RESEARCH ARTICLE OPEN ACCESS

NEW VALLEY JOURNAL OF AGRICULTURAL SCIENCE
Published by Faculty of Agriculture, New Valley University, Egypt

Print ISSN 2805-2420 Online ISSN 2805-2439

10.21608/NVJAS.2024.243002.1259

Evaluation of the Thermal Performance of a Single Slope Desalination Unit Using Sensible Heat Storage Materials

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Received: 17/12/2023
Revised: 11/05/2024
Accepted: 22/05/2024
Published: 01/06/2024

Abstract

Desalination can be used to raise the quality of water with desalination units. To improve productivity and yield of a desalination unit with a single slope can used sensible heat storage medium. At the Faculty of Agriculture, Agricultural Engineering Department, Suez Canal University, Egypt (latitude angle of 30.62ºN and longitude angle of 32.27ºE), four identical units of single-slope desalination units are designed. The unit is composed of basin with a 1 mm galvanized sheet construction with a 1.04 m2 net surface area, 0.1 m depth. The main condensation surface is a 3 mm transparent glass with a 31 ° angle on the horizontal facing south. The four units were fed with brackish water from the Suez Canal. Black granite, concrete stone and gravels were selected as a sensible heat storage material, which can store the largest amount of solar energy at different quantities (10, 15 and 20 kg). The findings of the experiment demonstrated that compared to conventional desalination units, the average daily production the clean freshwater content of desalination units equipped with sensible heat storage materials was higher.

Keywords: Desalination; Sensible heat storage; Single-slope desalination units; Solar energy; Brackish water

Introduction

Scientists have become more and more interested in the idea of the water-energy nexus in recent years as they try to determine the kinds of policies required to achieve the goals of sustainable development. The biggest obstacles to meeting fundamental necessities for humans are the increasing global population and the need for energy and freshwater. (Abdelkareem et al., 2018). To provide some context, a newly released research (UN WWDR 2020) estimates that 5.7 billion people will be affected by the freshwater crisis by the year 2050, up from the current estimate of 3.7 billion. (Ahmed et al., 2019). The capacity of desalination installations worldwide is rapidly rising between 2018 and 2022 at a pace of 9% acceleration, with the Middle East and Europe accounting for 74% of the growth (Ghorbani et al., 2020). Saltwater desalination is done to make up for the lack of freshwater availability. Different energy sources, including renewable and fossil fuels, are used in the desalination process. (Kavvadias and Khamis, 2014). Fossil fuels have been restricted in recent years due to their environmental issues and nature of depletion. (Elfasakhany and Mahrous, 2016).

The applications of desalination use renewable energy. One of the most common renewable energy sources is solar energy for desalination. When compared to other distillation techniques, solar distillation offers the most straightforward and appealing process. (Chaichan and Kazem, 2015). Solar radiation is a source of heat energy where saltwater or seawater evaporates then condenses as pure water. Active and passive stills are the two main categories of desalination units. (Sadineni et al., 2008). The basic principle of solar distillation is to evaporate brackish water using solar radiation as a heat source, condense the fumes on a glass, then gather the clean water from the condensed water. To create drinkable water via sun distillation, a desalination unit is used. This gadget is inexpensive and can be made of easily accessible materials. Following that, on an inclined glass surface, water vapor condenses, allowing clean water to flow into a collecting container. (Saito et al., 2014). Solar energy is used in a single basin desalination unit to produce drinking water from brackish or wastewater. It is possible to make with materials that are easily accessible locally. Additionally, its upkeep is inexpensive and only needs unskilled labor. (Abaas, 2005). However, it is challenging to use due to its low productivity. (Chaichan et al., 2012). One of the main issues with solar desalination is that it cannot operate continuously at night because of a lack of solar radiation, which leads to a shortage of clean freshwater supplies. (Zhang et al., 2013). The utilization of thermal energy storage systems to boost the energetic effectiveness of various applications has grown to be an important issue in the world of energy. (El-Sebaii et al., 2009). This study's primary objective was to use sensible heat storage materials (gravel, concrete stone, and black granite) to increase the output and efficiency of the single-slope desalination unit.

Materials and Methods

Experimental setup

Experiments were implemented on the four similar single sloped desalination unit units during the period from the 28th of July 2017 till 8th August 2017. The desalination unit were constructed and evaluated in the agriculture engineering department Faculty of Agriculture, Suez-Canal University in Ismailia, Egypt where (Latitude: 30.62°, Longitude: 32.27°, and Altitude: 17 m) Agricultural Engineering Department. Each desalination unit consists of wooden box, galvanized basin, glass cover, sensible storage material (black granite, concrete stone and Gravels). The desalination unit's rectangular basin has a surface area of 1.04 m2, it was built of galvanized iron sheet, and has overall measurements of 1.30 m long by width 0.80 m by depth 0.10 m. To optimize the solar energy absorbed, it’s coated in paint a matte dark color over a red-lead primer. Solar desalination unit has clear glass covering with a thickness 3 mm clear glass covering and is angled at a 31° horizontal plane to send out the most amount of incident flux incident of solar radiation on it as displayed in Figures (1, 2). Since silicone rubber can allow the expansion and contraction of materials that are different from one another, it serves a critical role in promoting condensation's effective operation where the glass cover is sealed using it. Each still has a supporting structure constructed of iron posts. Each of the galvanized basins had a wooden box attached to the outside that had the same shape as the basin but somewhat bigger in size in order to lower loss of heat from the bottom, sides and perimeter of the basins. In the gaps between each wooden and galvanized sheet, Thermal conductivity of Styrofoam with thick 70 mm is (= 0.04 W m -1K -1) for the outside walls and with a bottom layer of rock wool thickness 0.02 m where (thermal conductivity = 0.0346 Wm-1K-1). The four stills faced south and were set up on a suitable steel structure.

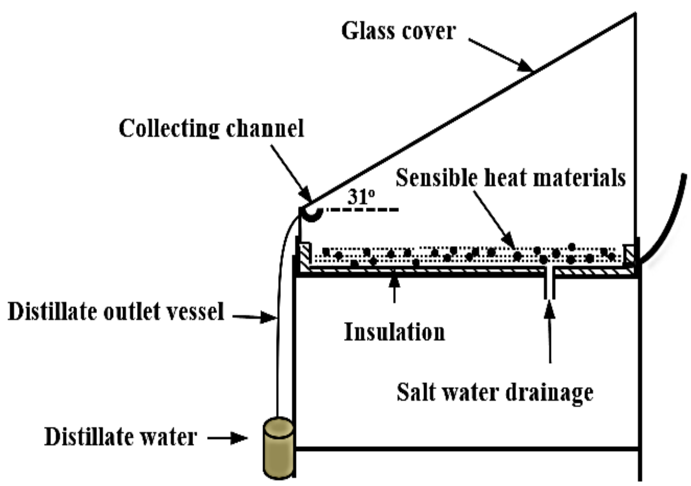

Figure (1): Schematic representation of the desalination unit experiment

Figure (2): Four solar desalination unit with and without solar storage materials

Heat storage system consists of black granite, concrete stone and gravels were used as sensible heat storage materials to increase and reinforce the productivity and thermal efficiency of solar collectors. It was placed in the still basin at a rate of 10, 15 and 20 kg as shown in Figures (3). First solar desalination unit was utilized not contain any storage material as a unit of control. Second solar desalination unit was used contain black granite as a storage material with mass of 10, 15 and 20 kg. Third solar desalination unit was used contain concrete stone with mass of 10, 15 and 20 kg. Fourth solar desalination unit was used contain gravels (10, 15 and 20 kg) placed over different days. Each amount of these different materials is placed for seven days with a constant quantity and depth of water and all-weather conditions prevailing. Thermo-physical features of sensible heat storage materials are listed after summarizing in Table (1) (CCR, 2001).

Table (1): Physical properties of the various materials which used as sensible storage materials

Materials	Thermal conductivity, (k), $Wm^{-1}K^{-1}$	Density, (ρ), kg m^{-3}	Specific heat, (Cp), J kg^{-1} K^{-1}	Thermal diffusivity, (θ), m^2 sec^{-1}
Black granite	2.9	2650	900	1.21×10^{-6}
Concrete stone	0.96	1800	1000	5.33 x 10-7
Gravels	0.36	1840	840	2.33×10^{-7}

(k) The thermal conductivity, (ρ) density, and (cp) the specific heat were used to determine (θ) the thermal diffusivity for the thermal storage materials according to the subsequent equation (**Incropera and Dewitt, 1996**).

$$\theta = \frac{k}{\rho\, c_p}$$

For the three investigated storage materials categories, the thermal diffusivity was found to be 5.33×10^{-7}, 1.21×10^{-6} and 2.33×10^{-7} m^2s^{-1} for the concert stone, black granite and gravel, respectively.

(a) (b) (c)

Figure (3): Sensible heat solar storage materials (a) black granite, (b) concert stone and (c) gravel

Methods

During operating the desalination units, the water depth was kept at 2 cm (i.e., 20 liters for each still basin). the black granite, concrete stone and gravels were used as sensible storage materials. During the experiment, solar radiation was transmitted through the glass cover and absorbed by both the brackish water and the storage materials. Part of the absorbed energy by the storage material transferred by convection to the brackish water. Another part of the solar heat energy was used to heat storage materials. where solid materials (black granite, concrete stone and gravels) were heated during the daytime. When the absorber surface temperature is lower than that of the solid materials (prior to sunset), reverse process occurs (discharging process) till solid materials lose the heat temperatures.

Suez Canal salinity water which is used as a desalination unit feed estimate of 32000 ppm. Experimental work was carried out on successive days during August month of 2017 Measurements were carried out for 24 hours from 7 am local time (after sunrise) of the next day. The yield from the still was collected and measured everyone hour during the day time and after sunshine the total condensate water was collected.

Overall thermal efficiency of the desalination unit

The daily average overall thermal efficiency (ηd) for the desalination unit was computed based on the daily average condensate production (M in kg), latent heat (L in kJ/kg) at an average basin water temperature (Tw), daily average incident solar radiation (I in W/m2), surface area of the desalination unit (A in m2). The overall thermal efficiency of desalination unit is calculated using the following formula Kantesh (2012)

The average latent heat (L) was determined by Kabeel and Abdelgaied, (2016) as follows:

L = 10 – 3 (2501.9 – 2.40706 Tw + 1.192217 x 10 – 3 Tw2 – 1.5863 x10 – 5 TW3)

Measurements

Above the Agricultural Engineering Department's roof has been put a meteorological station (Vantage Pro 2, Davis, USA) to measure various macroclimate variables such incident solar radiation (pyranometer), ambient air temperatures, and wind speed. In order to measure the temperatures at different sites in each desalination unit system (basin water temperature, Tw; vapour temperature, Tv; and interior glass temperature, Tg), eight thermocouples with a range of 0 to 100oC and an accuracy of 0.1oC were used. For the purpose of displaying and logging the data during the trial period, these sensors were connected to a data-logger system (Lab-Jack logger, USA). Using the data logger system, the output data were averaged every hour and logged every 10 minutes.

Results and Discussion

Black granite, concrete stone and gravel has been used as solar storage materials for storing solar thermal energy in the form of sensible heat storage materials. These materials were used in quantities of 10, 15 and 20 kg for each still. Throughout the experimental periods, average ambient air temperatures was31.5ºC every hour, while average hourly solar radiation flux located on the horizontal plane outside the desalination unit were 546.7 W m – 2. Average hourly wind speed throughout the same periods was 1.6 m s - 1.

Firstly: 10 kg storage materials

Three different solar storage materials (black granite, concrete stone and gravel) were studied and examined during the period starting on the 1st of August 2017 until the 7th of August 2017. During this period, solar radiation intensity available inside the desalination units, prevailing air temperature, and wind speed blowing over the desalination units fluctuated from day to day and from hour to hour. After putting in 10 kg of each black granite, concrete stone and gravel in three desalination units in addition to the control unit (without storage materials) and all units contain an equal amount of saline water (20 liter). Then average hourly located solar radiation on outside the desalination unit, temperatures (saline water, glass cover and water vapour) and the productivity of distillates was measured and recorded at the same time everyone hour and will be displayed gradually.

Solar radiation flux located on the desalination units is only the source of thermal energy needed for heating either the saline water or any inside objects of the desalination unit. Incident solar radiation inside the desalination unit in essentials affects the basin material (black galvanized steel), the saline water temperatures, and consequence the thermal performance of desalination unit. Figure (4) shows a plot of the hourly average incident solar radiation and the hourly average ambient air temperature. The hourly average solar radiation intensity progressively grew from sunrise until noon, when it peaked, and then gradually fell until just before sunset, when it was at its lowest level. It is noticed from shown Figure (4) the lowest and highest averages per hour solar radiation flux located on horizontal surface outside the desalination units during the experimental work, respectively, were 107 W m-2 at 6 PM and 828 W m-2 at 12 PM. During the experimental tests, the average hourly 1.8 incoming solar radiation was 523.8 W m – 2, whilst the average hourly air temperature outside the desalination units was 31.1 ºC under the average wind speed m s-1.

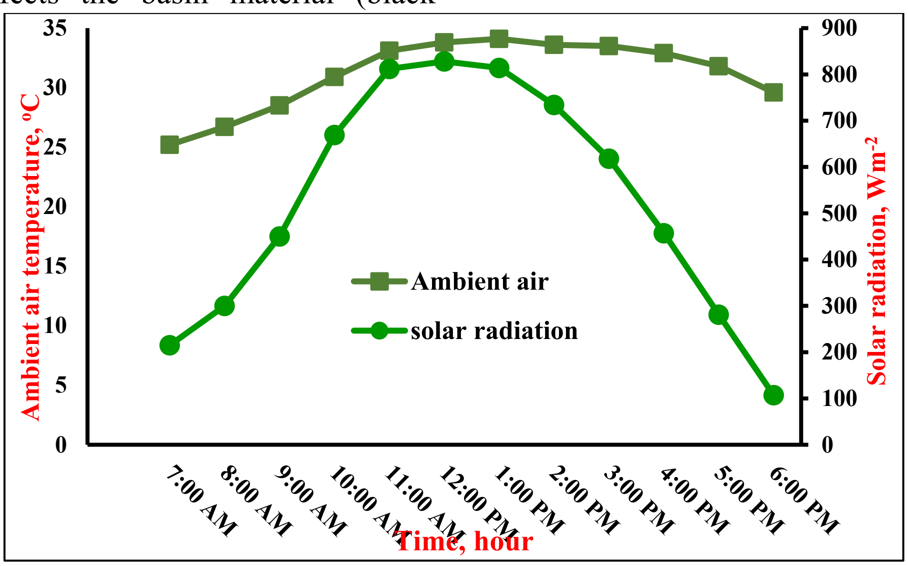

Figure (4): Average solar radiation and temperature of ambient air through hourly sunlight time from the 1st August till the 7th August 2017

Average temperature of saltwater for daytime under distillation units with and without storage materials are shown in Figure (5). Such as the thermal energy that the basin's black plate absorbs increased this resulted in a rise in the temperatures of plate and saline water inside the desalination units based on the amount of solar radiation that is available. It was noted that, Saline water temperature reached its highest levels at and around the solar noon. This happened based on the amount of solar radiation present. From Figure (5) it is noticed that within the daytime hours are 7 morning–12 afternoon (the charging and storing period) average saltwater temperature under the distillation unit contain less storage materials increased rapidly compared with the average saline water under the solar with storage materials. In the afternoon (the time when heat is being released and evaporates) The heat that had been stored left the storage materials to saltwater. It is seen from Figure (5) that the saline water inside control still cooled faster than the other desalination units combined storage materials. As within this period average saline water temperature decreases in the opposite direction from when it is heating or charging (from 7 AM to 12 PM). The basin water's evaporation rate increased as a result. Additionally, it was noted that the highest temperatures of salinized water for the desalination units without storage materials (control), with black granite, with concrete stone and with gravel values were 65.2, 66.3, 66.4, and 66.6°C, obtained at solar noon, respectively, as a result of the highest quantity of solar radiation absorbed at that particular moment. Due to rising loss of heat energy from the desalination units into the ambient environment by convection in the afternoon, The temperatures of saline water for the four desalination units decreased, especially when the temperatures of water were higher than the rate of absorbed solar radiation. The four desalination units' respective average hourly temperature of saltwater were 46.0, 48.9, 49.8, and 51.6 o C. The desalination unit with gravel produced the highest hourly average saline water temperature during the day. One of the most crucial factors that significantly affects the quantity of clean freshwater is the saline water temperature. alternatively, it can be said that the solar storage materials raised the temperature of saline water by 6.2, 8.3 and 12.2 % above that without storage materials if the black granite, concrete stone and gravel storage materials were each fastened to the desalination unit. This is because solar storage materials capture and hold solar energy during the day and release it during the late afternoon and evening.

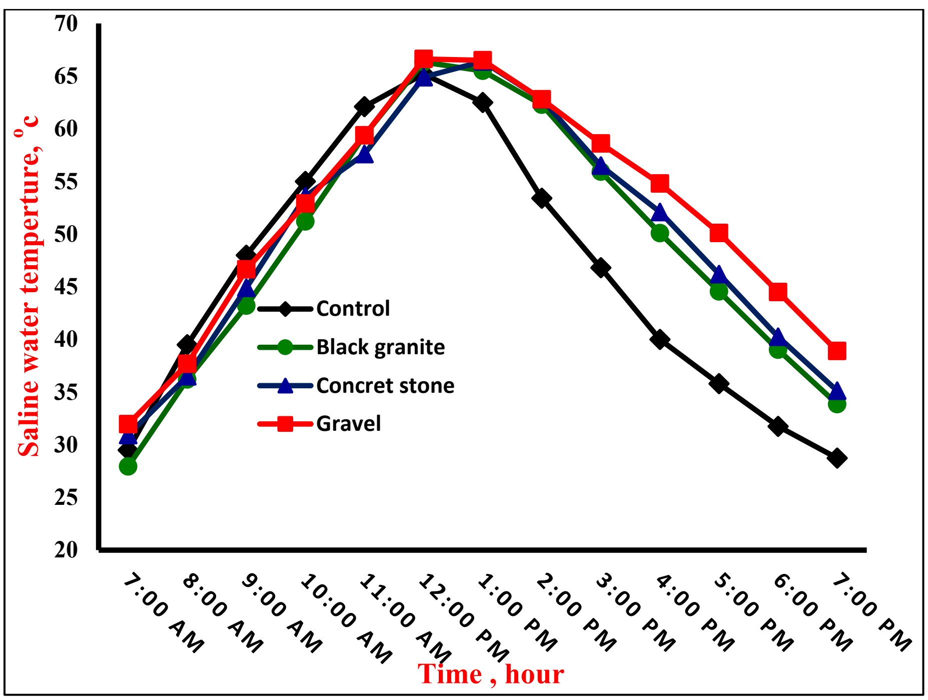

Figure (5): Average hourly temperatures of saline water for the desalination units with 10 kg storage materials

Figure (6) displays the relationship between the solar storage materials into the desalination unit and the hourly average water vapour temperatures. Because of the fact that water vapor particles have sufficient thermal energy to comprise sensible heat to evaporate, the temperatures of the water vapor were the maximum temperatures of operating of the four different desalination units. It was evident that by 12 o'clock the temperatures of the water vapor were their highest levels. Figure (6) obviously reveals that, water vapour temperature inside desalination units with storage materials temperature after 12 PM (discharging period mode) was continuously higher than the water vapour temperature under the desalination unit without storage materials It is noted that the four desalination units' respective average hourly temperature of water vapor were 52.1, 54.4, 55.8 and 57.2ºC. In Figure (6) it demonstrates that, the average temperature of water vapour under the desalination units comprised 10 kg storage materials increased by 4.4, 7.1 and 9.7 °C for the solar with black granite, with concrete stone and with gravel, respectively.

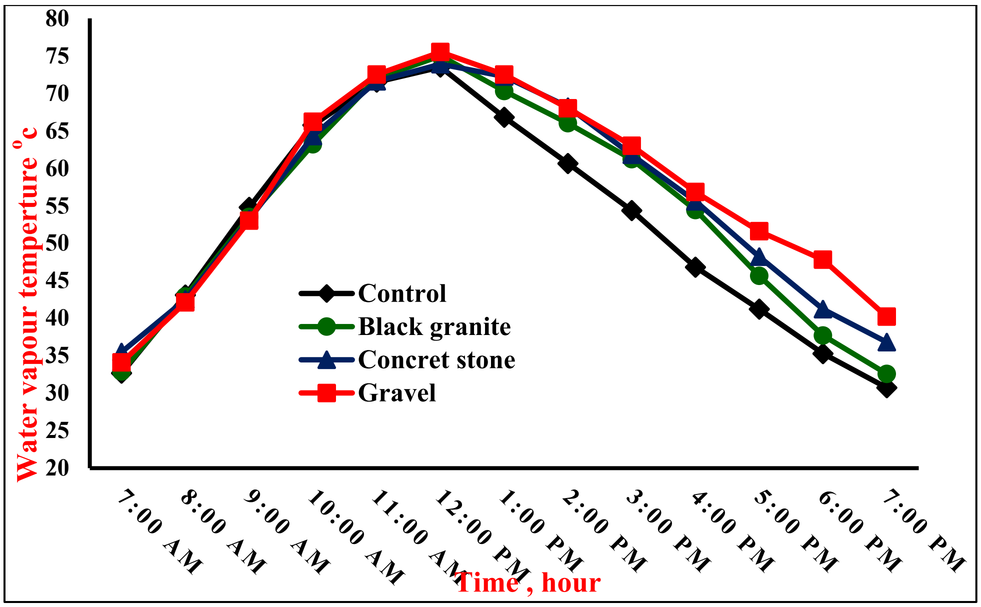

Figure (6): temperature of Water vapour for the four desalination units with 10 kg storage materials versus solar time

Figure (7) shows the average hourly temperature of inner glass for the four desalination units with and without storage materials. There was a lot more condensation of water vapor on the inner surface of the glass cover because the temperature of the glass cover is lower than the dew point temperature of water vapor. Because the water absorbed less heat energy in the early morning (between 7 and 8 h), productivity was lower where the glass temperature was closest to that of the water vapour. The average hourly temperatures of inner glass for the four desalination units (control, with black granite, with concrete stone and with gravel), respectively, were 43.2, 45.1, 45.6 and 46.2ºC

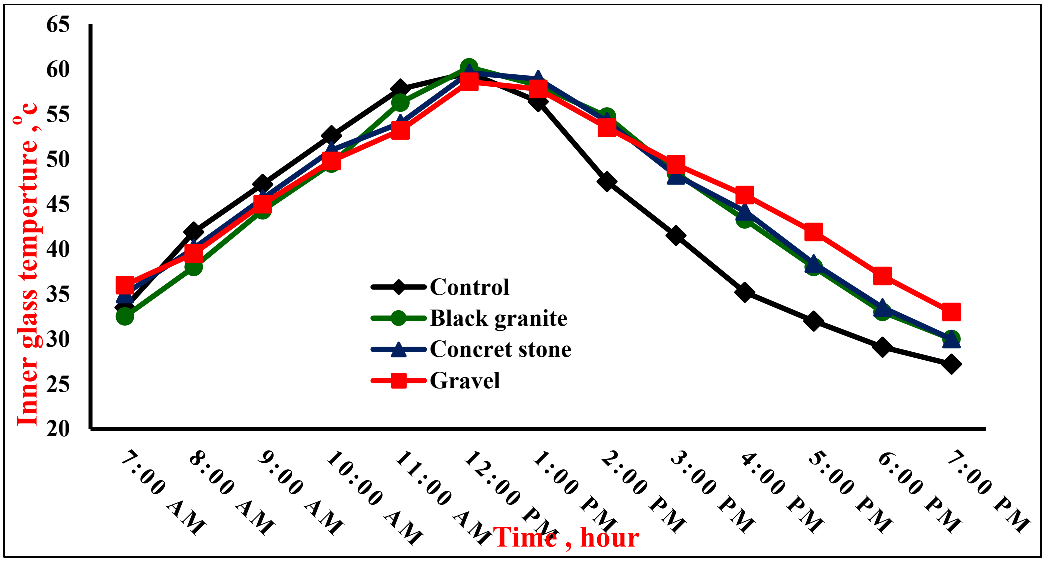

Figure (7): average hourly Inner glass cover temperatures for the four desalination units without and with 10 kg storage materials

The desalination process is powered by the temperature differential between the glass cover and the salty water. Both productivity and evaporation rate increase with increasing temperature differential. The temperature differential between the glass cover and saline water is shown in Figure (8). It was evident that the temperature of the glass cover is slightly higher in the morning than the water temperature because the glass is exposed to direct sunlight during that time, which causes its temperature to rise more quickly than the water's. Consequently, the difference between the two temperatures has a negative value. These differences remained negative until the water's temperature rose above the glass cover's temperature. For each of the four desalination units, the maximum positive differences were 6.1, 7.6, 8.6 and 9.3ºC respectively .

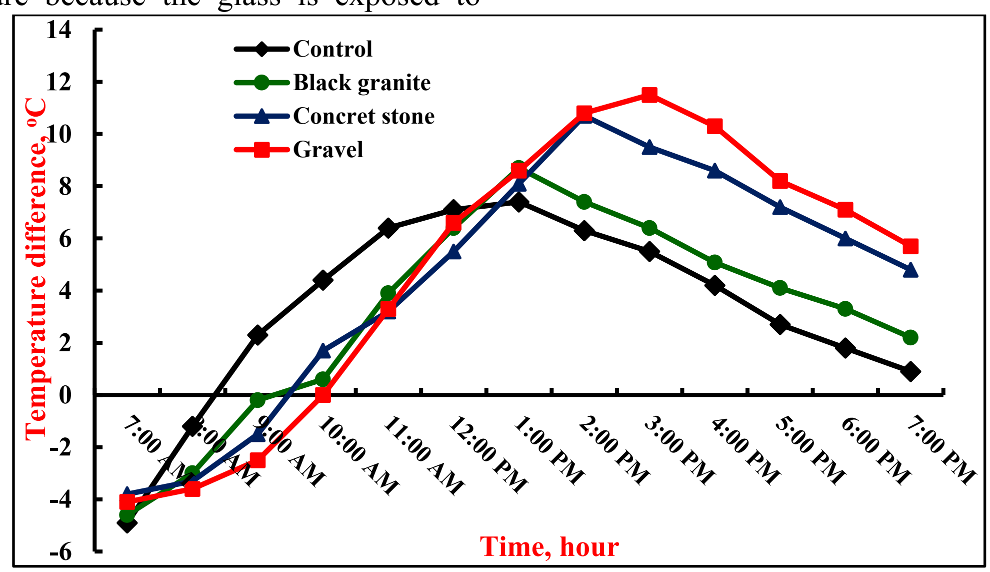

Figure (8): The average hourly temperature difference between the inner glass cover and saltwater 1for the four desalination units

Appear how much the desalination units were adapted to the heat storage material in the economical productivity rate of clean freshwater. For each of the four desalination units, the clean freshwater productivity rate expressed in milliliters per square meter per hour is presented in Figure (9). The results demonstrated that, because of the rise in thermal energy gained from the saltwater at which condensation inside the stills raised, the solar intensity is directly related to the yield of clean freshwater from the desalination unit (Sathyamurthy et al., 2014). The four desalination units ' clean freshwater productivity grew steadily from early in the morning until it peaked in the afternoon. The productivity rate of clean freshwater will be directly proportional to both wind speed and solar radiation intensity, and inversely proportional to temperature of ambient air Average daily output of clean freshwater from the four desalination units (control, with black granite, with concrete stone and with gravel), respectively, were 207.5, 233.6, 254.3 and 265.7 ml/ m2h .

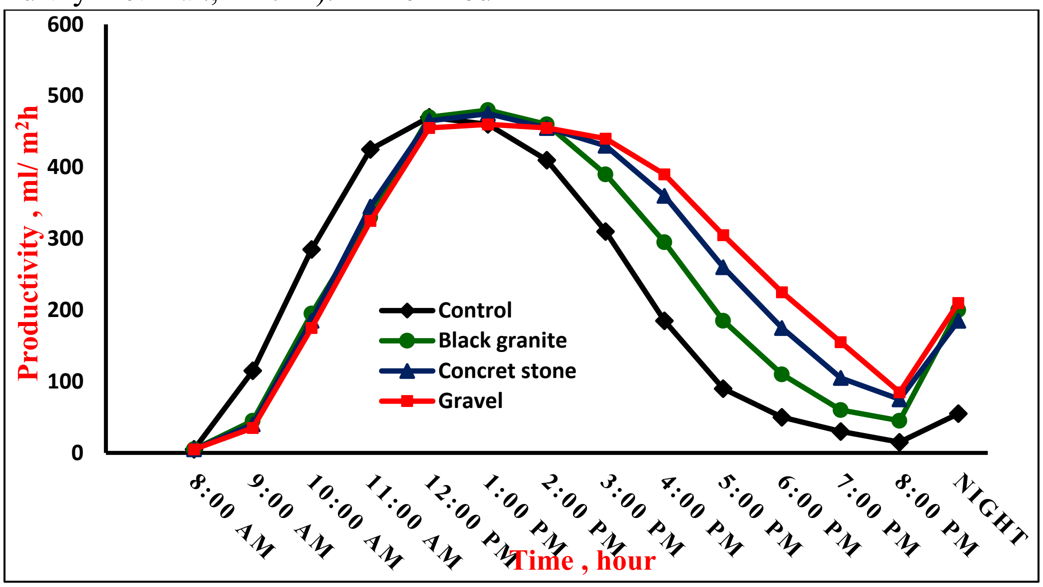

Figure (9): Average hourly rates of productivity for the four desalination units with 10kg storage materials

The accumulated freshwater production from desalination units both with and without heat-storage material has appeared in Figure (10). The four desalination units combined daily productivity of clean freshwater reached about 2905, 3270, 3560 and 3720 ml/m2day, respectively. The findings of the experiment demonstrated that the average daily freshwater productivity for the three desalination units with storage materials exceeded the value of the traditional desalination unit. Produced the highest rate of productivity from the desalination unit with gravel because gravel has a higher specific heat capacity than other materials. Consequently, the freshwater productivity rate throughout the day and at night for the three desalination units with storage materials increased by 12.6, 22.5 and 28.1% for desalination unit with black granite, with concrete stone and with gravel in contrast to the traditional desalination unit, respectively .

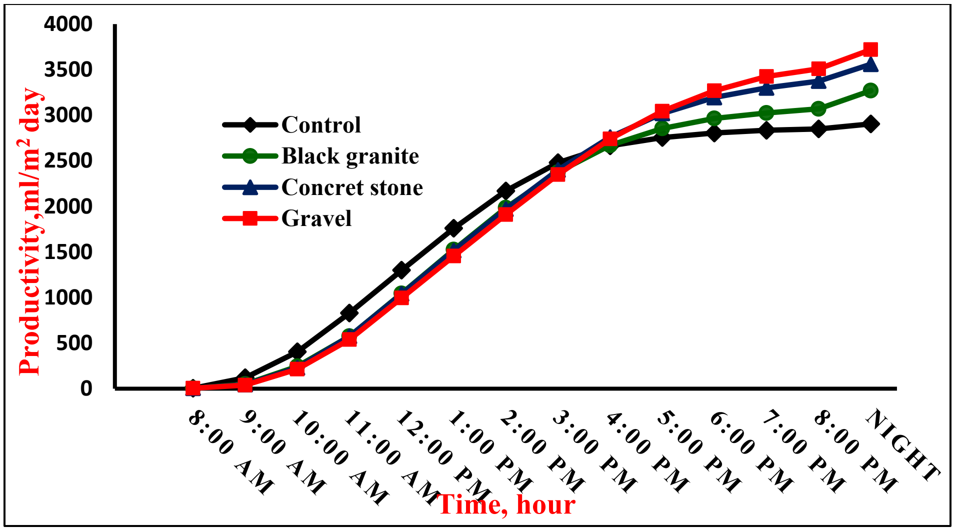

Figure (10): Impact of storage materials on the desalination units' cumulative productivity

Since it can indicate the optimal way to operate a desalination unit, the volumetric thermal efficiency of the device is thought to be most important criteria for assessment. The multiplication of heat energy transfer via evaporation-condensation and the latent heat of saltwater evaporation divided by the solar energy accessible within the desalination unit (input heat energy) is the single-slope desalination unit's thermal performance efficiency. The temperature of brackish water has an inverse relationship with the latent heat of water evaporation. It changed regarding the period of time as the saline water temperature changed. Therefore, the hourly averages latent heat of evaporation of water for the four-desalination unit during this experiment, respectively, were 2392.1, 2382.4, 2380.1 and 2378.6 kJ/kg. The four tested stills' hourly average thermal efficiency when average prevailing weather conditions, as shown in Figure (11). Because of the low levels of flash water production, low solar intensity, and low temperature of saltwater in the basin morning, the thermal efficiency was low. Nevertheless, even with the reduced sun radiation in the afternoon, the saltwater temperature in the basin and the productivity were both high, resulting in a high thermal efficiency as displayed in Figure (11). Throughout the experimental evaluations, the average volumetric thermal efficiency per hour was 25.1, 28.9, 31.6 and 35.3 % for the control desalination unit, still with black granite, still with concrete stone and still with gravel, respectively. The findings demonstrate a direct relationship between desalination unit productivity and volumetric thermal efficiency. The three stills' respective thermal efficiency with storage materials are still very high even during the last hours of the daylight. That is because, even with less solar radiation, the still's water temperature is high enough to cause condensation.

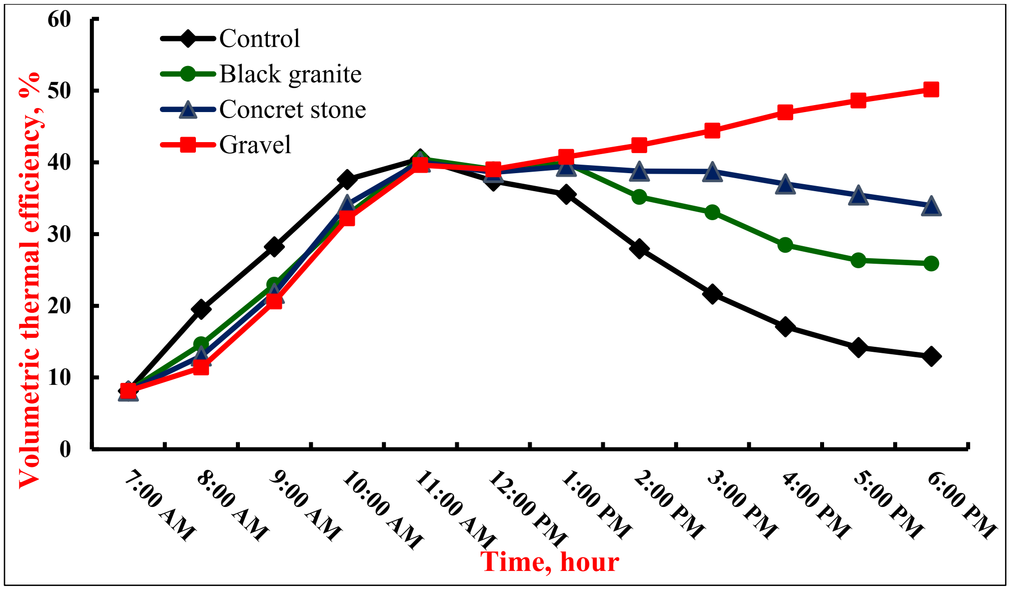

Figure (11): Volumetric thermal efficiency for desalination units with 10 kg storage materials for every hour of the day

Secondly: 15 kg storage materials

After putting in 15 kg of each black granite, concrete stone and gravel in the three desalination units in addition to the control unit (without storage materials). Where these units contain an equal amount of saline water (2 cm depth). Figure (12) shows the the impact of solar intensity on the surrounding air temperature. for the four different desalination units. In the course of the experimental trials, the average hourly solar radiation received was 568.1 W m – 2, under the average wind speed per hour of 1.1 m s-1, while the average outdoor air temperature per hour the desalination units was 30.7 ºC.

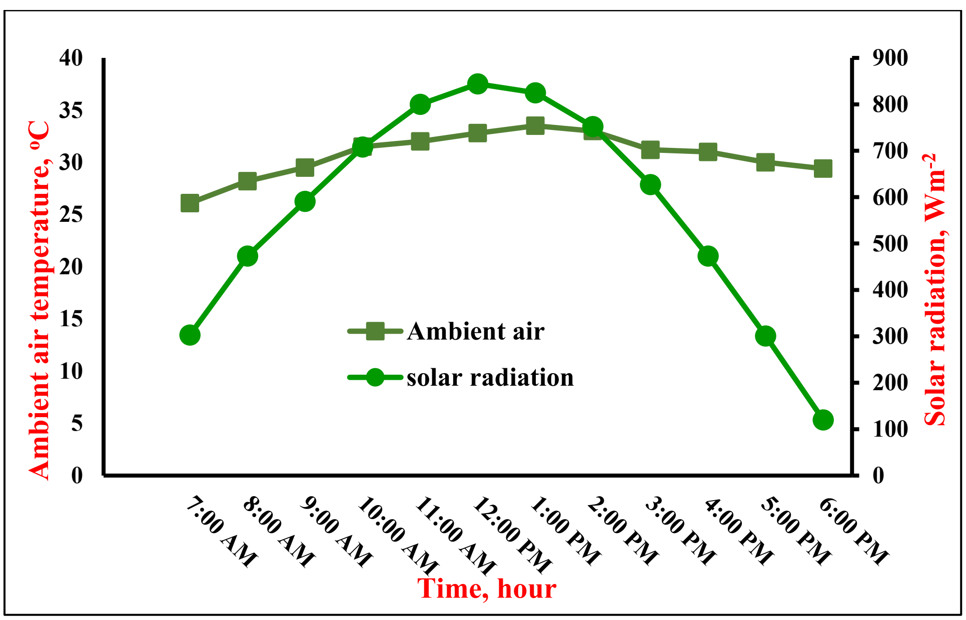

Figure (12): Hourly average of incident solar radiation and temperature of the surrounding air in relation to the solar cycle from the 10th August till the 17th August 2017

The impact of the presence of solar storage materials in the four desalination units on the saltwater temperatures is shown in Figure (13). It noted that the highest temperatures of salinized water for the desalination units control, with black granite, with concrete stone and with gravel, They were obtained at solar noon, in the same order, were 64.4, 64.5, 64.0 and 64.8°C because of the peak absorption of solar radiation during that period. Average temperatures of saltwater under the desalination unit compressed storage materials were increased above the still without storage materials by 8.6, 8.9 and 11.7 % for the still with black granite, concrete stone and gravel, respectively. The desalination unit with gravel produced the highest hourly average saline water temperature during the day. One of the key factors that significantly affects the productivity of clean freshwater is the temperature of the saline water .

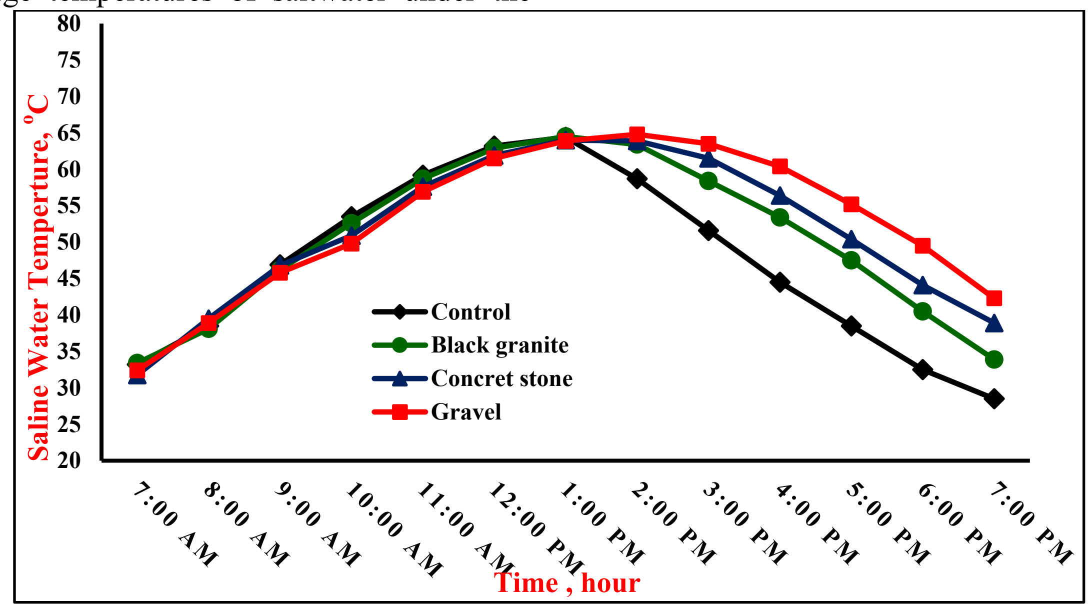

Figure (13): Average temperature of saltwater per hour for the four desalination units under 15 kg solar storage materials

The hourly average water vapour temperature distributions for the four desalination units with and without storage materials were graphed in Figure (14). It is noticed from shown Figure (14) the average hourly temperatures of water vapor to the four desalination units were determined to be 52.8, 55.4, 57.1 and 58.5ºC for the control desalination unit, with black granite, with concrete stone and with gravel, respectively under the previously stated average weather conditions.

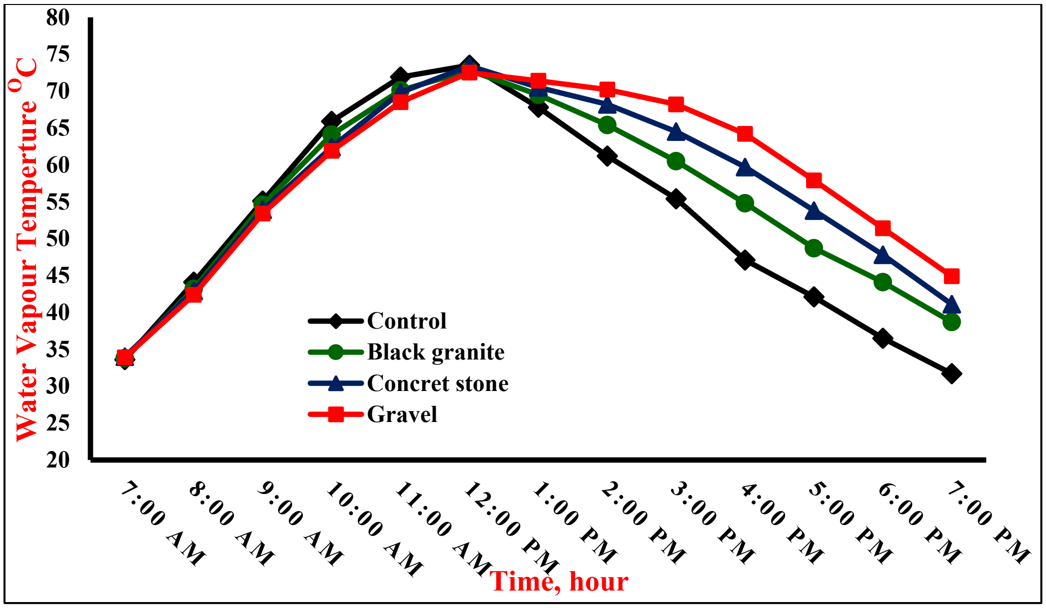

Figure (14): temperature of Water vapour for the four desalination units during the solar cycle under desalination units with 15 kg solar storage materials

Figure (15) shows the four desalination units ' hourly average inner glass temperatures. The average temperatures of inner glass per hour for the four desalination units (control, with black granite, with concrete stone and with gravel), respectively, were 43.8, 46.5, 46.5 and 47.1ºC. Figure (15) shows the increases in the temperature of the glass lid as the solar radiation incident on glass increases .

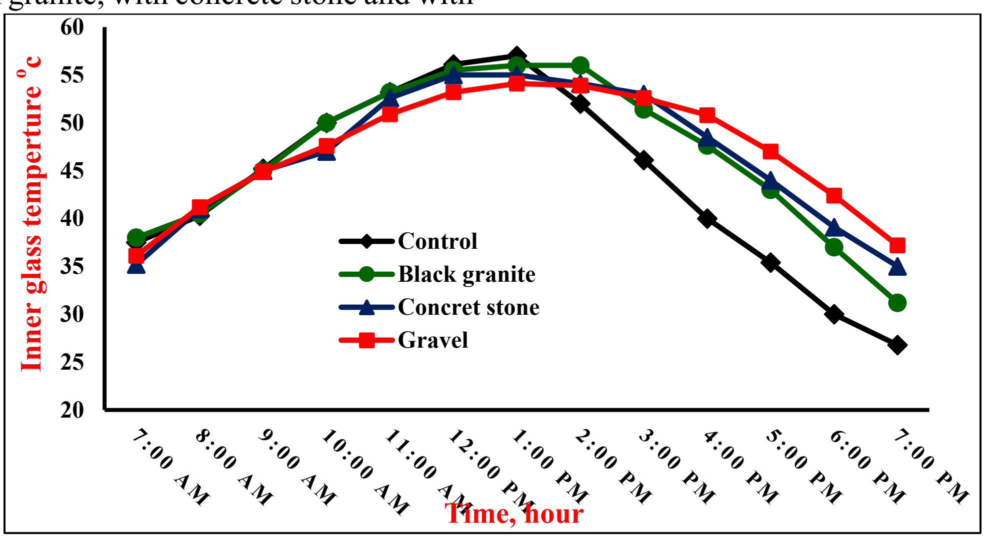

Figure (15): Average temperature inner glass cover per hour for the four desalination units with 15 kg storage materials and control trial

Figure (16) depicts the temperature variance between the glass cover and the water. The maximum positive differences for the four desalination units (control, with black granite, with concrete stone and with gravel) were 7.4, 8.5, 9.8 and 10.9ºC respectively. The average hourly temperature differences between the inner glass cover and the salted water were found to be 3.4, 3.8, 4.9 and 5.6 ºC respectively.

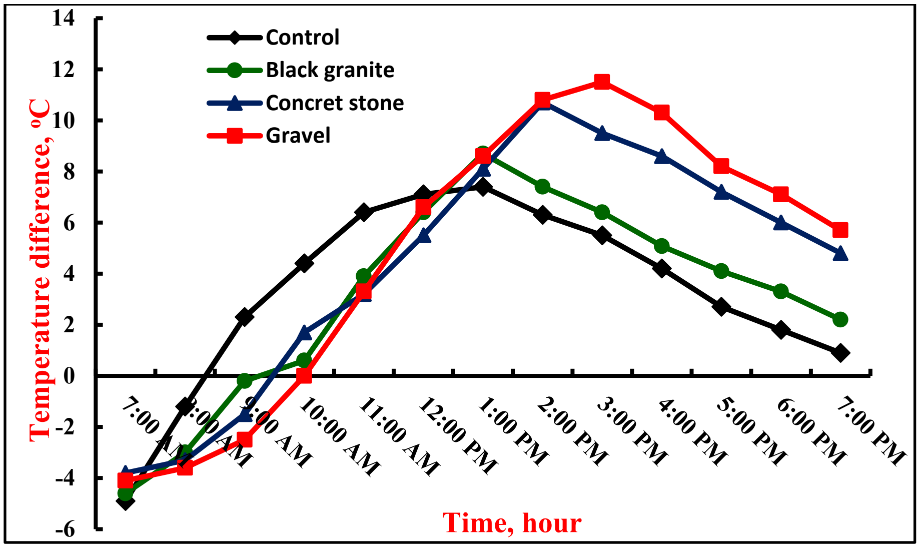

Figure (16): Average hourly temperature differential between the inner glass cover and saltwater for the four desalination units with 15 kg storage materials

Freshwater yield accumulated over time in desalination units with and without heat-storage materials is drawn in Figure (17). The total daily output of freshwater from the four desalination units almost arrived to 3040, 3570, 3935 and 4150 ml/m2 day, in the same order. The findings of the experiment demonstrated that the average daily freshwater yield for the three desalination units with storage materials exceeded the value of the traditional desalination unit. The desalination unit that used gravel had the highest productivity rate. But it is also higher after increasing the amount of storage materials from 10 kg to 15 kg. Consequently, the freshwater productivity rate all day and through the night for the three desalination units with storage materials increased by 17.4, 29.4 and 36.5% as opposed the traditional desalination unit, in the same order.

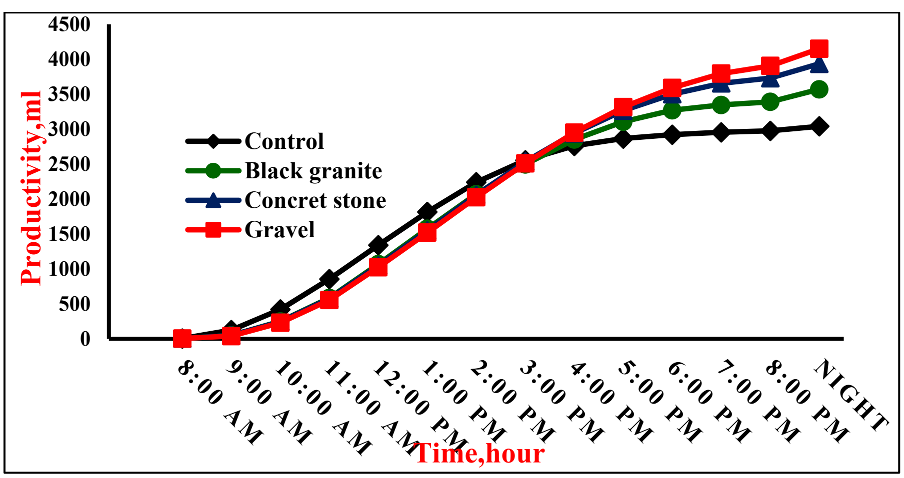

Figure (17): Impact of storage materials on the accumulated yield of desalination units under 15kg storage materials.

Average hourly thermal efficiency of the four examined desalination units under the typical conditions of the day are depicted in Figure (18). Throughout the experimental testing, average of the volumetric thermal efficiency per hour was 25.8, 31.8, 35.3 and 43.3 % for the control desalination unit, still with black granite, still with concrete stone and still with gravel, respectively. The three desalination units' respective thermal efficiency with storage materials is still very high even in the last hours of the daylight .

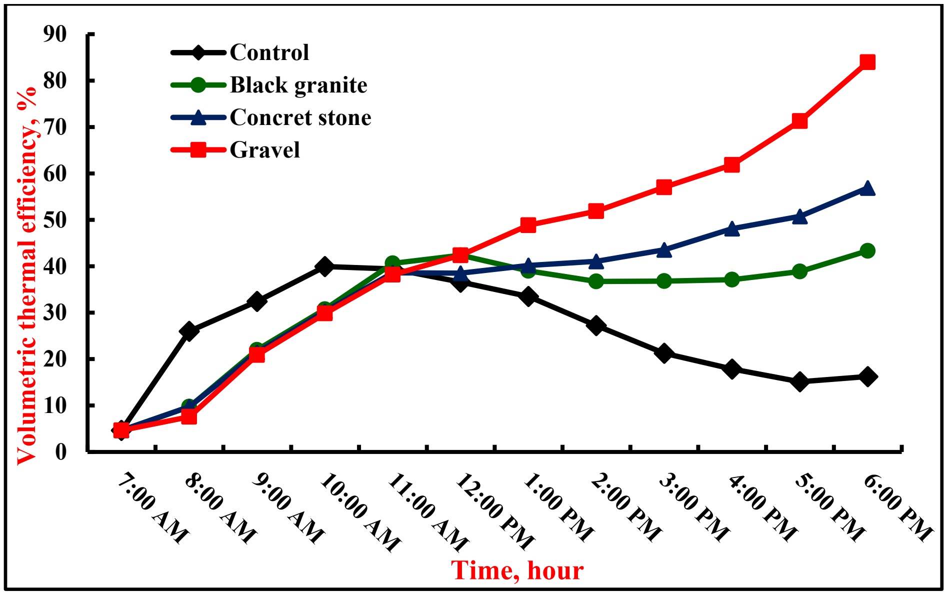

Figure (18): Volumetric thermal efficiency for desalination units with 15 kg storage materials as a function of the hour of the day

Thirdly: 20 kg storage materials

The average hourly solar radiation impact and the average hourly ambient air temperature are plotted in Figure (19). In the course of the experimental attempts, the average hourly solar radiation was 548.1 W m– 2. Meanwhile, the average hourly temperature of ambient air outside the desalination units and wind speed were 32.6 ºC and 1.6 m s-1, respectively .

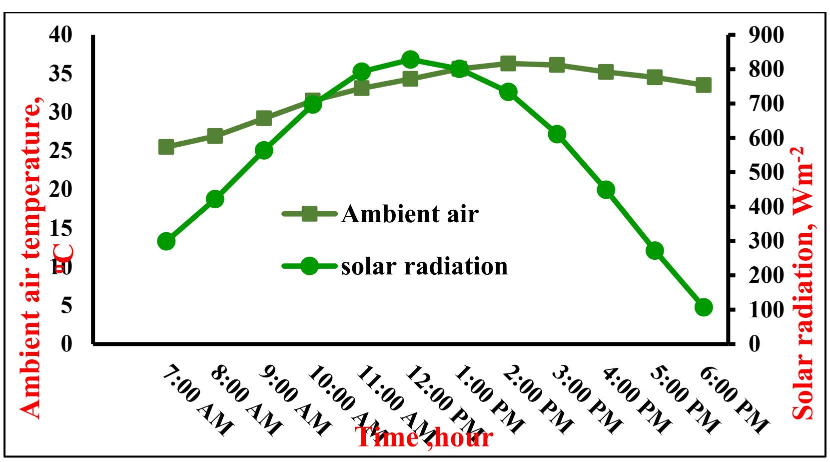

Figure (19): average hourly of incident solar radiation and temperature of the ambient air compared to solar time

Average hourly saline water temperature inside desalination units as affected by the solar storage materials are shown in Figure (20) at the average environmental conditions. Additionally, it was noted that the highest temperature of saltwater for the desalination units without storage materials, with black granite, with concrete stone and with gravel it was accomplished at solar noon, in the same order, were 63.2, 64.5, 64.8 and 64.1°C because at that moment the highest quantity of solar radiation was being absorbed .

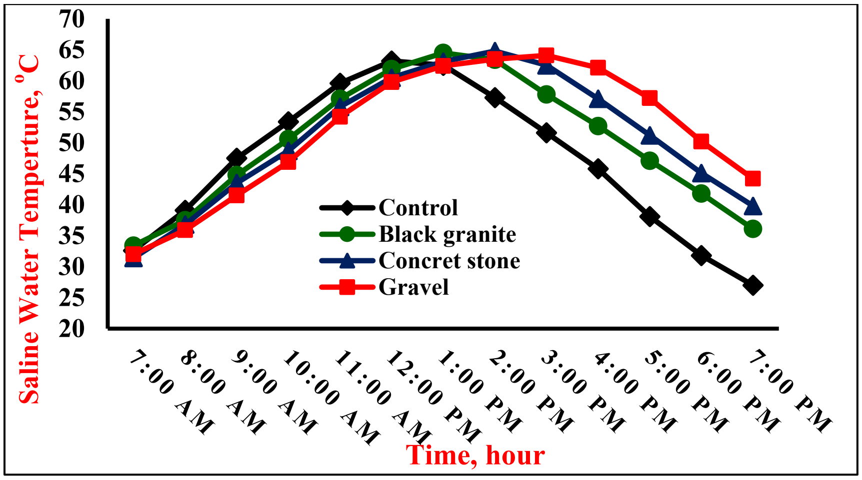

Figure (20): Average hourly temperature of saline water for the four desalination units under 20 kg solar storage materials

The four desalination units ' average hourly temperature distributions of water vapor were plotted in Figure (21). Due to the vapour molecules have sufficient thermal energy to include sensible heat to evaporate, the maximum operating temperatures were observed in the temperature of water vapour for the four different desalination units. It was evident that at 12 PM, The temperatures of the water vapor reached their maximums. It is observed that the average hourly water vapor temperature for the desalination unit without storage materials, with black granite, with concrete stone and with gravel, respectively, were 52.5, 55.0, 56.5 and 58.0 ºC .

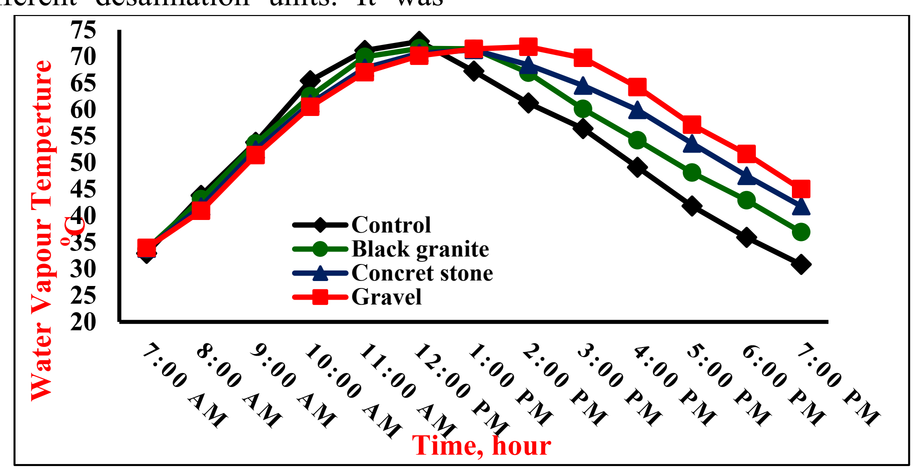

Figure (21): Temperature of water vapour for the four desalination units during solar time under 20 kg storage materials

Figure (22) shows the average hourly temperatures of inner the glass for the four desalination units. There was a lot more condensation of water vapor on the glass covers inside surface because the temperature of the glass cover is lower than the dew point temperature of water vapor. Because the water was absorbing less heat energy in the early morning (between 7 and 8 PM), productivity was lower because the temperature of the glass was closest to that of water vapor. The four desalination units' average inner glass temperatures over the course of an hour, respectively, were discovered to be 43.6, 46.8, 46.4 and 47.2ºC.

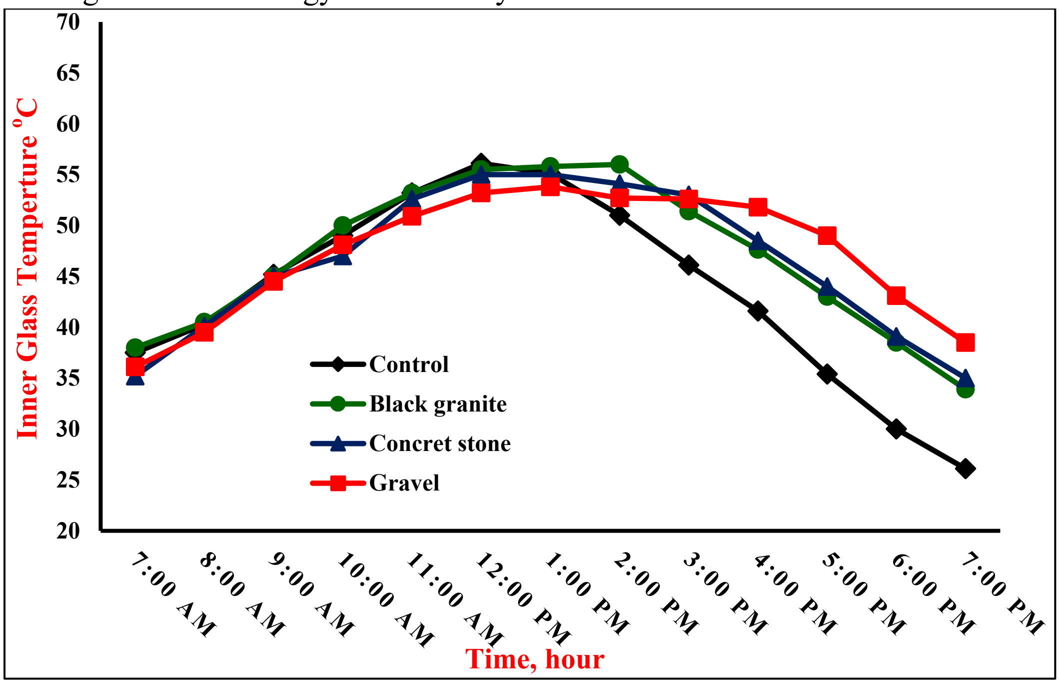

Figure (22): Average hourly Inner glass cover temperatures for the four desalination units with 20 kg storage materials and without storage materials

Figure (23) depicts the variation in temperature between the inner glass cover and salted water. The four desalination units' greatest positive differences were 7.4, 8.7, 10.7 and 11.5 ºC respectively. The average hourly differences temperature between the inner glass cover and saltwater water were found to be 3.3, 3.1, 4.4 and 4.6 ºC respectively.

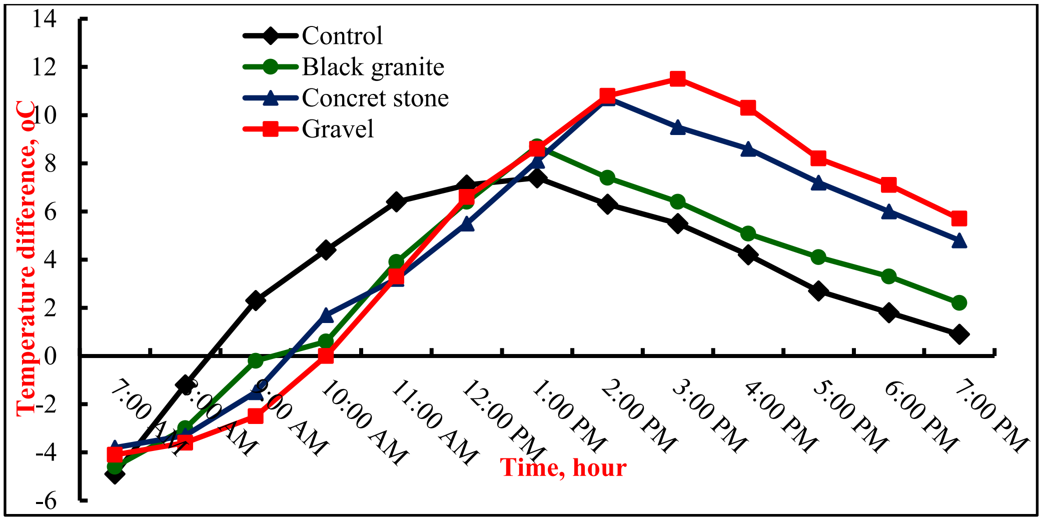

Figure (23): Average hourly difference temperature between inner glass cover and saltwater for the four desalination units with 20 kg storage materials

The accumulated freshwater production for the desalination units with and without heat storage material is graphed in Figure (24). Total per day output of clean freshwater from the four desalination units was roughly equal to 2985, 3500, 3765 and 4005 ml/m2day, in the same order. The best production rate was produced from the desalination unit with gravel but the results of this experiment after increasing the amount of storage materials to 20 kg were less than the results when the amount of storage materials was 10 kg. Consequently, the freshwater productivity rate throughout the day and at nighttime for the three desalination units with storage materials increased by 17.3, 26.1 and 34.2% in contrast to the traditional desalination unit, in that order.

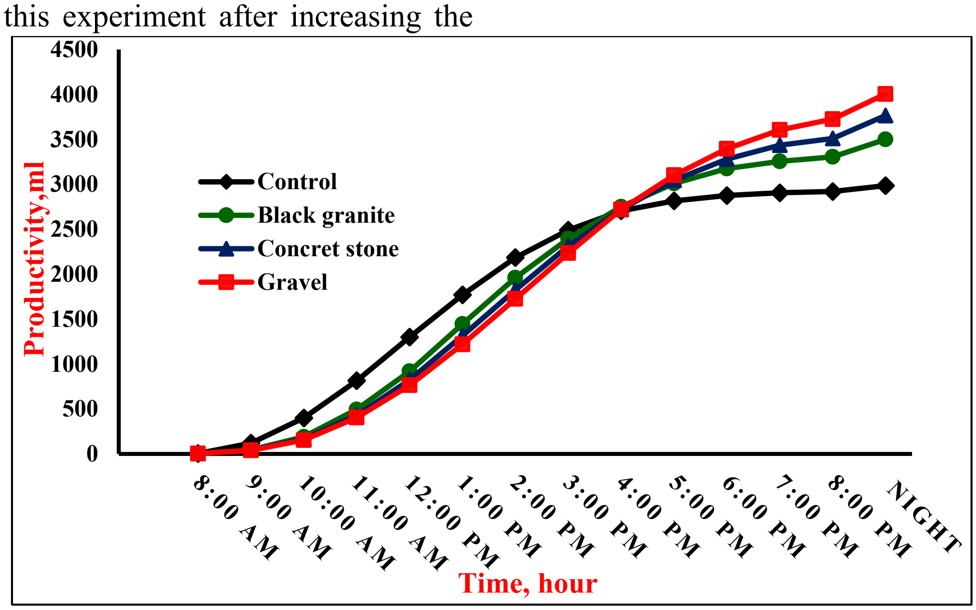

Figure (24): Impact of storage materials on the total productivity over time of desalination units under 20 kg solar storage materials

The hourly average thermal efficiency of the four tested stills in average prevalent weather conditions, which are shown in Figure (25). Because of the low levels of clean freshwater production, low solar intensity, and low temperature of saltwater in the basin during the early hours of the day, the thermal efficiency was low. Nonetheless, In spite of the low solar radiation in the afternoon, Both the temperature and productivity of the saltwater in the basin were high, resulting in a high thermal efficiency. Over the course of the experimental testing, the average hourly volumetric thermal efficiency was 24.5, 30.3, 34.6 and 37.1 % for the control desalination unit, still with black granite, still with concrete stone and still with gravel, respectively. These differences in thermal performance efficiency occurred because of the variations in temperature of saline water between the four desalination units and due to increasing the intensity of solar radiation. The findings demonstrate a direct relationship between desalination unit volumetric thermal efficiency and productivity. Even at the end of the sunshine hours, the three stills with storage materials maintain a very high thermal efficiency.

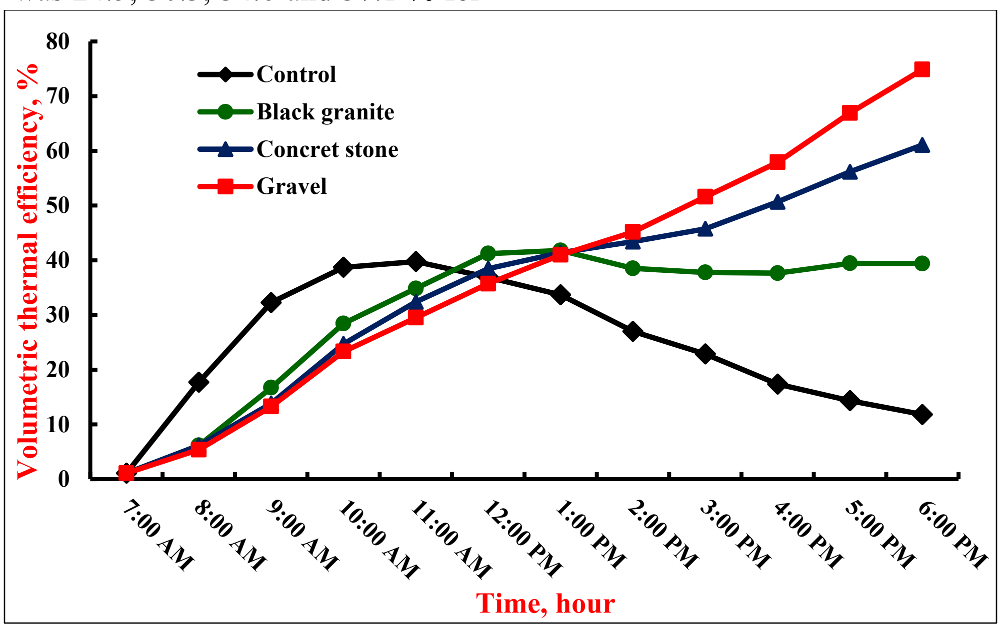

Figure (25): Volumetric thermal efficiency for desalination units with 20 kg storage materials as a function of the hour of the day

Conclusion

For 10 kg storage materials

The four desalination units gave total daily production of clean freshwater about reached to 2905, 3270, 3560 and 3720 ml/m2day, for desalination unit without storage material, with black granite, with concrete stone and with gravel, respectively .

The average volumetric thermal efficiency was per hour 25.1, 28.9, 31.6 and 35.3 % for the control desalination unit, still with black granite, still with concrete stone and still with gravel, respectively .

For 15kg storage material,

The four desalination units gave total daily production of clean freshwater about reached to 3040, 3570, 3935 and 4150 ml/m2day, for desalination unit without storage material, with black granite, with concrete stone and with gravel, respectively .

The average volumetric thermal efficiency was per hour 25.8, 31.8, 35.3 and 43.3 % for the control desalination unit, still with black granite, still with concrete stone and still with gravel, respectively.

For 20 kg storage materials

The four desalination units gave total daily production of clean freshwater about reached to 2985, 3500, 3765 and 4005 ml/m2day, for desalination unit without storage material, with black granite, with concrete stone and with gravel, respectively .

The average volumetric thermal efficiency was per hour 24.5, 30.3, 34.6 and 37.1 % for the control desalination unit, still with black granite, still with concrete stone and still with gravel, respectively.

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تقييم الأداء الحراري لوحدة التقطير الشمس ذات الميل من جانب واحد باستخدام مواد مخزنة للحرارة

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الملخص العربي

تم اجراء تلك الدراسة بجامعة قناة السويس ، كلية الزراعة، قسم الهندسة الزراعية خلال 2017 لدراسة تأثير استخدام وسائط التخزين الحراري على كفاءة وإنتاجية وحدات التقطير الشمسي. حيث تم تصميم أربع وحدات متماثلة من وحدات التقطير الشمسي ذات الميل من الجانب الواحد. وتتكون الوحدة من حوض مصنوع من الصاج المجلفن بسمك 1 مم وبمساحة سطحية 1,04 م^2 وعمق 0,1 م وكان سطح التكثيف الرئيسي عباره عن غطاء من الزجاج الشفاف بسمك 3 مم يميل بزاوية مقدارها 31^{o}على الأفقي موجه ناحية الجنوب. تم تغذية الوحدات الأربعة بمياه مالحة من قناة السويس. وتم اختيار الجرانيت الاسود وكسر الحجارة والزلط كوسائط لها قدرة على تخزين الحرارة المحسوسة والتي يمكن من خلا لها تخزين أكبر كمية من الطاقة الشمسية باستخدامهم كميات مختلفة (10،15،20 كجم). أظهرت النتائج التجريبية أن متوسط الإنتاجية اليومية للمياه العذبة لوحدات التقطير الشمسي ذات مواد تخزين الحرارة المحسوسة كانت أعلى من تلك المستخدمة في التقطير الشمسي التقليدي. كان متوسط الكفاءة الحرارية الحجمية في الساعة 27.5 و 32.2 و 40.3 و 35.7٪ لوحدة التقطير الشمسي التقليدية.

الكلمات الدالة: وحدة التقطير الشمسي– المواد المخزنة للحرارة