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Research article

Using Graphene Materials to Enhance the Multi-Effects Solar Still Performance

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The exponential growth of living and the growth of the population in the world have led to a large demand for potable water. The shortage of fresh water in the desert countries, such as rivers, lakes, and drinkable water wells needs sustainable solutions. The use of solar energy which is abundant in KSA throughout the year to convert the salty water of seas and oceans to freshwater is the most promising solution to meet the increasing of potable water needs. Many studies investigated the applications of the direct solar still which is a promising desalination technique since it costs very little to construct and operate, has low maintenance requirements, and can be constructed using local material, but most of the previous studies concluded that the solar still has low performance and it cannot be used to produce a huge amount of desalinated water. Therefore, in this study a mathematical model was developed to study the enhancement of the solar still using a multi-effects design with a graphene-coated material. This type of design was implemented to enhance the water evaporation and solar absorption rate of the still. Consequently, the water productivity and the temperature distribution of water were enhanced and the performance of the solar still increased by around 21%.

1. INTRODUCTION

The KSA is making a huge effort to ensure every person in the kingdom has access to clean water, however, due to the less rainfall in many parts of the Kingdom, and general scare renewable water, access to clean water is still an issue of concern in many towns and villages in the KSA. What driving the thing to the worst is that the Saudi population is growing fast. and is expected to reach about 34.5 million by 2020, up from 32.8 mil-lion in 2017.[1] Saudi Arabia comprises the majority of the Arabian Peninsula and is among the biggest arid countries without perpetual rivers or lakes. As well as most of the other countries of the Gulf Cooperation Council (GCC) already classified by the United Nations as water-scarce nations; apart from Oman, KSA is relying on desalination for the freshwater supply.[2]

Currently, KSA relies on many mitigation measures that can be used to reduce dependence on conventional water resources (surface waters and fossil aquifers or groundwater) encompassing wastewater recycling and reuse and desalination system. In addition, KSA has emphasized the shift from supply development to demand management to use critical and non-renewable water resources efficiently. KSA's current desalination systems consume a huge amount of energy accounting for 25% of the oil resources.[3] The total volume of renewable resources and non-conventional resources including desalinated water and treated wastewater is estimated at 5.20 billion cubic meters (BCM) with an annual water utilization of 15.97 BCM and 2.42 BCM for irrigation and municipal as well as 0.80 BCM for industrial purposes.[4]

Using solar energy can ease this situation by capitalizing on KSA's abundant solar sources as well as seawater and underground brackish water.[5] This is where the role of the proposed technology comes in, with the additional benefit of supplying clean wa-ter and sparing the need for costly and time-consuming infrastructure that would other-wise be needed to connect them to the national water supply network. Having access to clean drinking water will help improve people's health, and importantly help the country sustain its strategic national development goals. The development of efficient and low energy and low-cost direct solar still technology that utilizes renewable energy for freshwater production, aligns well with the KSA Transformation Plan, Vision 2030 to increase desalination by 50%. The main concept of this project is to create a new design with new features to get an optimum solution for the shortage of freshwater, especially in new projects, such as the NEOM project or the Red Sea project. The study was investigated by Ali. E. Muftah shows the various parameters affecting the efficiency of the solar sills, such as water depth, ambient air temperature, the thickness of the solar collector, and wind speed. The study found that the reflectors as a design parameter can improve the amount of absorbed solar radiation on the basin of the solar still.[6] The dramatic growth of population had increased rapidly a few years ago. The consumption of an amount of potable water has rapidly increased. The purified water became necessary globally wise because the source of freshwater has reduced re-markable

due to global warming and lack of rains.[7] Distillation technology has become necessary worldwide, but poor countries cannot build desalination technology; therefore, solar still became the alternative way to get potable water with low cost and no conventional energy used. Solar still provides distillate water using so-lar irradiation energy with easy and relatively cheaper technology.[8] In several research studies, the parameters that are affecting the solar still directly or indirectly have been classified into three main categories: climate conditions, operational conditions, and design conditions.

Various experimental, analytical, and numerical investigations on the different design aspects of solar stills were conducted. The studies came up with different findings as a single-slop solar still are recipient to higher levels of solar intensity compared to its doubled-slop solar still design, Garg and Mann.[8] Rubio E. et al. were designed it's doubled-sloped solar still with controlled water at the different glass, and they found that the productivity has no significant differences between the production of single-sloped or doubled-sloped designs.[9] Sona wane et al studied enhancing solar still productivity by optimizing the angle of phase wax material change material (PCM) embedded absorber surface. They found that PCM can improve the productivity of a single-solar still by 62% compared with those designed and running without PCM material. V. Velmurugan et al were investigated the single-sloped solar still with two different depths. They used five numbers of 10 mm depth of trays using galvanized iron material. They noticed that the productivity of solar still can improve. The productivity increases by 76% when fins are employed in the stepped solar still. They compared the theoretical and experimental work and the results agreed well.[10] Sona wane et al studied enhancing solar still productivity by optimizing the angle of phase wax material change material (PCM) embedded absorber surface. They found that PCM can improve the productivity of a single-solar still by 62% compared with those designed and running without PCM material. V. Velmurugan et al investigated the single-sloped solar still with two different depths. They used five numbers of 10 mm depth of trays using galvanized iron material. They noticed that the productivity of solar still can improve. The productivity increases by 76% when fins are employed in the stepped solar still. They compared the theoretical and experimental work and the results agreed well.[10] Hitesh Panchal et al studied the performance analysis of evacuated tubes coupled solar still with double basin solar still and solid fins, they found that the fins increase by 25% distillate water after doing a series of experiments.[11–13]

The solar collector performance is dependent on a lot of factors one of which is the materials utilized for the various components of the system, most important the Absorber plate. For a performance analysis carried out by the different researchers. The absorber plate material was considered to be mild steel and galvanized iron. According to the researchers, "the optimization of thickness and material used in the design of the FPC will yield the desired effect to maximize its performance.[14–20]

2. MULTI-EFFECTS SOLAR STILL DESIGN

In this study, the proposed design aims to improve the efficiency of the solar still productivity. The design and operational considerations have been investigated in the mathematical model. The multi-effects were designed to have four staired basins and coated by graphene to increase the absorptivity of a solar irradiation. Each basin collects a certain level of feed water and can evaporate a distilled water separately. Each distilled water will be collected on a separate distilled tray. The accumulation of distilled water in each tray will be collected in the distilled tank, as shown in the figure 1. The salt agglomeration on in each basin will be cleaned and drained via the brine water drainage line and then collected in the brine water tank. The feed water pump is used to pump a salt water from the lower level to higher level (basin4) and the water moves naturally from basin4 to the basin3, the basin2, and the basin1, respectively, as shown in figure1. Removing the salt agglomeration from each basin is by moving the graphene layer which is a movable coating surface.

The solar intensity received by the basin plat of the solar still is evaluated by:

$$I(t)A_b\alpha_b - Q_{c\,b-w} - Q_{loss} = m_b C_{pb}\frac{dT_b}{dt} \tag{1}$$

For the temperature of water:

$$I(t)A_w\alpha_w + Q_{c\,b-w} = Q_{c\,w-g} + Q_{r\,w-g} + Q_{e\,w-g} + m_w C_{pw}\frac{dT_w}{dt} \tag{2}$$

The temperature of the glass can be evaluated by:

$$I(t)A_g\alpha_g + Q_{c\,w-g} + Q_{r\,w-g} + Q_{e\,w-g} + = Q_{r\,g-sky} + m_g C_{pg}\frac{dT_g}{dt} \tag{3}$$

3. RESULTS AND DISCUSSIONS

This study aims to investigate the thermal analysis and the productivity of a multi-effects solar still. The mathematical model has been developed using the energy balance on the solar still system. In some cases, numerical and analytical investigations have been developed to study the agreement obtained by analytical and numerical solutions (FDM-Crank Nicolson Method). Figures 2a, 2b, 2c, and 2d illustrate the temperature of water in the basin, glass, and air temperature which have been evaluated for four months. The water temperature reaches approx. 70°C in April. The variation of the temperatures is based on the variation of the atmospheric conditions, such as the velocity of wind, outside air temperature, and solar intensity for each month, as shown in figure3. All of these temperatures will affect strongly on the solar still productivity (distilled water). The accumulation of the water productivity for each month has been studied by getting the amount of evaporative heat required. In addition to that, the Crank-Nicolson numerical method were employed to compare the results against of those obtained analytically, as shown in figure4a. The productivity of distilled water has increased over the following months because the variation of the temperature and solar intensity which affect on the water temperature and increases

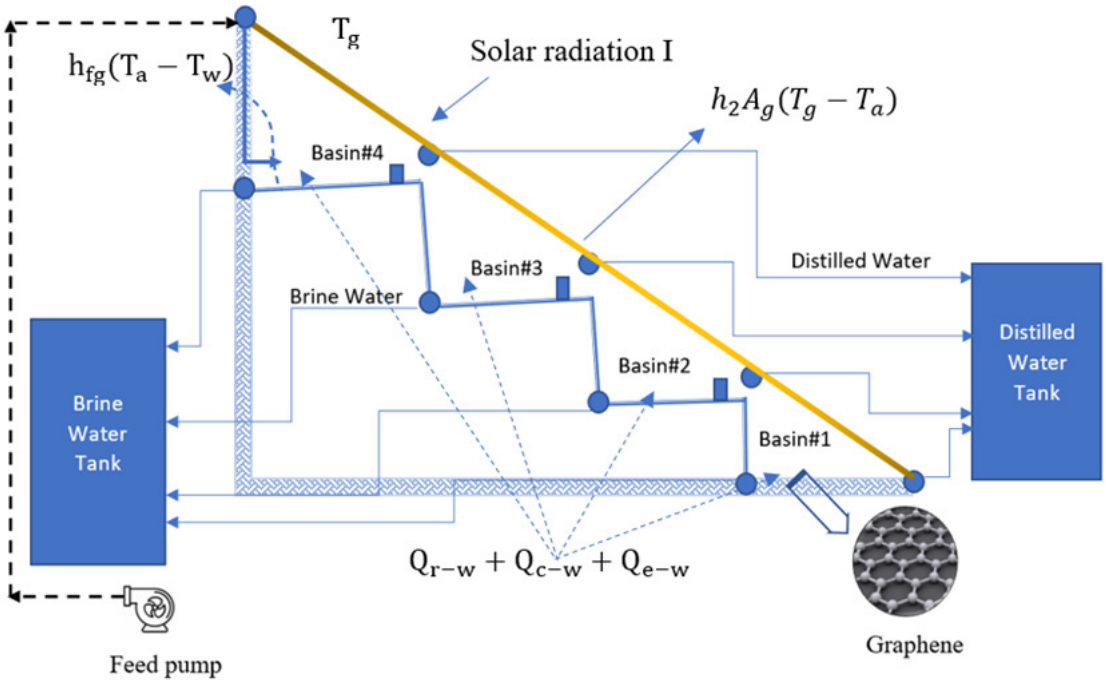

Fig. 1. Multi-effects solar still basins

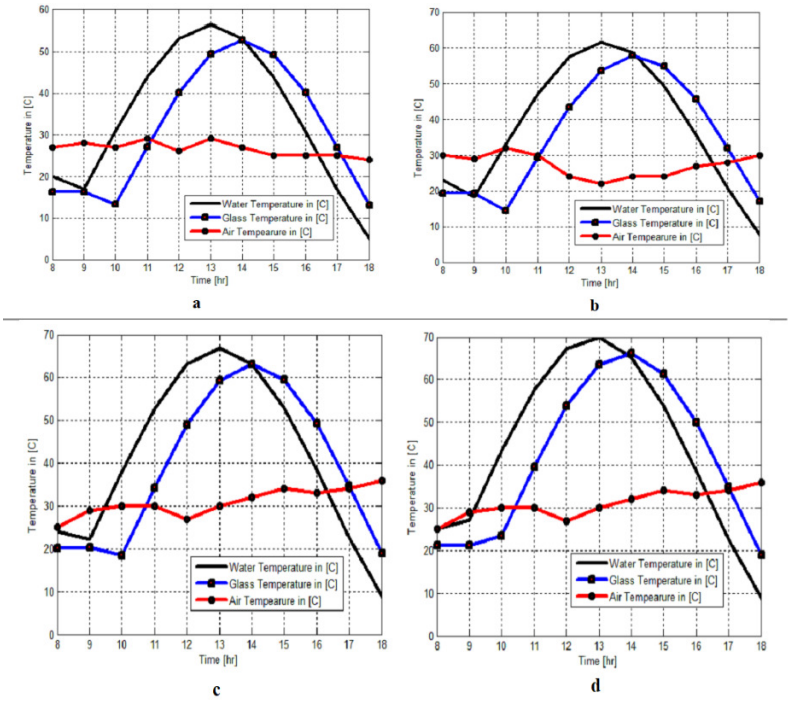

Fig. 2. Temperature of water, glass, and air of 15 days of (a) January,2021, (b) February,2021, (c) March 2021, and (d) April 2021 at AL Madinah, KSA

the evaporative heat. The three basins almost produced the same amount of distilled water.

Figure 4a illustrates the analytical solution against those obtained by numerical solution using (FDM-Crank Nicolson) of May and June months. The results show a strong agreement. The figure5b shows the comparison of accumulated distilled water of four months. The maximum productivity of distilled water was in April either in a single basin or a multiple basin. The figure 5c illustrates the water temperature with a basin coated by a graphene plate or without. The effect of graphene coated on the basin surface was being observed clearly and the evaporative heat flux increased as well. The highest accumulative distilled water was in 10th of May.

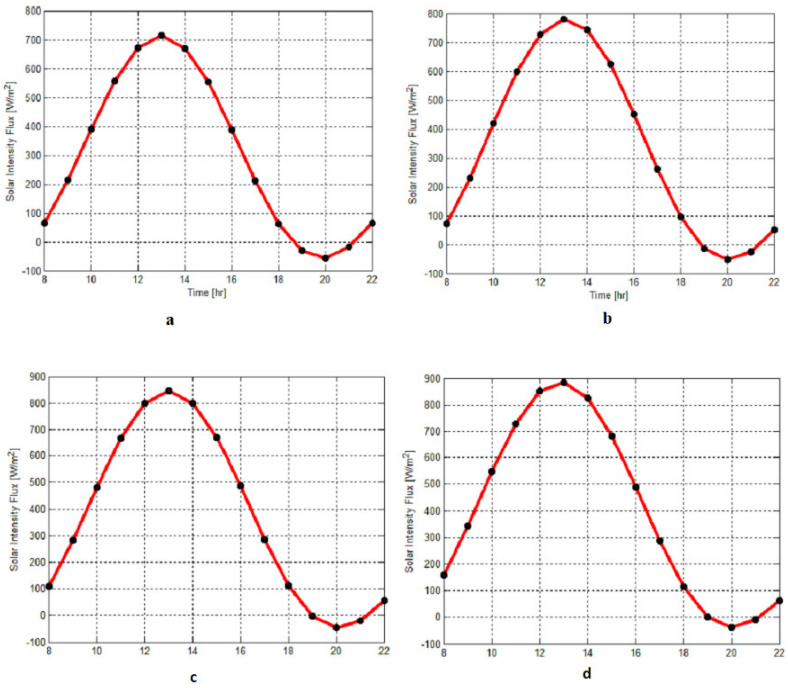

Fig. 3. Solar intensity flux W/m2 of 15 days of (a) January 2021, (b) February 2021, (c) March 2021, and (d)A pril 2021 at AL Madinah, KSA

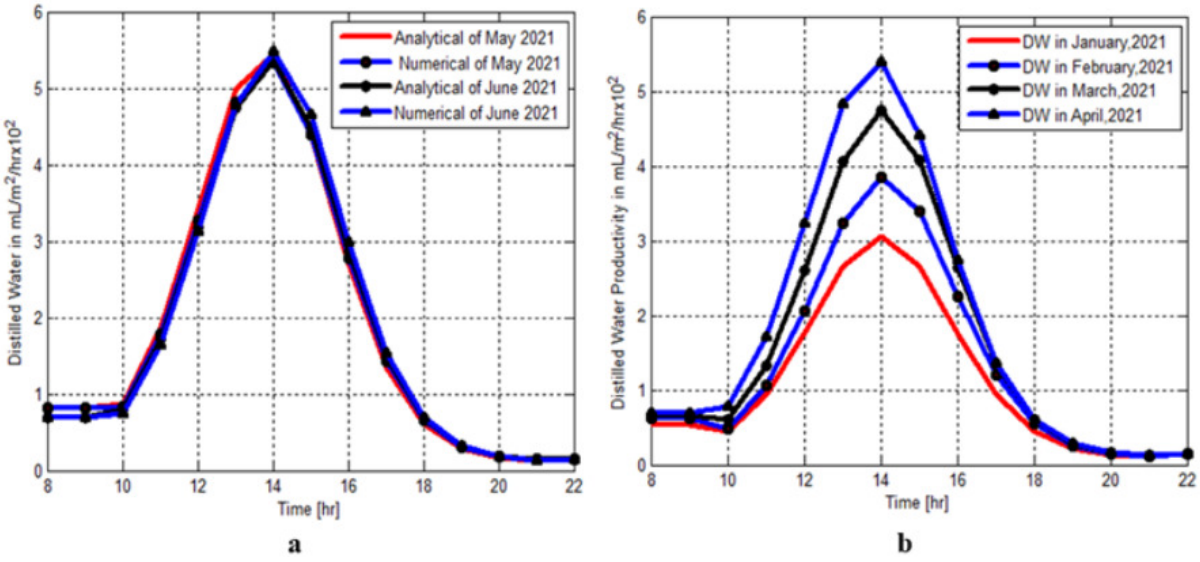

Fig. 4. The distillate water productivity (a) May and June (b) January-April,2021

4. CONCLUSIONS

This study was conducted to investigate the multi-effects solar still performance with and without using graphene material. The water temperature, glass temperature, and the amount of evaporative heat were evaluated numerically and analytically by developing a mathematical model using energy balance. The distillate water productivity increases by 21% if the basins were coated with graphene materials. The study was taken from January till April,2021 and these months have various atmospheric conditions in Almadinah Almunwwarah,KSA

NOMENCLATURES

I Solar Intensity (W/m^2)
Ta Air Temperature (^oC)
T_w Water Temperature (°C)
h_w heat transfer coefficient of water in W/m^2
Q_{rg-w} Reynolds number

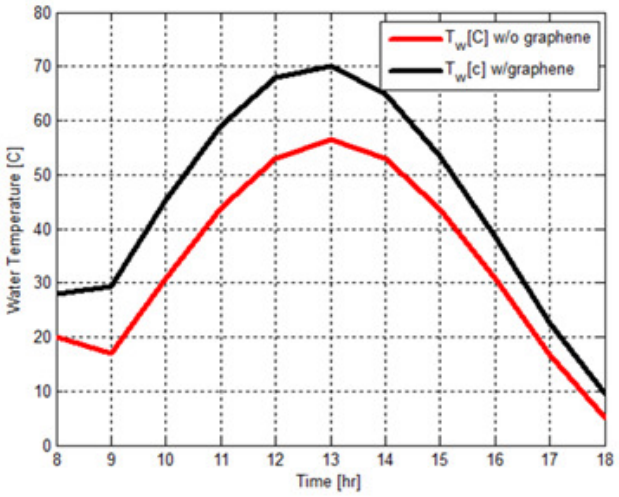

Fig. 5. Water temperature (T_w)with and w/o coated - graphene material

$Q_{rg\text{-}sky}$ Heat radiation from glass to sky (W/m^2)
Q_{loss} Total heat loss to the surrounding (W/m^2)
$h_{c\ w\text{-}g}$ heat transfer coefficient from water to glass (W/m^2)
$h_{e\ w\text{-}g}$ Evaporative convective heat transfer coefficient from water to glass (W/m^2)
$Q_{c\text{-}b\text{-}w}$ Heat transfer from basin to water (W/m^2)
α Absorptivity
ε Emissivity
C_{pw} Specific heat at constant pressure of water [kJ/kg.K]
A_b , A_g Area of the basin (m^2) and area of glass (m^2), respectively

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