2 - 3 ˚C until after sunset. Noting that, the brine in the DCSS remained higher than the SCSS from sunrise until after sunset.

The hourly average salt water temperatures for the two different number of cover and Water salinity, respectively, were augmented from 41.82(±13.04) to 45.09 (±12.37), and 45.06(±14.05) to 46.59 (±12.77) ˚C from 1st May to 30th June months, respectively as shown in Table (3). Accordingly, the differences in salt water temperatures between the beginning and end of this experiment increased by 3,27, and 3.53 ˚C for the two different cover of salt water, respectively. These differences are due to the increased intensity of solar radiation. The hourly average salt water temperatures during this experiment for the two different solar stills of salt water were 43.45 (±12.71), and 45.82 ˚C (±13.41), respectively.

Despite the same intensity of solar radiation (432.82W ±74.49) was received by the two solar still, there were differences in brine temperatures due to retention thermal resulting from the number of covers between the two solar stills. The salt water temperature for DCSS was higher than that of the SCSS by about 3.12˚C.

The surface temperatures of the solar stills' cover were strongly affected by salt water temperatures, wind speed, ambient and number of cover. Therefore, the lowest and highest cover temperatures for the two different covers of brine occurred during 1st May to 30th June months, respectively, as the hourly average ambient air temperatures during 1st May to 30th June, respectively, were 24.33(±2.36) and 28.03 ˚C (±2.54).

Table (4): Hourly maximum, minimum and average temperatures of basin (Tp), brine (Tw) glass cover (Tg), latent heat of evaporation (hfg), thermal efficiency (ɳth), distillation efficiency (ɳ) and daily maximum, minimum and average productivity rate of fresh water (m) for the four different stills.

Month	Type of Solar still		T_p, °C	T_w, °C	T_g, °C	h_{fg}, kJ/kg	$ɳ_{th}$, %	ɳ, %	m, ml/m^3/d
May	Single cover	Maximum	67.70	63.70	31.5	1500.76	87.17	67.4	2178.00
		Minimum	21.56	19.86	19.00	1220.97	6.75	6.30	1723.00
		Mean	44.95	41.82	27.99	1365.16	48.39	53.35	1912.00
		SD	±13.79	±13.04	±3.52	±83.24	±31.48	±15.40	±163.00
	Double cover	Maximum	73.45	68.66	33.27	1491.80	92.85	62.45	2067.00
		Minimum	22.97	21.40	20.09	1186.04	7.19	5.86	1709.00
		Mean	48.10	45.06	29.60	1143.99	50.05	45.66	1833.00
		SD	±14.84	±14.05	±3.72	±90.98	±33.59	±14.63	±198.00
June	Single cover	Maximum	68.86	64.86	32.55	1455.69	91.78	69.63	2363.00
		Minimum	28.27	26.93	24.82	1212.12	13.28	11.63	1883.00
		Mean	48.46	45.09	29.70	1344.00	48.88	55.46	2074.00
		SD	±13.43	±12.37	±2.75	±84.08	±29.47	±13.23	±198.00
	Double cover	Maximum	73.96	69.89	33.87	1446.64	94.07	67.61	2206.00
		Minimum	30.15	29.02	26.23	1177.20	14.53	12.13	1761.00
		Mean	51.85	46.59	31.41	1321.38	52.68	54.36	1945.00
		SD	±13.43	±12.77	±2.75	±84.08	±30.31	±13.43	±189.00
Average	Single cover-	Mean	46.70	43.45	28.85	1354.58	48.63	54.41	1993.00
		SD	±13.61	±12.71	±3.14	±83.66	±30.41	±14.32	±180.50
	Double cover	Mean	49.98	45.82	30.55	1332.68	51.37	50.01	1889.00
		SD	±14.14	±13.41	±3.23	±87.53	±31.84	±14.03	±193.50

The hourly average cover temperatures during May for the two different solar stills (single cover, and double cover) of salt water were 27.99 (±3.52), and 29.60 ˚C (±3.72), respectively. The average temperature difference between the brine and the cover surface during May for the two different solar stills was 13.83, and 15.46 ˚C, respectively.

Whereas, these differences for two different solar stills during the Junewere 15.39, and 15.19 ˚C, respectively,

The hourly average temperature difference between the cover surface and the ambient air for different solar stills of salt water during June were 1.67, and 3.38 ˚C, respectively. As a result of these differences of the different temperature between the brine and the cover, the ability to transfer thermal energy through evaporation - condensation, and then the productivity rate of fresh water with one cover, (the smallest temperature difference between of the cover and salt water) than salt water. It was higher than that of other solar still.

The thermal efficiency of a single slope solar still is the product of thermal energy transfer by evaporation-condensation and the latent heat of evaporation of brine divided by the solar energy available inside the solar still (input Thermal energy). The latent heat of evaporation of water is inversely proportional to the temperature of the saline water. It was changed with respect to the time as the salt water temperature changed. Therefore, the hourly averages latent heat of evaporation of water for the two different solar stills during this experiment, respectively, were 1354.58 (±83.66), and 1332.68 (±87.53) kJ/kg. The thermal performance efficiency for the two solar stills with different single slope solar stills of cover during May and June are showed in Figure (5).

. The thermal efficiency for the two solar stills varied with respect to the solar time. It was changed from hour to hour, day to day, and month to month according to changes in environmental factors (solar radiation intensity, wind speed, and ambient air temperature) and experimental factors (number of cover, water salinity, and temperature). It was observed that the thermal performance efficiency of the two solar stills was increased from 6:00 AM until the high level which was identified at 1:00 PM for the two solar stills during May month. Due to the thermal energy stored in the salt water, while the highest thermal performance efficiency values for the two different solar stills were achieved at 2:00 PM during June as shown in Figure (5).

The hourly average thermal performance efficiency for the two different solar stills of salt water, were increased from 48.39 % (±31.48) to 48.88 % (±29.47), and from 50.05 % (±33.59) to 52.68% (±30.31) from May to June months as listed in Table (3). These differences in thermal performance efficiency occurred as a result of differences in salt water temperature between the two different solar stills and as a result of increased solar radiation intensity. The hourly average thermal performance efficiency of the two different for covers of the single-slope solar stills during this experiment were, respectively, 48.63 % (±30.41), and 51.37 % (±31.84) as listed Table (4). Therefore, the thermal performance efficiency of the double cover of single-slope solar stills was higher than that of the other solar still by 5.63 %. This is due to the increase in retention thermal, which is directly proportional to the increase in the number of covers.

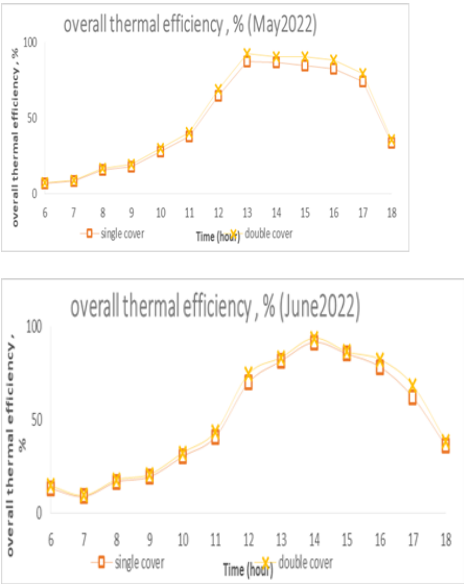


Figure (5): Hourly average thermal performance efficiencies for the two different number of glass covers for salt water during this experiment

The hourly average of the distilled yield in mm during the day light-time for the two different number cover during May and June is plotted in Figure (6). It was augmented gradually from 6:00 Am until reached the higher level at 1:00 Pm when salt water temperatures reached maximum values at that time for two different cover and salinity numbers, they decreased after that. From Figure (6) , it was observed that the maximum values of distillated yield was achieved at 1:00 pm increased from 124.41 to 133.83 ml/h, and 108.27 to 115.51 ml/h, from May to June for the two different number cover and water salinity, respectively. These variations occurred because of the increasing in the intensity of solar radiation from 403.04 (±259.13) to 434.86 (±272.46) W, for single cover and from 382.89 (±246.18) to 423.12 (±258.85) W, in DCSS, and consequently, the brine temperatures were increased. The productivity of fresh water that were distillated from the two identical solar stills with two different number cover, salt water is strongly affected by the intensity of solar radiation, temperature of salt water, still cover temperature, ambient air temperature, and wind speed. The productivity of freshwater distilled in ml / m^2/ day during this experiment varied from day to day. And months to another. The productive the accumulated distilled yield for the two solar stills, SCSS and DCSS,during this experiment, respectively, were augmented from 1912.00(±163.00) to 1974.00 (±198.00), and 1833.00 (±198.00) to 1845.00 (±189.00) ml/m2 /day from May to June. These variations in the accumulated distilled yield between May to June were occurred because of the increasing in solar radiation intensity and salt water temperatures. Therefore, the accumulated distilled yield of fresh water for the two different number covers, were increased from May to June by 162.00 and 112.00 ml/m^2/day. The average daily accumulated yield for the two solar stills, SCSS and DCSS during this experiment were 1993.00 (±180.50), and 1889.00 (±193.50) ml/m^2/day, respectively. In the light of the above, the SCSS increases the productivity rate by 10.84% as compared to DCSS. Accordingly, the productivity of distilled water decreases as the number of covers for the solar still increases.

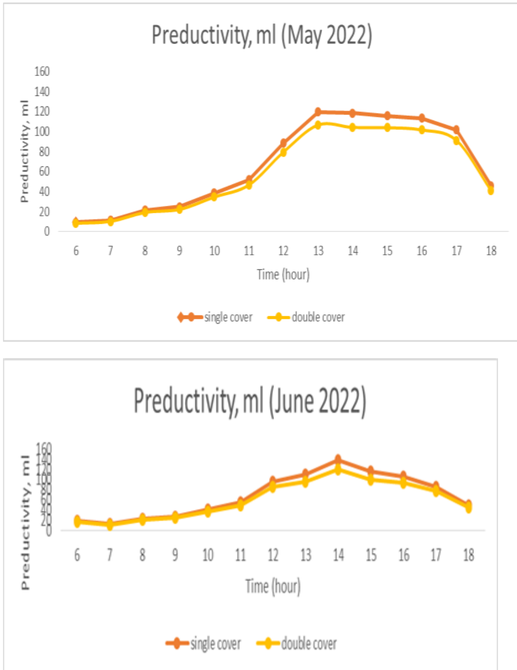
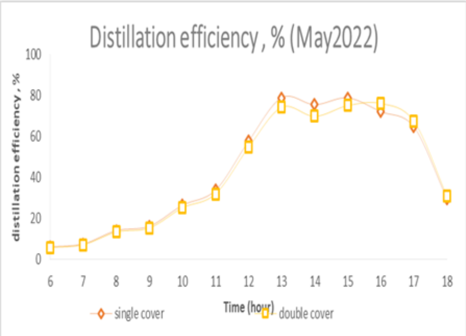


Figure (6): Hourly average productivity for the two different number of glass covers for brine during the present experiment.

The daily average distillation efficiency for the two solar stills, SCSS and DCSS, during this experiment, respectively, were incresed from 53.35 % (±15.40) to 55.46 % (±13.85), and from 45.66% (±14.63) to 54.36 % (±13.43) from May to June. These variations in the distillation efficiency between May and June were can be attributed to the reasons mentioned above.

So, the distillation efficiency for the two solar stills, SCSS and DCSS,were increased by 2.1 %, and 8.70 % from May to June. It was observed that, the differences between the thermal performance and distillation efficiency diminished with respect to the time from May to June as listed in Table (4). From Figure (7), it was observed that the distillation efficiency increased gradually from the lowest value at 6:00 am until reached to maximum values at 1:00 pm during May and 2.00 pm for June. This phenomenon occurred because of the intensity of solar radiation was increased during June month, and consequently the brine temperatures as compared to the month of May.



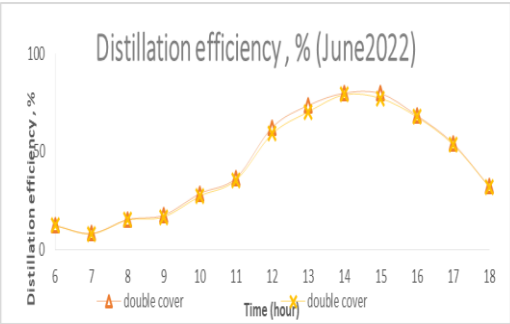


Figure (7): Hourly average distillation efficiencies for the two different number of glass covers for salt water during this experiment.

4. Discussion

The water obtained through the distillation process is free from pathogens and constitutes a valid source of safe drinking water which also eliminates heavy metals, salts, etc. Solar distillation could provide a practical solution to the potable water for the people living in remote and isolated areas in Egypt, and other low-resource countries where only brackish or salty water is available for most of the year.

The solar still may be preferable on a local scale since community systems in isolated villages providing piped water to individual homes are not practical. It is clear from the results that with increasing of solar energy intensity, the rate of fresh water production increases, and this result is consistent with (AbdelLatif et al., 2020).

The double glass cover was used in attempt to raise the temperature of brine, but it turned out that as a result of the heat being trapped, the temperature of the inner glass cover rises, which leads to fresh water refluxing into the distillation basin.

5. Conclusions

Based on the obtained results from the present study, the following conclusions can be pointed out as:

(1) Using the tilt angle of 30º for the solar still cover resulting in an increment in the incident solar radiation flux by 76.19% as compared to the incident solar radiation on the horizontal surface.

(2) The black basin temperature inside of the single-slope solar still of double cover was higher than that of the other single-slope solar still of single cover by 6.8% , while, the brine temperature with single-slope solar still of double cover was higher than that of the single-slope solar still of double cover by 5.5%.

(3)The potential differences in the temperature between the cover surface (DCSS) and the ambient air, , were 4.37, and 2.67ºC, respectively. This is can be ascribed to the increase in retention thermal, which is directly proportional to the increase in the number of covers.

(4) The hourly average thermal performance efficiencies for the two different cover of single-slope solar stills (double cover and single cover), respectively, were 51.37%, and 48.63%. So, the thermal performance efficiency for the single-slope solar still of double cover was higher than that of the single-slope solar still of single cover by 6.25, respectively, due to the higher retention thermal.

(5) The hourly averages distillation efficiency for the two different single-slope solar stills, SCSS and DCSS, during this experiment were 50.01%, and 54.41%, respectively.

(6) The daily average productivity for the two single-slope solar stills of , SCSS andDCSS, 1889, and 1993 ml/m2/day, respectively. So, the single-slope solar still with single cover increased the productivity by 5.5% as compared to the other single-slope solar still with the double cover. The lowest productivity rate in the single-slope solar still with double cover occurred because the temperature of the inner cover rises and water condenses from the cover and returns to the basin.

(7) The total soluble salt in well water used in the present study decreased significantly from 15023 ppm to 50.8 ppm as distilled fresh water.

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